

GARLIC AND GINGER EXTRACT ASSISTED SILVER NANOPARTICLES FOR INHIBITION OF ALDOSE REDUCTASE TO PREVENT ADVANCED GLYCATION END PRODUCT FORMATION

DIPAK BABASO BHINGARDEVE^{1*}, SANDEEP BALVANT PATIL²

¹Department of Pharmaceutics, Shree Santkrupa College of Pharmacy, Ghogaon, Karad, Maharashtra, India. ²Department of Pharmacology, Dr. Shivajirao Kadam College of Pharmacy, Kasabe Digraj, Sangli, Maharashtra, India.

*Corresponding author: Dipak Babaso Bhingardev; Email: deeppak.deve12@gmail.com

Received: 29 August 2025, Revised and Accepted: 13 April 2026

ABSTRACT

Objectives: One of the main causes of the development of diabetes problems is the production of advanced glycation end products (AGEs) with aldose reductase (AR) playing a pivotal role in the polyol pathway under hyperglycemic situations.

Methods: In this study, silver nanoparticles (AgNPs) synthesized using water extract of garlic (*Allium sativum*) and ginger (*Zingiber officinale*) were assessed for its potential to inhibit AR and prevent AGE formation. The biosynthesized AgNPs exhibited a spherical morphology with an average particle size of 138 nm and a zeta potential is -20.3 mV, indicating good stability. The phytochemicals in garlic and ginger served as both reducing and stabilizing agents during nanoparticle formation, enhancing the biological activity of the AgNPs.

Results: *In vitro* AR inhibition assays demonstrated significant dose-dependent inhibition by the garlic-ginger AgNPs compared to standard controls. Furthermore, antiglycation assays revealed a marked reduction in AGE formation, suggesting that the nanoparticles effectively mitigate glycation processes.

Conclusion: These findings indicate that garlic and ginger-assisted AgNPs can serve as a promising natural nanomedicine approach for targeting diabetic complications by simultaneously inhibiting AR activity and AGE formation. Future studies will focus on *in vivo* validation and mechanistic insights to further establish their therapeutic potential.

Keywords: Aldose reductase, Silver nanoparticles, Polyol pathway, Advanced glycation end products, Green synthesis.

© 2026 The Authors. Published by Innovare Academic Sciences Pvt Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>) DOI: <http://dx.doi.org/10.22159/ajpcr.2026v19i5.56683>. Journal homepage: <https://innovareacademics.in/journals/index.php/ajpcr>

INTRODUCTION

Diabetes mellitus, a fast-growing global health issue, is characterized by consistently rising blood sugar levels that are caused by either reduced insulin production or action, or both. International diabetes federation Assess in 2021, more than 537 million adults had diabetes [1]. One of the major concerns associated with diabetes is the rising of chronic problems, which are driven largely by persistent hyperglycemia. The synthesis of advanced glycation end products (AGEs), as well as overactivation of the polyol pathway by the enzyme aldose reductase (AR), are two of the most notable metabolic processes linked to these problems [2].

AGEs are formed through a non-enzymatic reaction between reducing sugars and proteins, lipids, or nucleic acids. These products accumulate in tissues and trigger a cascade of deleterious effects, including oxidative stress, inflammation, and cellular dysfunction, all of which contribute to the development of diabetic nephropathy, retinopathy, neuropathy, and heart diseases [3]. Polyol pathway exacerbates these effects under hyperglycemic conditions by converting excess glucose to sorbitol, mediated by AR. This conversion depletes nicotinamide adenine dinucleotide phosphate (NADPH) and increases osmotic stress, thereby amplifying oxidative damage and AGE formation [4]. Consequently, inhibiting AR and AGE formation represents a promising therapeutic strategy for preventing consequences from diabetes.

Conventional AR inhibitors (ARIs), for example, epalrestat and sorbinil, have shown some clinical efficacy but are often limited by their adverse effects and lack of long-term safety [5]. This has driven interest in natural alternatives, particularly those derived from medicinal plants. Plant extracts rich in bioactive compounds have demonstrated potent antioxidant, anti-inflammatory, and antiglycation properties, making them attractive candidates for therapeutic development [5].

