



Production and Characterization of Nanoparticles from Citronella (*Cymbopogon nardus*) Extract Based on Chitosan Compounds

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Abstract

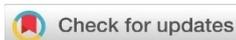
Background: The use of nanoparticles in Indonesia has been developing and is now being applied across sectors, including agriculture, health, and industry. Nanoparticles derived from *Cymbopogon nardus* can be used as nanopesticides because they contain several compounds that suppress pathogen growth and reduce pest populations. Chitosan is an additional compound used in the fabrication of these nanoparticles. **Methods:** This research used materials and tools, including a PSA (Particle Size Analyzer), a SEM (Scanning Electron Microscope), *Cymbopogon nardus*, and chitosan. The research stages included extraction of *Cymbopogon nardus*, nanoparticle fabrication, PSA analysis, zeta potential measurement, and SEM observation. **Results:** The PSA test revealed that the *Cymbopogon nardus* nanoparticles had an average size of 907.2 nm. The zeta potential of the nanoparticles was -40.62 mV, indicating good electrostatic stability. SEM images showed that the nanoparticles had an irregular shape. **Conclusions:** The *Cymbopogon nardus* nanoparticles produced in this study, as characterized by PSA, zeta potential, and SEM analyses, demonstrated the expected characteristics of nanoparticles.

Keywords: Chitosan, *Cymbopogon nardus*, chitosan, Nanoparticle, PSA, SEM

Introduction

The use of nanoparticles in Indonesia has grown and is now being applied across sectors such as agriculture, healthcare, and industry. This technology was specifically developed to produce nano-sized dosage forms, ranging from 10 nm to 1000 nm (Aloys et al., 2016). Nanoparticles can penetrate intercellular spaces and cell walls more efficiently than larger particles. Nanoparticles can enhance chemical reactions, thereby reducing the amount of catalytic material needed. Products made with nanoparticles are higher quality, more durable, and more environmentally friendly. In Indonesia, several studies have explored ionic gelation methods to produce nanoparticles from plant extracts, with promising results. One example is the production of nanoparticles from Vernonia amygdalina leaf extract, which successfully produced particles with an average size of approximately 111.3 nm. These findings indicate that the ionic gelation method can be used effectively to produce plant extract-based nanoparticles with relatively small, uniform particle sizes (Ansari & Jahan, 2021).

Nanoparticle synthesis technology using polymer-based systems is generally carried out using two main approaches: polymerization of synthetic monomers and polymer dispersion methods. In the polymerization process of synthetic monomers, a water-insoluble monomer is dispersed into a water dispersion phase, which is then induced and controlled by a chemical initiator, pH variations, and stabilizers. The manufacture of nanoparticles using polymers has a precipitation principle. This process involves forming an emulsion of an



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organic phase dissolved in a polymer with an aqueous phase; for particle formation, the organic phase must then be removed. Several types of polymer dispersion methods include solvent evaporation, emulsification, ionic gelation, and spray drying (Abdassah, 2017). This study specifically uses the ionic gelation technique, known for its simple process, use of non-organic solvents, and ease of use. This technique provides an efficient alternative for nanoparticle production, especially when considering sustainability and environmental safety.

The production of nanoparticles from citronella certainly requires other compounds to reduce it in its oxidized state. Therefore, the compound used is chitosan. Chitosan is a biopolymer carrier compound that can be used for sustainable pesticide release due to its good biocompatibility, biodegradability, and bioactivity. Chitosan is an abundant natural cationic biopolymer obtained from the partial deacetylation of chitin (Shukla et al., 2013). This biopolymer consists of a linear β -(1 \rightarrow 4) glycosidic bond formed from 2-acetamido-d-glucose and 2-amino-d-glucose units. The amine functional group in chitosan has a pKb value of around 6.5, which increases its solubility in neutral and acidic environments (Mohammed et al., 2017). In addition, the amine group contributes to the physicochemical properties of biopolymers, enabling the development of chitosan-based materials via synthetic methods such as gelation (Van Bavel et al., 2023). Liang et al. (2018), conducted a study on temperature-responsive chitosan-coated silica nanoparticles in avermectin insecticides. The results showed that higher avermectin release was obtained at higher temperatures, with 18.85% at 25°C and 34.21% at 50°C.

