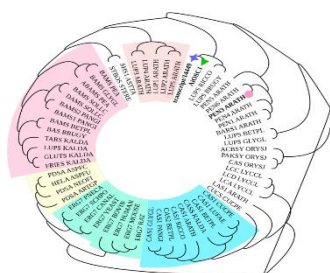


Neem Research Newsletter

Volume 6, Issue 4, 2026



WORLD NEEM ORGANISATION (WNO)



From

The Editor's Desk.....

I am happy to summarise several novel research findings on neem in diverse areas. Neem-based botanicals were found to provide suppression of diamondback moth and cabbage aphid that infect cabbage and kale comparable to commercial biopesticides under controlled and semi-field conditions. A study on the molecular mechanisms underlying azadirachtin on insect hosts revealed that Sirt5, a key regulator of metabolic and stress responses mitigates azadirachtin-induced midgut damage by modulating cell death pathways. Neem-mediated nanoparticles was found to be a potent and promising strategy for controlling the causative agent of white spot disease in ornamental fish.

An interesting study on the genetic diversity and population structure of *A. indica* in Ahmedabad indicated that urbanization has not severely disrupted genetic connectivity in *A. indica*, reflecting its resilience and adaptive potential in a metropolitan environment.

Neem extract was found to be highly effective against 11 bacterial species in hospital settings. Formulation of decoctions of neem leaf into capsules for malaria treatment were demonstrated to be effective thereby overcoming bulkiness and instability of bitter decoctions. In patients with chronic kidney disease-associated secondary hypertension, aromatherapy massage using Neem, Ylang-ylang and Frankincense oil essential oil was found to induce short-term within-session reductions in resting cardiovascular parameters. Components of neem leaves were shown to exhibit antimicrobial and antioxidant activities besides suppressing the proliferation of cancer cells. Zinc oxide nanoparticles synthesised from neem extracts displayed dose-dependent inhibition of cancer cell proliferation by inducing cancer cell death.

Neem was demonstrated to possess strong antibacterial potential and may serve as promising natural agent for managing animal wound infections caused by pathogens. Based on an experimental study, the synergistic action of the bioactive compounds in neem leaf extract was suggested as a promising, natural, and cost-effective phytogenic alternative to in-feed antibiotics for enhancing productivity and ensuring safe broiler meat.

S. Nagini

Core Founding Member, WNO
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Neem in Agriculture

[Efficacy of homemade botanical insecticides against diamondback moth \(*Plutella xylostella*\) and cabbage aphids \(*Brevicoryne brassicae*\) on Brassica crops.](#)

Munyoki N, Karanja EN, Akutse KS, Adamtey N, Musyoka M, Fiaboe KKM, Bautze D, Nderitu E, Matheri F, Thomas D, Kiboi M, Tanga CM. Sci Rep. 2026 Apr 20. doi: 10.1038/s41598-026-50001-7. Online ahead of print. PMID: 42010016