Ginger (*Zingiber officinale*) and garlic (*Allium sativum*) are two examples of medicinal herbs that have been used traditionally for a long time to treat metabolic diseases. Garlic contains organosulfur compounds such as allicin, S-allyl cysteine, and diallyl disulfide, which exhibit significant antioxidant and anti-inflammatory effects [6]. Ginger contains phenolic compounds like gingerols, shogaols, and zingerone, which also demonstrate strong free radical scavenging, anti-inflammatory, and anti-diabetic properties [7]. Numerous investigations have revealed the inhibitory effects of garlic and ginger extracts on AR activity and AGE formation, suggesting their potential in managing diabetic complications [8,9].

In parallel, nanotechnology has emerged as a transformative approach in medicine, offering novel solutions for drug delivery and disease treatment. The distinctive physicochemical characteristics and wide range of biological activities of silver nanoparticles (AgNPs), like their antibacterial, Anti-inflammatory, and antioxidant action, have been subject of much research [10]. However, traditional chemical production of AgNPs frequently uses hazardous reducing agents, which raises questions over their safety for environment and biological health. To overcome these limitations, green synthesis methods using plant extracts have gained traction.

Green synthesis of nanoparticles leverages the reducing and stabilizing capabilities of plant phytochemicals, offering a biocompatible and eco-friendly alternative. Garlic and ginger extracts contain a rich array of bioactive compounds has capacity to transform silver ions to elemental silver and stabilizing resulting nanoparticles [11]. These phyto-assisted AgNPs not only exhibit enhanced biocompatibility but may also retain the therapeutic benefits of the plant extracts used in their synthesis.

In this context, the present study aims to synthesize AgNPs using aqueous extracts of garlic and ginger and evaluate their potential to inhibit AR and prevent AGE formation. The biosynthesized AgNPs exhibit an average particle size of 138 nm and a Zeta Potential of -20.3 mV, indicating good stability as well as dispersion. These attributes imply their appropriateness for use in biomedical conditions, especially in targeting oxidative and glycation pathways involved in diabetic complications.

By integrating the antidiabetic properties of garlic and ginger with the nanoscale advantages of AgNPs, this study proposes a dual-action therapeutic strategy. The garlic-ginger assisted AgNPs are expected to inhibit AR, reduce AGE accumulation, and potentially modulate other pathways involved in oxidative stress and inflammation. This approach represents a novel and promising avenue in nanomedicine for the management of diabetes and its difficulties.

METHODS

Fresh garlic (*A. sativum*) and Ginger (*Z. officinale*) were purchased from a nearby marketplace and authenticated by a plant taxonomist. Silver nitrate (AgNO_3 , $\geq 99\%$ purity), bovine serum albumin, D-glucose, DL-glyceraldehyde, NADPH, aminoguanidine, and Additional analytical-grade compounds were acquired from Sigma-Aldrich in the United States. Each solution was prepared using double-distilled water.

Preparation of plant extracts

Garlic and ginger rhizomes were washed, peeled, and ground into a fine paste. Ten grams of each were separately boiled in 100 mL of distilled water for 15 min at 60°C [12]. Whatman No. 1 filter paper was used to filter this mixture once they had cooled. For further usage, the resultant aqueous extract was kept at 4°C .

Green AgNPs synthesis

90 mL of 1 mM AgNO_3 solution was stirred constantly at room temperature while 10 mL of garlic, ginger, or a combination of extracts was added to generate AgNPs [13,14]. After that, the reaction mixture was incubated for 24 h in the dark to prevent photoactivation. AgNP synthesis was confirmed by color changes from pale yellow into brown carried on by surface plasmon resonance. For additional analysis, nanoparticles were centrifuged for 20 min at 12,000 rpm, cleaned 3 times with distilled water, and then dried at 60°C .

Statistical analysis

All experiments were carried out in triplicate, and data are expressed as mean $\pm$ standard deviation (SD). Statistical analysis was performed using one-way analysis of variance followed by Tukey's *post hoc* test to determine significant differences between groups. A $p < 0.05$ was considered statistically significant.

AgNP evaluation

- Using Fourier transform infrared spectroscopy (FTIR), functional groups that are in charge of stabilizing and reducing AgNPs were identified by recording FTIR spectra between 4000 and 400 cm^{-1} [15].
- Scanning electron microscopy (SEM) and transmission electron microscopy: Used to determine morphology and size distribution of the nanoparticles.
- X-ray diffraction (XRD): XRD analysis was conducted to confirm the crystalline nature of the nanoparticles [16].
- Zeta potential analysis: Zeta potential to assess colloidal stability [17,18].