Citronella nanoparticles will be tested for particle size (PSA), Zeta Potential, and SEM (Scanning Electron Microscope) images. A Particle Size Analyzer is a device used to determine particle size using a technique called PSA. The primary methods used in the most common Particle Size Analyzer (PSA) are Laser Diffraction (LD) and Dynamic Light Scattering (DLS). The Laser Diffraction (LD) and Dynamic Light Scattering (DLS) testing processes use a wet method for sample preparation and dispersion to prevent particle agglomeration and achieve a homogeneous dispersion (Asif et al., 2022). The PSA test results are distributed, so the measurement results can be assumed to describe the overall condition of the sample (Ansari & Jahan, 2021). PSA is also used to determine the particle-size distribution in a sample. Particles can be in the form of powders, suspensions, emulsions, or aerosols (Ameen et al., 2023). The size and shape of the powder affect its flow and agglomeration properties. Larger, spherical particles typically flow more easily (Nzilu et al., 2023). Smaller particles dissolve more readily, increasing the suspension's viscosity. Smaller droplet size and higher surface charge increase the stability of suspensions and emulsions (Ahmadi et al., 2021).

Zeta potential reflects the surface electrical charge between particles in a colloidal system, which directly affects the aggregation tendency and dispersion stability of nanoparticles (Veena et al., 2024). SEM is an electron microscope tool that can image the surface morphology of a substance using an electron beam (Mariappan et al., 2014). In addition, a scanning electron microscope (SEM) is used to analyze the surface structure of particles. This tool operates by illuminating the sample surface with a high-energy electron beam to produce a high-resolution image (Abdellatif et al., 2022). Because the electron beam can only interact with conductive surfaces, non-conductive samples must first be coated with a conductive material (Karuppannan et al., 2021). The reflected electrons, or generated secondary electrons, are received by the SEM detector, which then interprets the reflection location based on the highest intensity (Sharma et al., 2021). This information helps describe the morphology, grain size, and surface texture of particles (Younas et al., 2021). The detector in the SEM detects the reflected electrons and determines the beam location (Bahjat et al., 2021).

The main ingredients used for nanoparticles vary depending on the product being produced. This study used nanoparticles from citronella (*Cymbopogon nardus*) extract, which can be used as a nanopesticide. Nanopesticides are pesticides that utilize nano-sized particles (Kadir et al., 2025). The application of nanoparticles in agriculture can

increase crop production, reduce mineral loss, reduce pest or disease populations, and reduce the use of chemical fertilizers (Awan et al., 2021). Citronella is known for its distinctive aroma and contains essential oils with main components such as Citronellal, Geraniol, and Citronellol. These compounds have biological activities, such as antifungal and antibacterial, and belong to the monoterpene terpenoid group, which is effective in inhibiting the growth of pathogenic microorganisms (Nurmansyah, 2010). The volatile compounds in citronella are widely used in bactericidal, virucidal, insecticidal, and antiparasitic applications (Bayala et al., 2020).

The effectiveness of using citronella as a nanopesticide has also been demonstrated through a nano-emulsion formulation with clove oil. A study by Noveriza et al. (2017) showed that this combination was effective as a virucide against patchouli mosaic virus. Tests showed that a 1% dose of the citronella formula provided up to 74.87% inhibition of mosaic virus infection in *Chenopodium amaranticolor* test plants. Field testing results in West Java showed formula efficiency ranging from 6.38% to 20.63%, while in Banten it ranged from 12.12% to 48.55%. In addition to controlling disease, nanopesticides also function to improve plant nutrition, remediate soil, and reduce abiotic stress (Shangguan et al., 2024). Therefore, processing citronella into nanoparticles is an innovative approach for developing more effective and environmentally friendly botanical pesticides. This research focused on the synthesis process and characterization of citronella nanoparticles to support their use as active ingredients in nanopesticides.