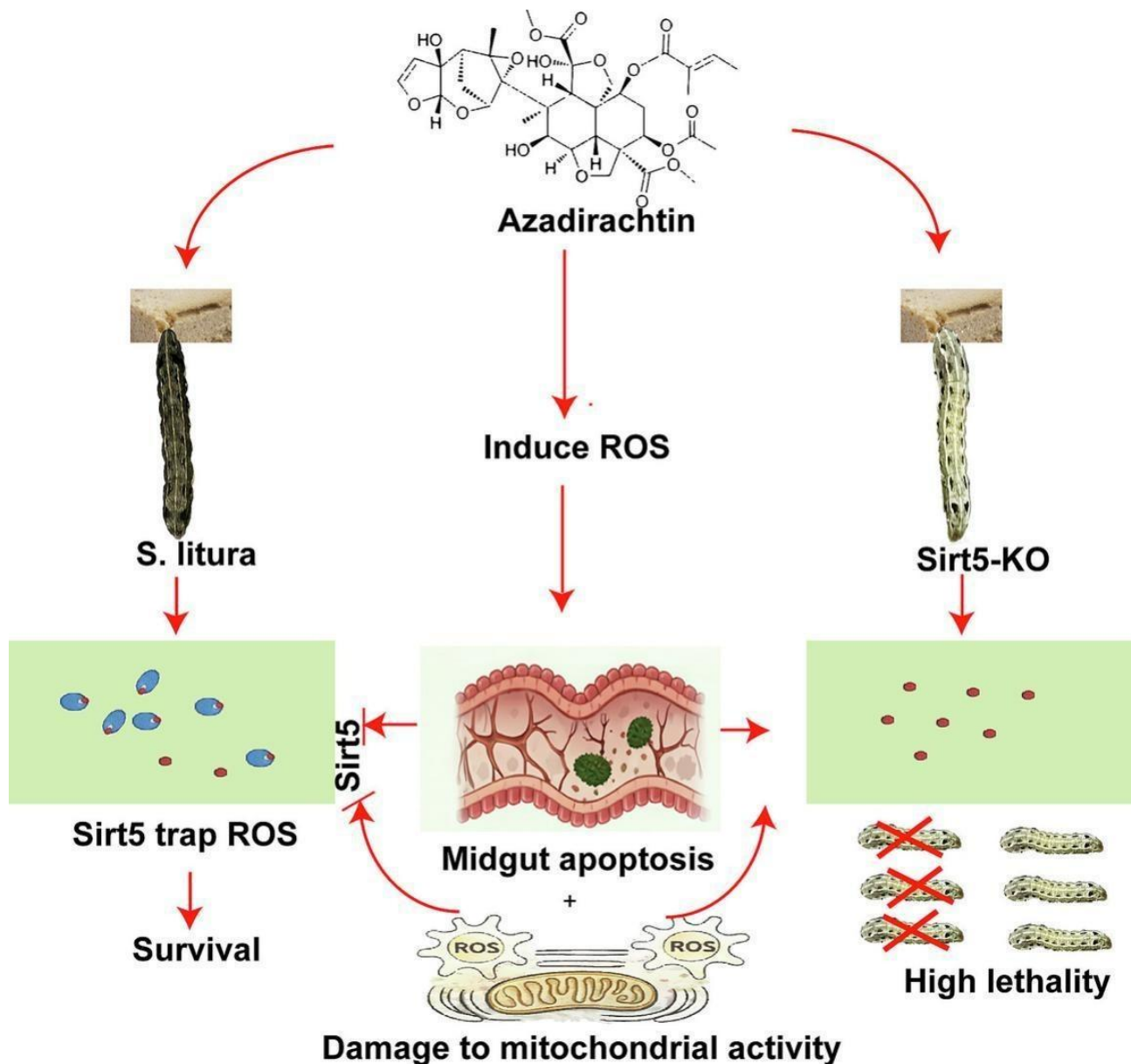
The growing need for accessible alternatives to synthetic insecticides has renewed interest in farmer-made botanical formulations for pest management. This study evaluated the efficacy of selected homemade botanical insecticides against diamondback moth (*Plutella xylostella*) and cabbage aphid (*Brevicoryne brassicae*) on cabbage (*Brassica oleracea* var. *capitata*) and kale (*B. oleracea* var. *acephala*) under laboratory and semi-field conditions. Three homemade formulations were assessed: a one-day-old multi-plant extract with neem (*Azadirachta indica*; PE + N), a one-day-old extract without neem (PE), and a fourteen-day-old, fermented extract without neem (PE14). These were compared with three commercial botanical products. In replicated leaf- and plant-based bioassays, neem-based treatments (PE + N and Nimbecidine) consistently caused higher pest mortality than non-neem formulations. Both treatments achieved over 50% mortality of *P. xylostella* and *B. brassicae* at higher concentrations, with shorter median lethal times (LT₅₀) and lower median lethal concentrations (LC₅₀). Formulations without neem remained below the 50% mortality threshold under most conditions. Efficacy was lower under semi-field conditions than in laboratory assays, reflecting environmental influences on botanical stability. These findings demonstrate that neem-based homemade botanicals derived from farmer practices can provide pest suppression comparable to commercial biopesticides under controlled and semi-field conditions. While variability in efficacy and lack of formulation standardization remain challenges, such botanicals represent a promising complementary option within integrated pest management strategies for smallholder farming systems.

[Functional analysis of Sirt5 in the effect of azadirachtin on the intestinal injury of *Spodoptera litura*.](#)

Yang X, Xiao Y, Hao S, Liu J, Guo H, Xu Y, Goldsmith MR, Smagghe G, Xia Q, Mita K. Pestic Biochem Physiol. 2026 May;220:107097. doi: 10.1016/j.pestbp.2026.107097. Epub 2026 Apr 5. PMID: 42034444

Azadirachtin, a major botanical insecticide, is widely recognized as a sustainable alternative to synthetic pesticides, yet the molecular mechanisms underlying its effects on insect hosts remain poorly understood. Transcriptomic analysis, RT-PCR, and qPCR revealed significant upregulation of Sirt5 in the midgut following azadirachtin exposure. In the present study, we investigated the role of Sirt5, a key regulator of metabolic and stress responses, in mediating midgut damage in *Spodoptera litura* under azadirachtin stress. Functional assays showed that overexpression of Sirt5 in SpLi-221 cells suppressed lysosomal activity under stress, whereas CRISPR/Cas9-mediated knockout (KO) of Sirt5 led to elevated expression of autophagy-related genes (Atg6, Atg16, Atg101) and the

apoptosis marker caspase-1. Compared with the wild-type control group, the mortality of the larvae lacking Sirt5 increased from 49% to 95% when fed with the median lethal dose of azadirachtin. These findings indicate that Sirt5 mitigates azadirachtin-induced midgut damage by modulating autophagy and apoptosis pathways. The present study provides the first experimental evidence linking Sirt5 to host responses against azadirachtin, offering new mechanistic insights into botanical insecticide action and identifying a potential target for enhancing sustainable pest management strategies.