AR inhibition assay

A modified version of the bioassay procedure was followed, as referenced in previous studies [19,20]. To make bioassay solutions, extracts were dissolved in dimethyl sulfoxide (DMSO) at a concentration of 10 mg/mL. Reaction mixture had a total volume of 1.0 mL and was prepared at 25°C . It comprised 0.1 mL of lens supernatant enzyme, 0.7 mL of 50 mM sodium phosphate buffer, pH 6.2, and 0.1 mL of 10 mM D-galactose as the substrate, with or without 0.5 mL of the plant extract formulation.

To start the reaction, 0.1 mL of 0.15 mM NADPH was added, followed by incubation for 45 min. After the incubation period, 0.1 mL 1M NaHCO_3 was transfer to terminate the reaction. A spectrophotometer was used to detect absorbance at 340 nm. Phosphate buffer (pH 6.2) was used to create a negative control. While rutin served as the standard reference [19-21]. All bioassays were performed in triplicate to ensure accuracy and reproducibility. Statistical analysis revealed a significant ($p < 0.05$) concentration-dependent inhibition of AR activity by the test formulation compared to the control. FTIR spectrum is shown in Fig. 1.

RESULTS

FTIR study

This FTIR spectrum suggests the sample contains aromatic compounds with hydroxyl, alkyl, and ester functionalities – possibly a phenolic ester or an aromatic compound with ether/ester linkages shown in Table 1.

Particle size measurement

AgNP has an average particle size of 138.0 nm which is within nano-size range. The polydispersity index (PDI) of 0.228 indicates moderate monodispersity. The AgNPs show a moderate size distribution with a reasonable level of uniformity depicted in Fig. 2.

Zeta potential

Zeta potential of -20.3 mV indicates that the AgNPs carry a negative surface charge. At -20.3 mV, the nanoparticles are moderately stable,