Methods

Tools and Materials

The tools used in this study were a SEM-EDX (JEOL JSM-6510LA) and a PSA (Type/Brand) machine. The materials used in this study were 250 g of citronella, 96% ethanol, distilled water, carboxymethyl chitosan, AlCl₃, and acetic acid.

Citronella Extract Preparation

The citronella samples were of productive age; the roots and leaves were then removed and cleaned with clean water. The required 250 grams of citronella for nanoparticle production yielded 78 g of dry citronella powder. The dry citronella powder was dissolved in 600 ml of 96% ethanol. The solution was microwaved for 7 minutes, filtered using filter paper, and then evaporated to remove the solvent until the extract was thick. The resulting extract weighed 26.246 g.

Citronella Nanoparticle Preparation

The initial step in producing citronella nanoparticles was to add 1 liter of distilled water to a beaker. Two grams of carboxymethyl chitosan were added bit by bit into a beaker while stirring with a magnetic stirrer. Next, 2 g of citronella extract was added bit by bit until fully dissolved, followed by 20 mL of 0.1% AlCl₃ and 10 mL of acetic acid. The beaker was then covered with plastic wrap, ultrasonicated for 5 minutes, stirred with a homogenizer for 1 minute, and evaporated for 45 minutes to a thick consistency. The resulting thick extract was dried using a cabinet dryer (brand/type), and the dried sample was ground.

PSA (Particle Size Analyzer) Test

The PSA tool is used to measure particle sizes in the nanoscale to microscale range. The advantage of using PSA lies in its ability to measure particles without damaging the sample's physical structure and to produce data with a high degree of accuracy. The results from this test enable further analysis of the particle size distribution. This

distribution is expressed in three main approaches: the number of particles, the intensity of scattered light, and the volume of particles detected during the measurement process.

Zeta Potential

Particle dispersion stability is assessed by measuring the zeta potential. When the zeta potential value is less than -30 mV or more than +30 mV, it can be concluded that the resulting nanoparticle system tends to be more stable. This is closely related to the repulsive forces between particles. Conversely, if the zeta potential value is in the range close to zero, the repulsive forces between particles are weakened, which ultimately increases the potential for particle aggregation within the dispersion system.

SEM (Scanning Electron Microscope) Photo

SEM is an electron microscope-based observation tool that works by focusing an electron beam onto the surface of an object. SEM can produce high-resolution, high-contrast 3D images. SEM images can reveal information such as surface characteristics, object texture, shape, particle size, and particle arrangement within the object.

Result

Nanoparticle characterization is a crucial step to ensure the resulting dosage system has the physicochemical properties required for the formulation. Key parameters commonly analyzed include particle size, zeta potential, and surface morphology, as assessed by scanning electron microscopy (SEM). Particle size, in the nanometer range, significantly determines nanoparticles' ability to increase surface area, improve dispersion stability, and facilitate penetration into target tissues. Meanwhile, zeta potential is an indicator of the electrostatic stability of the nanoparticles in their dispersion medium. A high zeta potential (either positively or negatively charged) indicates sufficient repulsive forces between particles, thus reducing the tendency for aggregation during storage.

SEM analysis provides a visual depiction of particle shape, uniformity, and surface smoothness. A spherical, relatively homogeneous morphology indicates that the ionotropic gelation process is effective, producing neither cavities nor large aggregates. These three parameters—size, zeta potential, and morphology—can determine whether the resulting nanoparticles are stable, conform to the ionic gelation formation mechanism, and meet the criteria for further application. Table 1 presents a summary of the characterization results of citronella nanoparticles obtained from this study.