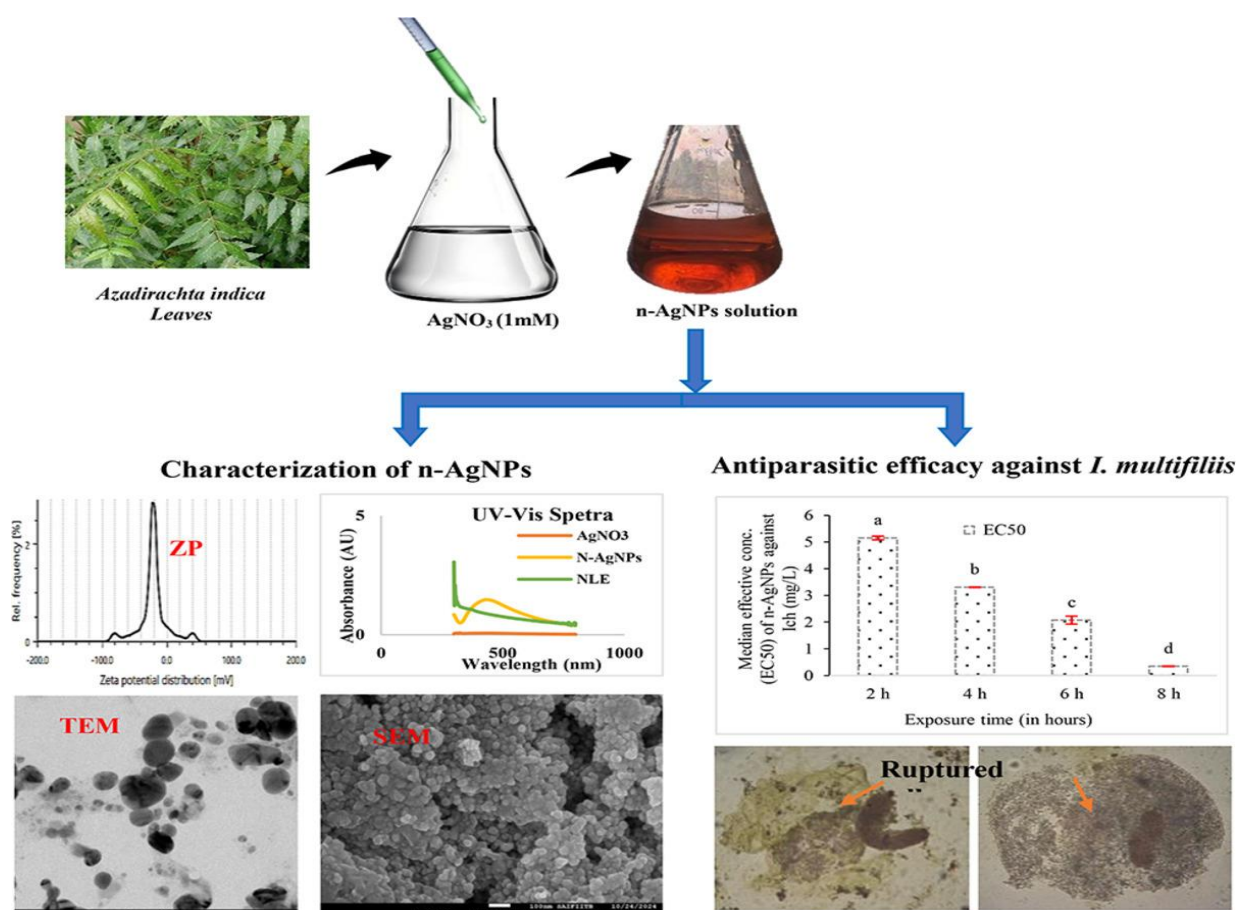


Neem in Aquaculture

[Green Silver Nanoparticles as a Potential Control Strategy against Ichthyophthirius multifiliis: Efficacy and Toxicity evaluation in Goldfish, Carassius auratus.](#)

Kumari P, Sarker S, Vimal B, Saini VP. Acta Trop. 2026 Apr 29;108112. doi: 10.1016/j.actatropica.2026.108112. Online ahead of print. PMID: 42066840