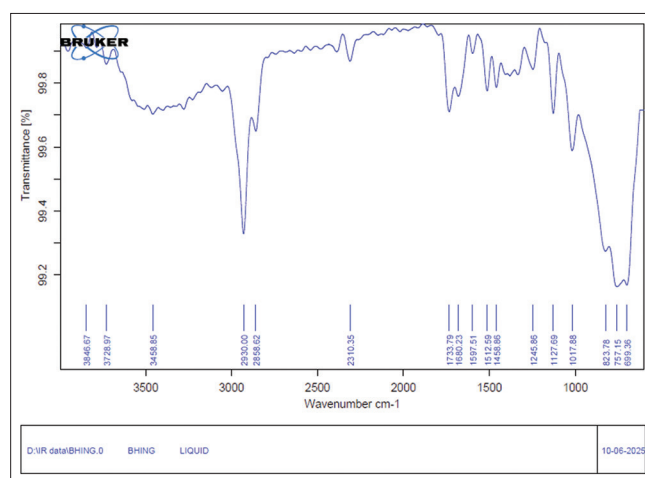


Fig. 1: Fourier transform infrared spectroscopy spectrum

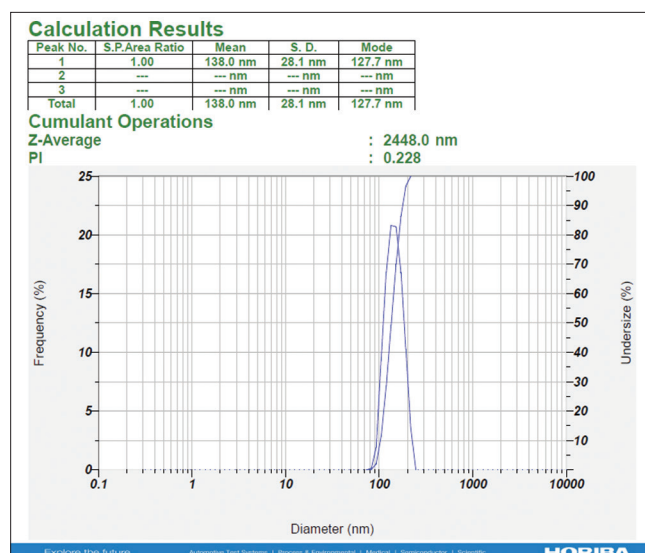


Fig. 2: Particle size measurement

Table 1: FTIR analysis

Wavenumber (cm ⁻¹)	Approximate functional group/vibration	Interpretation
3848–3548	O–H stretch (broad, hydrogen-bonded)	May indicate alcohols or phenols
2999–2858	C–H stretch (sp ³ , alkanes)	Indicates presence of alkyl groups
2310	Possibly atmospheric CO ₂ or C≡C/C≡N stretch (less common)	Might be nitrile or alkyne group
1733	C=O stretch (esters, aldehydes, ketones)	Strong carbonyl presence
1653–1452	C=C stretch (alkenes, aromatic), C–H bending	Suggests aromatic rings or alkenes
1245–1017	C–O stretch (ethers, esters), C–N or aromatic in-plane bending	Common for esters or aromatic ethers
823–693	Aromatic C–H bending (out-of-plane), fingerprint region	Confirms substituted aromatic rings

FTIR: Fourier transform infrared spectroscopy

Table 2: SEM interpretation

Image No.	Observation	Interpretation
1	Very fine, uniform texture with minimal visible grain structure	Initial stage; precursor or unsynthesized material with amorphous nature
2	Increased granularity; small aggregates appear	Nucleation stage of nanoparticles; some clustering observed
3	Clusters more defined, particles begin to take shape	Early growth phase; primary particles forming
4	Rounded and distinguishable particles seen clearly	Nanoparticles become more crystalline and defined
5	Larger, well-formed particles with consistent morphology	Mature nanoparticles with uniform size and shape distribution
6	Similar to 5, but includes red markings/measurements of particle size	Detailed particle size analysis; supports size uniformity or dispersion study

Table 3: Aldose reductase inhibition assay

Groups	Concentration (µg/mL)	Mean optical density±SD	Percentage inhibition±SD
Control	-	0.315±0.008	42.85±1.21
Standard	200	0.215±0.006	31.74±1.03
(rutin)	400	0.198±0.007	37.14±1.12
	600	0.096±0.005	69.52±0.89
	800	0.088±0.004	72.06±0.75
	1000	0.015±0.002	95.23±0.42
Test batch	200	0.1977±0.005	37.23±0.97
	400	0.1820±0.006	42.22±0.86
	600	0.1348±0.004	57.20±0.68
	800	0.1005±0.003	68.09±0.71
	1000	0.0887±0.002	71.84±0.53

All data are presented as mean±SD (n=3), and the differences between groups were statistically analysed using one-way analysis of variance. SD: Standard deviation

suggesting some electrostatic repulsion is present to prevent rapid aggregation as shown in Fig. 3.

XRD

XRD pattern indicates (Fig. 4) that sample is polycrystalline, containing one or more crystalline phases. The presence of sharp and intense peaks suggests a high degree of crystallinity, reflecting well-ordered crystal structures. Notably, multiple sharp peaks are observed in the range of 20°–40° (2θ), which are characteristic of specific crystallographic planes. For phase identification, these peaks can be compared to common databases like powder diffraction file or International Centre for Diffraction Data. A general broad rise in background intensity between 10° and 50° is also evident, a feature commonly associated with polycrystalline or semi-crystalline materials. The highest intensity peaks exceed 400 counts, further emphasizing the presence of strong diffraction planes. In addition, red tick marks observed on the pattern likely represent reference peak positions from known standard phases, which serve as a comparison to validate the experimental data during phase identification. SEM analysis was depicted in Fig. 5 and it was interpreted in Table 2.

SEM

The SEM images (a–f) illustrate the gradual formation and development of silver nanoparticles. Image (a) shows a smooth and fine texture, indicating the initial stage with no distinct particle formation. In images (b) and (c), small aggregates begin to appear, representing