Table 1. Test Results of Lemongrass Nanoparticles

Parameter	Value	Unit	Interpretation
Nanoparticle size (PSA test)	907,2	nm	Still in the nanoparticle range (10–1000 nm).
Zeta potential	-40,62	mV	Very high values in absolute terms indicate electrostatic stability.
Morphology (SEM)	Irregular	-	Non-spherical shape; may indicate aggregation or non-homogeneous ionic gelation process. .

Nanoparticles are produced from citronella plants using the ionic gelation method. This technique involves cross-linking interactions between polyelectrolytes and doubly charged ions as their charge partners. The main principle in the formation of chitosan nanoparticles using this method is the electrostatic interaction between the positively charged amine groups in chitosan and the negatively charged groups of polyanions such as tripolyphosphate. This interaction results in ionic complexation, which triggers precipitation and forms spherical particles.

Chitosan itself is a natural polymer widely used as a coating material due to its non-toxic, environmentally friendly, biodegradable, and antimicrobial properties (Sutanto et al., 2022). This compound consists of N-acetyl-glucosamine and glucosamine units derived from the deacetylation of chitin (Pellis et al., 2022). Chitin's highly crystalline structure is due to strong hydrogen bonds, and its linear structure is composed of (1,4)- β -N-acetylglucosaminyl units with two hydroxyl groups and one acetamide group. The presence of amine (NH₂) and hydroxyl (OH) groups makes chitosan hydrophilic (Pertwi et al., 2023). This property underlies chitosan's potential to increase the solubility of active ingredients in nutraceutical products, especially in polar solvents.

PSA is a tool used to measure the size of nanoparticles in a sample. According to Sari et al. (2017), the wet method is generally preferred for PSA testing because it offers higher accuracy than the dry method, especially for very small particles that are prone to agglomeration. This technique involves dispersing particles in a liquid medium, thereby preventing particle clumping. In Figure 1, the X-axis (horizontal) shows the nanoparticle size in nanometers (nm), while the Y-axis (vertical) shows the signal intensity produced by the nanoparticles. Nanoparticle characterization using PSA testing showed that the citronella nanoparticle sample had a size of 907.2 nm. This size fits within the nanoparticle size range of 10–1000 nm.

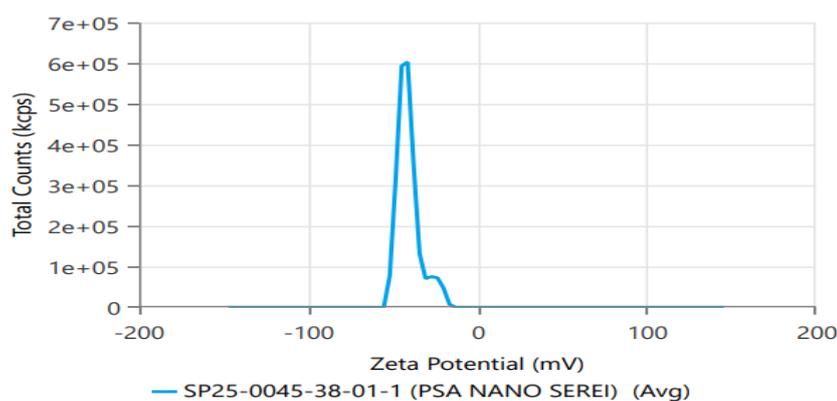


Figure 1. Size graph of citronella nanoparticles through zeta potential test.