Ichthyophthirius multifiliis, the causative agent of white spot disease, poses a major challenge to ornamental fish culture. Seasonal surveillance of goldfish (*Carassius auratus*) from Galiff Street Fish Market, Kolkata, identified *I. multifiliis* as the dominant ectoparasite, with prevalence rates of 79.3% (post-monsoon), 71.0% (pre-monsoon), and 53.84% (monsoon). The green synthesized silver nanoparticles using neem leaf (n-AgNPs) were confirmed by a characteristic reddish-brown coloration, UV-Vis absorption peak at 421 nm, zeta potential (-23.5 mV), and spherical, uniformly dispersed particles with an average size of 25 ± 5 nm. FTIR analysis indicated the presence of functional groups involved in phytochemical-mediated reduction and stabilization. In vitro assays showed an antiparasitic efficacy (AE) of 100% against trophont stage of *I. multifiliis* at 10, 7.5, 5, and 2.5 mg/L with median effective concentrations (EC_{50}) 5.15, 3.30, 2.07, and 0.34 mg/L at 2, 4, 6, and 8 h, respectively. Further, the microscopic examination revealed complete immobilization of trophonts accompanied by membrane rupture and extrusion of cellular contents could lead to parasite death. The acute toxicity assays of n-AgNPs in goldfish indicated 96 h LC_{50} values of 10.22 mg/L. Overall, the findings highlight neem-mediated green n-AgNPs as a potent and promising strategy for controlling *I. multifiliis*; however, further in vivo studies are required to validate their practical application and assess long-term host safety.

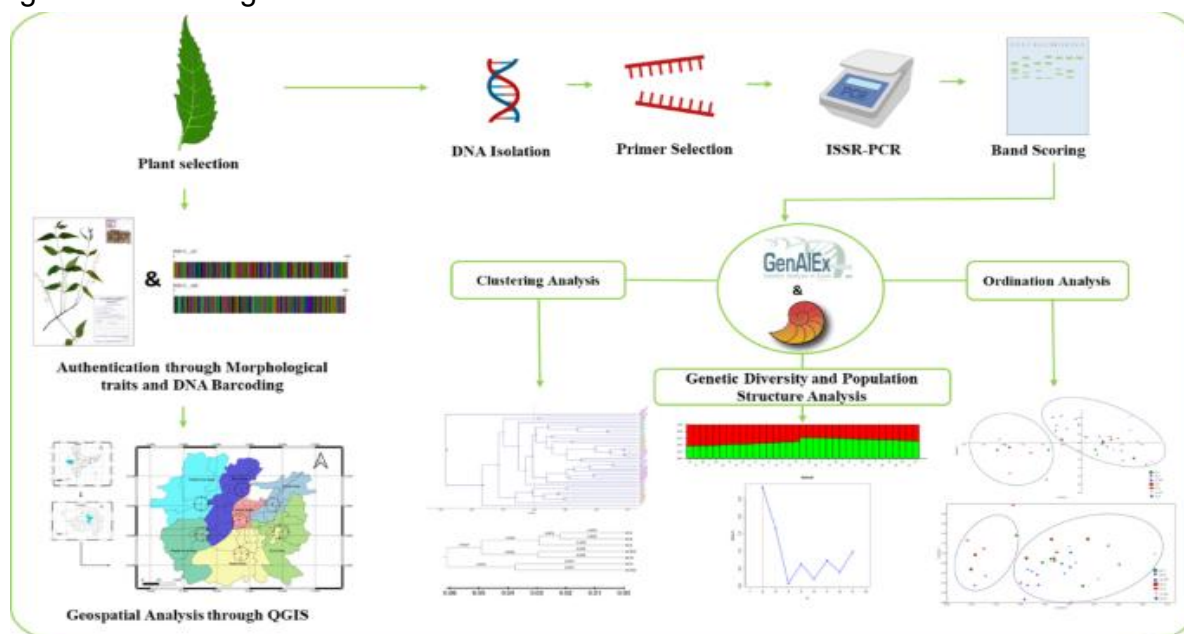


Neem- Genetic Diversity

[Assessment of Genetic Diversity and Population Structure on *Azadirachta indica* A. Juss. in an Urban Metropolitan: Ahmedabad, India.](#)

Kavithiya JJ, Prajapati KV, Trivedi PG, Sindhav GM. Biochem Genet. 2026 Apr 7. doi: 10.1007/s10528-026-11373-7. Online ahead of print. PMID: 41945285