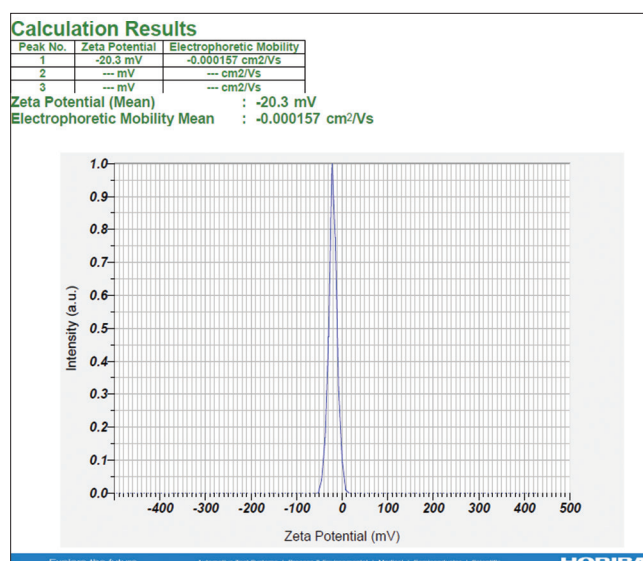


Fig. 3: Zeta potential measurement

the nucleation phase. Images (d) and (e) show more defined and clustered nanoparticles with increased size and clearer morphology, indicating the growth phase. Finally, image (f) reveals densely packed, well-formed nanoparticles with relatively uniform shape and size, confirming successful synthesis and stabilization. Overall, the sequence demonstrates the transition from initial formation to fully developed nanoparticles with improved uniformity.

AR inhibition assay

Test batch shows a concentration-dependent inhibitory effect on AR enzyme activity, according to the AR inhibition study. At higher concentrations (800 and 1000 µg/mL), the test batch showed significant inhibition (68.09% and 71.84%, respectively), which is comparable to the standard Rutin (72.06% and 95.23% at the same concentrations).

Although the maximum inhibition by the test batch at 1000 µg/mL (71.84%) is slightly lower than that of the standard (95.23%), the results demonstrate that the test extract possesses potential inhibition of AR activity, which could help to avoid the development of AGEs. AR inhibition assay is shown in Table 3.