Another important parameter analyzed is the zeta potential, which determines the surface charge of particles and the stability of nanoparticle dispersions in liquid media. Zeta potential is measured using a zeta sizer and provides information about the electrical conditions on the nanoparticle surface. Zeta potential generally depends on the nature of the nanoparticles and the dispersion medium (Pochapski et al., 2021). Figure 1 on the X-axis (horizontal) shows the zeta potential of the particles in millivolts (mV), while the Y-axis (vertical) shows the total counts in kilocounts per second (kcps). Figure 1 shows that the zeta potential of citronella nanoparticles is -40.62 mV. According to Mousa et al. (2021), nanoparticles with zeta potential values less than -30 mV and greater than +30 mV are considered more stable. Therefore, these citronella nanoparticles are stable. Under these conditions, nanoparticles tend to remain stable and do not aggregate. Stability in nanopesticides can increase their effectiveness without altering their physical form, such as color or odor.

Nanoparticle morphology analysis using Scanning Electron Microscopy (SEM) provides essential information about the size and shape of the resulting nanoparticles (Suryani et al., 2025). SEM is a method that can observe particle surfaces at a micro level through the principle of electron diffraction directed at minimal angles (Lakshmnarayanan et al., 2021). The use of an SEM microscope is constructive for observing particle shapes that cannot be seen with a conventional light microscope, as well as for providing information on particle composition, mechanical deformation, and grain boundaries (Alzubaidi et al., 2023). Morphological observations of citronella nanoparticles in this study used Scanning Electron Microscopy because SEM provides

direct visualization of particle shape, surface structure, and particle aggregation, thereby ensuring homogeneous nanoparticle formation. The morphological results of the citronella nanoparticles in Figure 2 indicate that the citronella nanoparticles have an irregular morphology. Observations were conducted with standard parameters, including a high voltage of 10 kV and a working distance (WD) of 10 mm, which also support EDX signal acquisition for X-ray elemental analysis. SEM photo observations showed that the citronella nanoparticles were irregularly shaped.

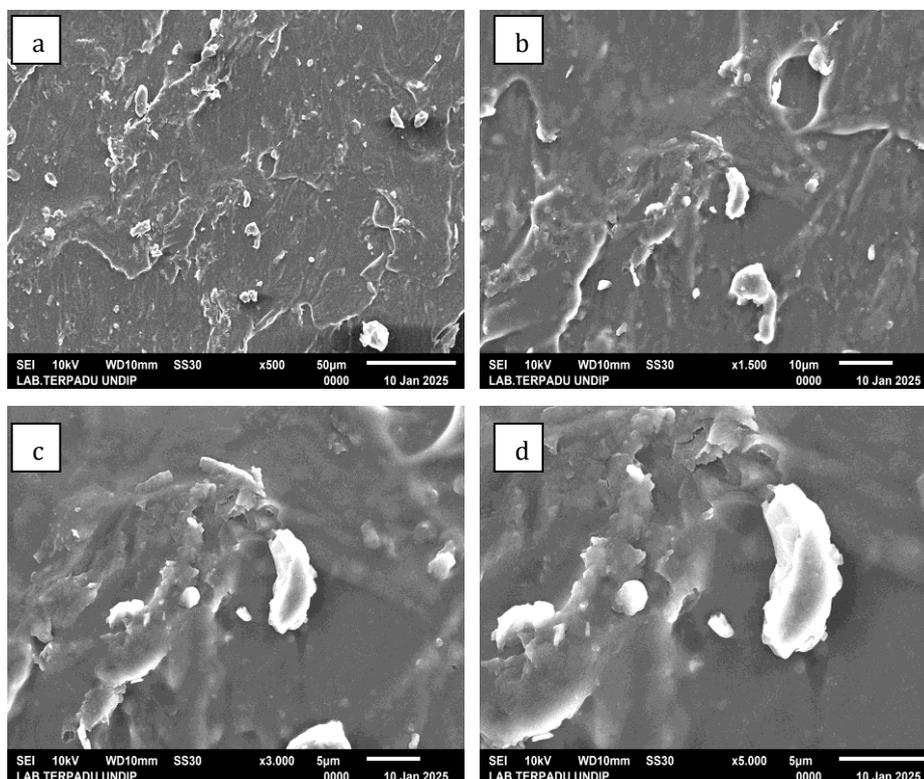


Figure 2. Morphology of Citronella Nanoparticles Using SEM Photos with Various Magnifications a) 500x; b) 1500x; c) 3000x; d) 5000x.