Azadirachta indica (A. indica) A. Juss., commonly known as Neem, is a valuable multipurpose tree with profound medicinal properties and socioeconomic importance, widely recognized since ancient Ayurvedic times. Despite its prominence, knowledge about its genetic diversity within the metropolitan area of Ahmedabad is limited. This study marks the first in-depth exploration of the genetic diversity and population structure of A. indica in Ahmedabad. The authenticity of the species was validated through DNA barcoding, and a Geographical Information System (GIS) was used to collect the samples. A total of 35 A. indica accessions were analyzed using five Inter Simple Sequence Repeat (ISSR) primers. Genetic diversity and population structure were evaluated using Inter Simple Sequence Repeat (ISSR) markers through polymorphism assessment, clustering, ordination, and Bayesian population structure analyses. ISSRs revealed a high level of polymorphism (75.66%), indicating substantial genetic variability among accessions. An analysis of genetic diversity indices revealed low to moderate diversity ($H_s = 0.14$, $H_t = 0.217$, $I = 0.217$). Analysis of Molecular Variance (AMOVA) analysis depicted 81% variation within the population and 19% among the population. Low to moderate genetic differentiation ($G_{st} = 0.319$) and moderate gene flow ($N_m = 1.06$) indicated that urban development has not hindered gene flow among populations. Mantel's test revealed a weak but significant correlation between genetic and geographic distances, suggesting limited isolation by distance. The estimated ΔK using STRUCTURE exhibited two subpopulations, representing two gene pools for A. indica accessions ($K = 2$). Collectively, these patterns indicate that urbanization has not severely disrupted genetic connectivity in A. indica, reflecting its resilience and adaptive potential in a metropolitan environment. These findings provide pivotal knowledge for further understanding the genetic diversity and population structure of A. indica in one of the fastest-growing cities in India, which can be utilized for new breeding programmes, sustainable development and future conservation strategies around the globe.

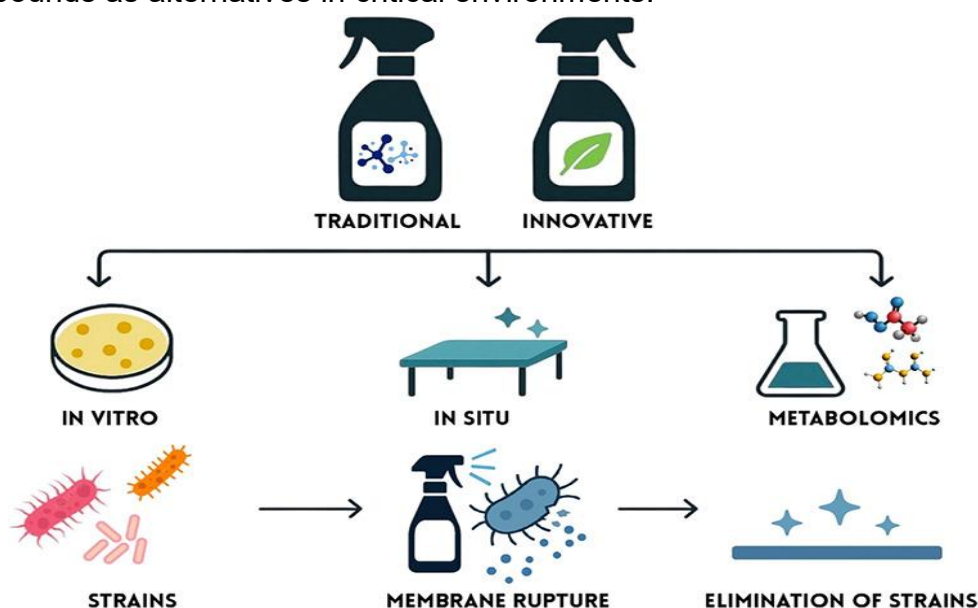


Neem for Human Health

[Traditional vs Innovative Sanitizers: *In Vitro* and *In Situ* Challenge in Multidrug-Resistant Bacteria.](#)

Ferreira GRA, Costa LRM, Miranda JL, Takeuchi MG, Chueiri MC, Ferreira Dumont C, Junior TLIFA, Ribas RM, Rossi DA, Loures GP, Souza HOA, Martins MM, de Bastos LM, Celestino MADS, de Melo RT. ACS Omega. 2026 Mar 18;11(12):18690-18703. doi: 10.1021/acsomega.5c08705. eCollection 2026 Mar 31. PMID: 41939385