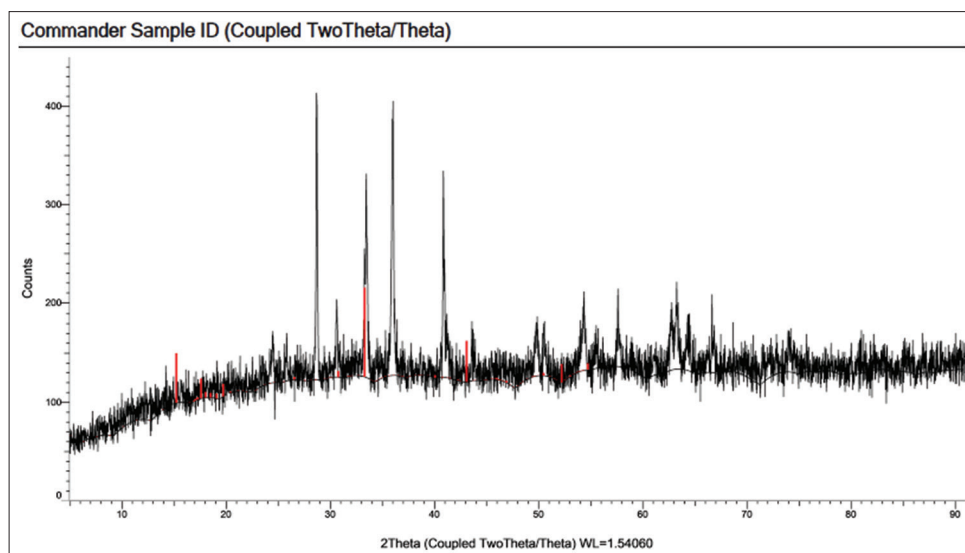


Fig. 4: X-ray diffraction analysis

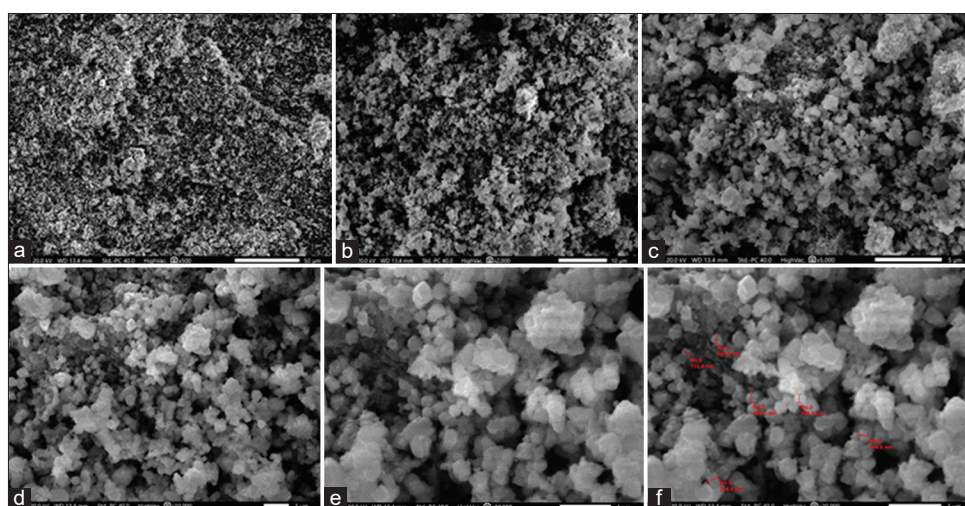


Fig. 5: (a-f) Scanning electron microscopy analysis

The present study demonstrated that AgNPs synthesized using aqueous extracts of *A. sativum* (garlic) and *Z. officinale* (ginger) exhibits significant biological activity against AR and AGE formation – two major contributors to diabetic complications. The biosynthesized nanoparticles were spherical in shape, moderately monodisperse (PDI=0.228), and negatively charged (-20.3 mV), indicating good colloidal stability. These physical properties are consistent with earlier reports, suggesting that green-synthesized AgNPs stabilized by plant phytochemicals possess excellent dispersion and bioavailability [22-24].

The observed AR inhibition by garlic-ginger AgNPs demonstrated a clear concentration-dependent pattern, comparable to that of the standard rutin. The significant inhibition (71.84% at $1000 \mu\text{g/mL}$) may be attributed to the synergistic action of phytochemicals such as allicin, S-allyl cysteine, gingerol, and shogaol, which are known to modulate glucose metabolism and prevent sorbitol accumulation [25,26]. These compounds likely interact with the NADPH-binding or catalytic sites of AR, reducing its activity and subsequent sorbitol-induced oxidative stress. Similar inhibitory patterns have been reported for plant-derived phenolics and sulfur compounds [27,28].

Furthermore, the antiglycation activity observed in the current study supports previous findings that phytochemicals can hinder the Maillard reaction, thereby limiting AGE formation. The AgNPs may enhance this

effect by providing a large surface area for the adsorption and stabilization of active biomolecules, thus improving their bioefficacy [29,30]. Such nanoparticle-mediated enhancement of phytochemical activity has been documented in several studies exploring nanocarriers for antidiabetic and antioxidant therapies [31,32].

In addition to their inhibitory potential, the antioxidant and metal-chelating properties of these nanoparticles likely contribute to lowering oxidative stress – a key factor linking hyperglycemia to tissue damage. The green synthesis approach ensures that the nanoparticles retain the inherent biological functionality of garlic and ginger, while reducing the toxicity typically associated with chemically synthesized AgNPs.

Overall, the findings suggest that garlic-ginger-mediated AgNPs could serve as dual-action therapeutic agents capable of inhibiting AR and preventing glycation-induced damage. This integrated nanomedicine strategy may provide a safer, plant-based alternative to synthetic ARIs. However, further *in vivo* studies are necessary to elucidate pharmacokinetics, biodistribution, and long-term safety before clinical translation.

CONCLUSION

Using extracts from *Z. officinale* (ginger) and *A. sativum* (garlic), the current study effectively demonstrated the green production of AgNPs,

providing an economical and environmentally beneficial method. The synthesized nanoparticles exhibited favorable physicochemical characteristics, confirming their stability and bioactivity.

Importantly, the enzyme AR, a crucial component of the polyol pathway that causes difficulties in diabetes, was significantly inhibited by the AgNPs. By inhibiting AR, the garlic and ginger-mediated AgNPs effectively reduced synthesis of AGEs, which links to oxidative stress and long-term damage in diabetes.

These findings suggest that herbal extract-mediated AgNPs possess dual bioactivity – both antioxidant and enzyme inhibitory – which positions them as promising agents in the prevention of diabetic complications. Further *in vivo* studies and clinical validations are needed to fully explore their therapeutic potential and safety profile.

AUTHORS' CONTRIBUTION

Mr. Dipak Bhingardeve performed the experimental work, generated data, and drafted the manuscript. Dr Sandeep Patil monitored the project, provided guidance, and edited the manuscript.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR FUNDING

None.