Multidrug-resistant (MDR) bacteria pose a threat to public health worldwide. In this context, disinfectants are used to prevent and control the spread of these pathogens in hospital and industrial environments. The objective of this study was to determine minimum bactericidal concentrations (MBC) for 10 traditional and innovative active ingredients against 11 bacterial species. At the same time, the efficiency test was applied *in vitro* and the effect on hospital surfaces was analyzed *in situ*. The most promising compounds were selected to determine their mechanism of action in the Gram-positive bacterium (*Staphylococcus aureus*/MRSA) and the Gram-negative bacterium (*Pseudomonas aeruginosa*/PA) by metabolomic analysis. Resistance to 50% of the active ingredients was observed in the five strains, and PA was resistant to 70% of them. Peracetic acid, chlorhexidine digluconate, and neem extract eliminated all strains within 1 min in MBC. In efficiency tests, traditional products killed bacteria, with an average reduction of 7.07 ± 0.331 log cycles. Neem extract achieved an average reduction of 6.60 ± 0.33 log across all strains. *In situ*, peracetic acid did not allow bacterial growth, while biguanide, neem extract, tea tree oil, and orange oil achieved a reduction of more than 4 cycles of bacterial control on the surface. The exposure of MRSA and PA to the most promising compounds promoted distinct alterations in intra- and extracellular metabolism, which were modulated by the bacterial cell wall structure. The study highlights the importance of evaluating the practical efficacy of disinfectants, emphasizing the diversity of approaches including natural compounds as alternatives in critical environments.



[Formulation and Evaluation of Capsules From *Azadirachta indica* and *Khaya senegalensis* for Malaria Treatment.](#)

Adoley WN, Johnson R, Boakye-Gyasi ME, Owusu FWA, Obeng LM, Osei-Asibey A, Asamoah Mensa KA, Zoiku FK.J Trop Med. 2026 Apr 20;2026:8366410. doi: 10.1155/jotm/8366410. eCollection 2026.PMID: 42017189

Malaria is a major public health problem, prevalent in Africa and endemic in Ghana. Besides the use of artemisinin combination therapy, plant medicine is well-recognised and accepted in Ghana. Decoctions of *Azadirachta indica* (AI) leaves and *Khaya senegalensis* (KS) stem bark are traditionally used for treating malaria. However, these decoctions are bitter, bulky and unstable compared to solid dosage forms. This study sought to formulate decoctions from these plants into capsules to tackle these setbacks. The maximum wavelength of absorption and the amount per dose of both plants' decoctions (120 mL) were determined. Four absorbents (bentonite, magnesium carbonate, microcrystalline cellulose and kaolin) at four concentrations (25, 50, 75 and 100 mg/dose) were used to formulate the decoctions into granules. The granules were assessed to select the best extract-absorbent granules for encapsulation and quality assessment. Antiplasmodial activity and cytotoxicity of the formulated capsules were also determined. AI containing 35 mg/dose of kaolin with a percentage release of $97.31 \pm 0.74\%$ and good flow properties was encapsulated. KS containing 50 mg/dose of bentonite with a percentage release of $97.54 \pm 0.88\%$ and good flow properties was encapsulated. Formulated capsules from both plants passed all quality control tests performed, with disintegration times of 10.01 ± 0.34 and 4.48 ± 0.23 min, and cumulative drug release of $78.13 \pm 0.37\%$ and $95.63 \pm 1.00\%$, for AI and KS, respectively. AI (IC_{50} , 2.74 ± 0.70 $\mu\text{g/mL}$) and KS (IC_{50} , 24.37 ± 4.19 $\mu\text{g/mL}$) had good to moderate antiplasmodial activity ($IC_{50} \leq 50$ $\mu\text{g/mL}$) using the SYBR green assay. Cytotoxicity studies also indicated that both AI and KS were selective for the *Plasmodium* parasite. The formulated capsules could therefore be used as an alternative to their bitter decoctions.

[Significance of Herbs in the Dental World.](#)

Haq IU, Nisa WU.J Coll Physicians Surg Pak. 2026 Apr;36(4):547-549. doi: 10.29271/jcpsp.2026.04.547.PMID: 42015445

Herbs have historically been used in dentistry. For instance, peppermint oil and clove oil have been used to alleviate a toothache by soaking a cotton ball in the oil and subsequently placing it in the cavity or applying it directly to the affected tooth. Dental caries and periodontal diseases are the most predominant diseases in dentistry. Periodontal diseases, such as gingivitis, respond to antibacterial mouthwashes. This commentary describes several significant herbs, including bloodroot, caraway, chamomile, myrrh, rosemary, sage, aloe vera, neem leaf, Echinacea purpurea, and Peganum harmala, that have been used in dentistry. Their topical use may gain popularity due to the lack of reported microbial resistance and their minimal side effects.

[Impact of aromatherapy neck massage on resting cardiovascular parameters in patients with chronic kidney disease and secondary hypertension: A self-controlled study.](#)

Deepa Y, Vijay A, Padmavathi K, Bhamini AS, Nithya Sree R, Mooventhan A.J Bodyw Mov Ther. 2026 Jun;46:697-702. doi: 10.1016/j.jbmt.2026.02.003. Epub 2026 Feb 11.PMID: 41927240

Objective: Chronic kidney disease (CKD) is characterized by kidney damage persisting for 3 months or more. Hypertension (HTN) is a common cause of CKD progression. Previous studies had shown that aroma massage can effectively reduce systolic blood pressure (SBP) and diastolic blood pressure (DBP) in HTN patients. However, no study has examined its impact on resting cardiovascular (CV) parameters. Thus, the objective of the study was to evaluate the impact of aromatherapy massage on resting CV parameters in patients with CKD associated with secondary HTN.