REFERENCES

- Magliano DJ, Boyko EJ. IDF Diabetes Atlas. 10th ed. Brussels: International Diabetes Federation; 2021.
- Verma R, Gupta A, Singh S. Evaluation of herbal-based silver nanoparticles for antidiabetic and antioxidant activity. *Int J Curr Pharm Res.* 2021;13(2):25-31. doi: 10.22159/ijcpr.2021v13i2.41784
- Brownlee M. Biochemistry and molecular cell biology of diabetic complications. *Nature.* 2001 Dec 13;414(6865):813-20. doi: 10.1038/414813a, PMID 11742414
- Ramana KV, Srivastava SK. Aldose reductase: A novel therapeutic target for inflammatory pathologies. *Int J Biochem Cell Biol.* 2010 Jan;42(1):17-20. doi: 10.1016/j.biocel.2009.09.009, PMID 19778627, PMCID PMC2787653
- Deshmukh P, Sharma A, Kaur G. Anti-diabetic plants and their recent applications: A review. *J Ayurveda Herb Med.* 2024;4(1):45-53.
- Amagase H. Clarifying the real bioactive constituents of garlic. *J Nutr.* 2006 Mar;136 3 Suppl:716S-25. doi: 10.1093/jn/136.3.716s, PMID 16484550
- Ayustaningwarno F, Anjani G, Ayu AM, Fogliano V. A critical review of ginger's (*Zingiber officinale*) antioxidant, anti-inflammatory, and immunomodulatory activities. *Front Nutr.* 2024;11:1364836. doi: 10.3389/fnut.2024.1364836, PMID 38903613
- Gupta RK, Kesari AN, Murthy PS, Chandra R, Tandon V, Watal G. Hypoglycemic and antidiabetic effect of ethanolic extract of leaves of *Annona squamosa* L. In experimental animals. *J Ethnopharmacol.* 2005 May 13;99(1):75-81. doi: 10.1016/j.jep.2005.01.048, PMID 15848023
- Bhandari U, Sharma JN, Zafar R. The protective action of ethanolic ginger (*Zingiber officinale*) extract in cholesterol fed rabbits. *J Ethnopharmacol.* 1998 Jun;61(2):167-71. doi: 10.1016/s0378-8741(98)00026-9, PMID 9683348
- Patel A, Patel M, Patel P. Phytochemical-based synthesis of silver nanoparticles and their biological evaluation for antioxidant and antimicrobial potential. *Int J Appl Pharm.* 2019;11(6):153-9. doi: 10.22159/ijap.2019v11i6.35479
- Ravikumar L, Velmurugan R, Vidiyala N, Sunkishala P, Teriveedhi VK. Nanotechnology-driven therapeutics for liver cancer: Clinical applications and pharmaceutical insights. *Asian J Pharm Clin Res.* 2025;18(2):8-26. doi: 10.22159/ajpcr.2025v18i2.53429
- Banerjee P, Satapathy M, Mukhopadhyay A, Das P. Leaf extract mediated green synthesis of silver nanoparticles from widely available Indian plants: Synthesis, characterization, antimicrobial property and toxicity analysis. *Bioresour Bioprocess.* 2014;1(1):3. doi: 10.1186/s40643-014-0003-y
- Rajasekar A, Selvaraj S, Lakshmi S. Green synthesis and characterization of silver nanoparticles using *Aloe vera* leaf extract and evaluation of their antidiabetic activity. *Int J Pharm Pharm Sci.* 2018;10(4):64-70. doi: 10.22159/ijpps.2018v10i4.25612
- Ahmed S, Ahmad M, Swami BL, Ikram S. A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: A green expertise. *J Adv Res.* 2016 Jan;7(1):17-28. doi: 10.1016/j.jare.2015.02.007, PMID 26843966, PMCID PMC4703479
- Song JY, Kim BS. Rapid biological synthesis of silver nanoparticles using plant leaf extracts. *Bioprocess Biosyst Eng.* 2009 Jan;32(1):79-84. doi: 10.1007/s00449-008-0224-6, PMID 18438688
- Singh P, Yadav R, Kaur N. Phytosynthesis of silver nanoparticles and assessment of their biological efficacy against diabetes and oxidative stress. *Int J Curr Res.* 2019;11(7):5432-8.