Methods: Thirty participants with CKD-associated secondary hypertension received each of the three sessions in the repeated-measure design: [i] Neem, Ylang-ylang and Frankincense oil (NYF) massage on Day-1, [ii] Neem oil massage on Day-2, and [iii] a control rest session on Day-3. SBP, DBP and pulse rate (PR), Pulse pressure (PP), mean arterial pressure (MAP), rate pressure product (RPP), and double product (Do-P) were assessed immediate pre- and post-session changes (within-session analysis) and average values across sessions were compared (between-session analysis) before and after intervention.

Results: The results showed a significant reduction in RPP in NYF and Neem session compared with control with no significant changes in SBP, DBP, PR, PP, MAP and Do-P in between session analysis. Within-session analysis showed a significant reduction in SBP, DBP, PR, PP, MAP, Do-P and RPP in NYF and Neem session, whereas control session showed significant reduction in PR and Do-P with no significant changes in SBP, DBP, PP and MAP.

Conclusion: The results of this exploratory study suggest that aromatherapy massage using NYF essential oil may induce short-term within-session reductions in resting CV parameters and may help reduce CV workload, as reflected by changes in RPP, in patients with CKD-associated secondary hypertension.

[Antioxidant, antimicrobial, and apoptosis-related activities of Azadirachta indica \(Neem\) leaf extract in MCF-7 and A549 cell lines.](#)

Toson EA, Marzouk M, Rezk NA, Rabei S, Zahran RF.Sci Rep. 2026 Apr 26;16(1):13413. doi: 10.1038/s41598-026-48147-5.PMID: 42036451

This study aimed to extract neem leaves components to determine their antimicrobial and antioxidants activities. In addition, their ability to suppress the proliferation of A549 and MCF-7 cells were studied to explore the possible underlying mechanisms involved during such effects. Therefore, the antimicrobial activity of the extract towards some bacterial and fungal strains was investigated using agar well diffusion method, minimum inhibition concentration (MIC) test, peroxidase (POX), and catalase (CAT) activities. Superoxide dismutase (SOD) and catalase (CAT) like activities as well as total antioxidant capacity (TAC) and DPPH scavenging activity were determined. Cells viabilities were also

measured by the mitochondrial-dependent reduction of MTT on A549 and MCF-7 cell lines. Cell cycle was flowcytometrically analyzed to detect which phase was arrested. Quantitative real-time PCR (RT-PCR) was done to assess the changes in apoptotic and anti-apoptotic genes. Results showed that, neem leaves extract was more effective towards Gram-negative bacteria (*E. aerogenes* and *E. coli*) than that of Gram-positive type (*B. cereus* and *S. epidermidis*). Also, the extract has a high antioxidant activity compared to that of the ascorbic acid (DPPH IC_{50} was 0.22 and 0.51 mg/ml for extract and ascorbic acid, respectively). Cytotoxicity assays confirm that the extract is able to suppress the proliferation of cell lines in a dose-dependent manner with IC_{50} of 128.1 and 55.7 μ g/ml for A549 and MCF-7, respectively. The extract promotes arrest of cell cycle at G₀, inhibited the anti-apoptotic genes and stimulated the pro-apoptotic ones. In conclusion, neem leaves extract could have promising roles in pharmaceutical and medical applications.

[Biosynthesis of zinc oxide nanoparticles and evaluation of anticancer activity against MCF-7 breast cancer cell line via phyto-synthesised nanoparticles.](#)

Tanwar SN, Parauha YR, There Y, Pethe AM, Dhoble SJ. Sci Rep. 2026 Apr 15. doi: 10.1038/s41598-026-47644-x. Online ahead of print. PMID: 41986450

The present research work aims to biosynthesize ZnO nanoparticles using plant-mediated extracts (*A. marmelos*, *A. indica* and a mixture of both extracts) and to evaluate their physiochemical properties and associated biological activities. Transmission electron microscopy (TEM) analysis revealed that the majority of ZnO nanoparticles were spherical, uniformly distributed, and exhibited an average size within the nanometer scale. Photosynthesised ZnO NPs were characterized with particular emphasis on zeta potential, a key parameter influencing nanoparticle stability and biological interactions and its correlation with cytotoxic efficiency. Anticancer potential was assessed in vitro against the MCF-7 human breast cancer cell line, revealing dose-dependent inhibition of cancer cell proliferation with IC_{50} values closely associative reactive oxygen species (ROS) generation, mitochondrial membrane disruption, and induction of apoptosis. The nanoparticle demonstrated significantly antimicrobial activity against Gram-positive bacteria and indicated potential antioxidant properties through the scavenging of DPPH and H_2O_2 , attributed to bioactive plant-derived surface capping agents. The finding indicates a significant correlation between the surface characteristics of nanoparticles and their biological efficiency. This indicates that ZnO NPs synthesised from plant extracts may have potential applications in various biomedical applications.

Neem in Veterinary Science

[Methanolic plant extracts: emerging biotherapeutic alternatives for animal wound infection control.](#)

Arbab S, Ullah H, Alzahrani KJ, Alsharif KF, Alzahrani FM, Abuderman A, Zeng Z. Front Vet Sci. 2026 Apr 13;13:1812558. doi: 10.3389/fvets.2026.1812558. eCollection 2026. PMID: 42052350

Wound infections caused by bacterial pathogens remain a major health concern, often delaying tissue repair and increasing morbidity. This study evaluated the phytochemical composition and antibacterial activity of methanolic leaf extracts from *Aloe vera*, *Lawsonia inermis*, *Azadirachta indica*, *Curcuma longa*, and *Achyranthes aspera* as potential natural alternatives for managing wound-associated infections. Phytochemical screening revealed the presence of alkaloids, flavonoids, tannins, phenolics, saponins, and steroids in all extracts, with *L. inermis* and *C. longa* showing particularly high levels of phenolics, tannins, and flavonoids, while *A. indica* exhibited abundant alkaloids and saponins. From 123 wound samples, six bacterial species were isolated: *Staphylococcus aureus* (38; 30.9%), *Streptococcus agalactiae* (17; 13.8%), *Proteus mirabilis* (22; 17.9%), *Escherichia coli* (18; 14.6%), *Pseudomonas aeruginosa* (15; 12.2%), and *Klebsiella pneumoniae* (13; 10.6%). Antibacterial activity assessed using the agar well diffusion method showed that *A. indica* produced the highest inhibition zones (12.5 ± 0.5 mm to 20.4 ± 0.9 mm), followed by *C. longa* (11.6 ± 0.5 mm to 19.2 ± 0.7 mm). The positive control, ciprofloxacin (10 μ g), exhibited inhibition zones ranging from 20.8 ± 0.5 mm to 26.1 ± 0.4 mm, whereas the negative control (10% DMSO) produced no inhibition. The observed antibacterial activity is likely due to the synergistic effects of bioactive phytochemicals, which disrupt bacterial cell membranes and inhibit bacterial growth. These findings indicate that *A. indica* and *C. longa* possess strong antibacterial potential and may serve as promising natural agents for managing wound infections caused by clinically relevant pathogens. Further *in vivo* and toxicity studies are recommended to validate their therapeutic applicability.

[Bioactive components of *Azadirachta indica* \(neem\) leaf extract enhance immunity, health, and production parameters in broilers.](#)

Islam MS, Parvez MAR, Islam S, Hasan MT, Alam MA, Hoque MN. Res Vet Sci. 2026 Mar;200:106040. doi: 10.1016/j.rvsc.2025.106040. Epub 2025 Dec 24. PMID: 41456577

This study investigated the efficacy of a chemically characterized neem (*Azadirachta indica*) leaf extract as a viable alternative to antibiotics for sustainable broiler production. Comprehensive phytochemical analysis (TLC, HPLC, GC-MS, NMR) identified and quantified key bioactive compounds—azadirachtin, nimbin, nimbolide, gedunin, and salannin—with the ethanolic extract yielding a higher concentration of these limonoids. The comparative efficacy of this standardized neem preparation was evaluated against danofloxacin (antibiotic) and butaphosphan (metabolic booster) in a 28-day trial with one

hundred and fifty Lohman meat chicks (10 birds/pen, 3 pens/treatment). The results demonstrated that neem supplementation significantly improved broiler performance. Birds in the neem groups, particularly the ethanolic group, achieved significantly higher final body weight and better feed conversion ratio, performing comparably to the antibiotic and booster groups. Immunologically, neem extracts significantly increased lymphocyte counts and reduced the heterophil-to-lymphocyte ratio, confirming an immunostimulatory and anti-stress effect. Serum biochemistry revealed significantly lower levels of liver enzymes (AST and ALT), indicating a hepatoprotective benefit. Histopathological examination confirmed healthier intestinal morphology, with quantifiably increased villus height and a superior villus-height-to-crypt-depth ratio in the duodenum and more caecal folds. Additionally, carcass quality and dressing percentage were significantly higher in neem-treated birds. The study concludes that the synergistic action of the identified bioactive compounds in neem leaf extract is responsible for its multifaceted benefits, making it a promising, natural, and cost-effective phytogetic alternative to in-feed antibiotics for enhancing productivity and ensuring safe broiler meat.