- Kaviya S, Santhanalakshmi J, Viswanathan B, Muthumary J, Srinivasan K. Biosynthesis of silver nanoparticles using Citrus sinensis peel extract and its antibacterial activity. *Spectrochim Acta A Mol Biomol Spectrosc.* 2011 Aug;79(3):594-8. doi: 10.1016/j.saa.2011.03.040, PMID 21536485
- Kumar Reddy KT, Dharmamoorthy G, Vasavi Devi D, Vidiyala N, Bagade OM, Elumalai S *et al.* Phytoconstituent-based green synthesis of nanoparticles: Sources and biomedical applications in cancer therapy. *Asian J Green Chem.* 2025;9(3):329-54. doi: 10.48309/ajgc.2025.501113.1669
- Haraguchi H, Ohmi I, Sakai S, Fukuda A, Toihara Y, Fujimoto T, *et al.* Effect of Polygonum hydropiper sulfated flavonoids on lens aldose reductase and related enzymes. *J Nat Prod.* 1996 Apr;59(4):443-5. doi: 10.1021/np9601622, PMID 8699190
- Naveen YP, Venugopal LJ, Chauhan JB. Antiglycation and aldose reductase activity of *Swietenia mahagoni* leaf extract. *Eur J Pharm Med Res.* 2016;3(5):631-4.
- Kim HM, Lee JM, Lee KH, Ahn YH, Lee SH. Aldose reductase inhibition by luteolin derivatives from *Parasenecio pseudotaimingasa*. *Nat Prod Sci.* 2011 Dec 1;17(4):367-71.
- Ahmed S, Saifullah AM, Swami BL, Ikram S. Green synthesis of silver nanoparticles using *Azadirachta indica* aqueous leaf extract. *Arab J Chem.* 2020;13(8):7056-67. doi: 10.1016/j.arabjc.2020.06.018
- Bhuyan T, Mishra K, Khanuja M, Prasad R, Varma A. Biosynthesis of silver nanoparticles using *Zingiber officinale* root extract and evaluation of their antimicrobial activity. *Appl Nanosci.* 2017;7(8):843-51. doi: 10.1007/s13204-017-0622-1
- Rautela A, Rani J, Debnath M. Green synthesis of silver nanoparticles using plant extracts and their antimicrobial activities: A review. *Mater Today Proc.* 2019;18:4356-61. doi: 10.1016/j.matpr.2019.07.371
- Burgos RA, Seguel K, Perez M, Meneses A, Ortega M, Guarda MI, *et al.* Andrographolide inhibits IFN-gamma and IL-2 cytokine production and protects against cell apoptosis. *Planta Med.* 2005;71(5):429-34. doi: 10.1055/s-2005-864138, PMID 15931581
- Thomson M, Al-Qattan KK, Divya JS, Ali M. Anti-diabetic and antioxidant potential of garlic and ginger in experimental diabetes. *J Ethnopharmacol.* 2016;189:360-8. doi: 10.1016/j.jep.2016.05.019, PMID 27211338
- Sharma B, Saluja M, Yadav S. Natural inhibitors of aldose reductase: Therapeutic potential and biochemical basis. *Curr Drug Targets.* 2021;22(10):1105-17. doi: 10.2174/1389450121666201126112828, PMID 33252328
- Gupta R, Sharma U, Bhattacharya S, Joshi P. Phytochemicals as potential aldose reductase inhibitors: A review. *Phytother Res.* 2020;34(10):2576-95. doi: 10.1002/ptr.6681, PMID 32632943
- Ahmed N, Thornalley PJ. Advanced glycation end products: What is their relevance to diabetic complications? *Diabetologia.* 2005;48(8):1547-59. doi: 10.1007/s00125-005-1870-5, PMID 15971065
- Nasrollahzadeh M, Sajjadi M, Iravani S, Varma RS. Green synthesis of metal nanoparticles using plant extracts: Mechanisms and applications. *J Clean Prod.* 2019;211:1336-50. doi: 10.1016/j.jclepro.2018.11.166
- Javed R, Usman M, Tabassum S, Zia M. Green synthesized silver nanoparticles for biomedical applications: Antioxidant, anti-inflammatory, and anticancer potential. *Mater Sci Eng C.* 2021;119:111575. doi: 10.1016/j.msec.2020.111575, PMID 33253927
- Rahman MM, Alam MM, Jahan I, Habib MR, Karim MR. Green-synthesized silver nanoparticles enhance the antidiabetic and antioxidant potential of medicinal plants. *Front Pharmacol.* 2022;13:838632. doi: 10.3389/fphar.2022.838632, PMID 35356412, PMCID PMC8952871