Optimal nanoparticle production is characterized by petite particle sizes with irregular structures. This nanoscale characteristic results in a larger surface area, which enhances the particles' reactivity. High reactivity increases the likelihood of interactions or chemical reactions with other substances, significantly increasing the effectiveness of the nanoparticles. Figure 2 (a) shows the morphology of citronella nanoparticles using SEM images at 500x magnification and a particle size of 50 μm . Figure 2 (b) shows the morphology of citronella nanoparticles using SEM images at 1500x magnification and a particle size of 10 μm . Figure 2 (c) shows the morphology of citronella nanoparticles using SEM images at 3000x magnification and a particle size of 5 μm . Figure 2 (d) shows the morphology of citronella nanoparticles using SEM images at 5000x magnification and a particle size of 5 μm .

The morphological characterization of citronella nanoparticles in this study indicates irregularly shaped particles. This non-uniform morphology is likely due to variations in the ionic gelation process, including the polymer-to-crosslinker ratio, chitosan solution viscosity, and stirring conditions during synthesis. These results align with research (Mulwandari & Sirajuddin, 2022) that reported citronella nanoparticles to have a spherical but irregular shape with varying sizes. This similarity suggests that morphological irregularity is a common characteristic of nanoparticles produced by chitosan-based ionic gelation, especially in natural materials with high matrix complexity.

This morphological variation has important implications for nanoparticle applications, particularly regarding penetration, distribution, and interaction with the

target. Irregular morphology can affect the effective surface area of the particles and the release rate of active ingredients when used in agricultural formulations. Therefore, although the ionic gelation method offers the advantages of simplicity, safety, and the use of environmentally friendly materials, further optimization is needed to produce nanoparticles with more uniform shapes and consistent sizes, thereby maximizing their physical and functional characteristics.

Conclusions

Citronella nanoparticles were successfully prepared using a chitosan-based ionic gelation method, with a particle size of 907.2 nm and a zeta potential of -40.62 mV, indicating good electrostatic stability. Despite their irregular particle morphology, these nanoparticles still have potential as a nanodrug system for agricultural applications, including nanopesticides, because their size enables more efficient penetration and interaction than conventional particles. The chitosan-based ionic gelation method has proven to be simple, safe, and environmentally friendly, thus having the potential for broad application development in the future. The citronella nanoparticles in this study are still relatively large and have irregular morphology, so further formulation optimization is needed to improve their uniformity.

Declaration statement

The authors reported no potential conflict of interest.

References

- Abdassah, M. (2017). Nanopartikel dengan gelas ionik. *Jurnal Farmaka*, 15(1), 45–52.
- Abdellatif, A. A. H., Alhathloul, S. S., Aljohani, A. S. M., Maswadeh, H., Abdallah, E. M., Hamid Musa, K., & El Hamd, M. A. (2022). Green Synthesis of Silver Nanoparticles Incorporated Aromatherapies Utilized for Their Antioxidant and Antimicrobial Activities against Some Clinical Bacterial Isolates. *Bioinorganic Chemistry and Applications*, 2022. <https://doi.org/10.1155/2022/2432758>
- Ahmadi, S., Fazilati, M., Nazem, H., & Mousavi, S. M. (2021). Green Synthesis of Magnetic Nanoparticles Using Satureja hortensis Essential Oil toward Superior Antibacterial/Fungal and Anticancer Performance. *BioMed Research International*, 2021. <https://doi.org/10.1155/2021/8822645>
- Aloys, H., Korma, S. A., Alice Tuyishime, M., Ali, A. H., Marie Alice, T., Chantal, N., Abed, S. M., & Ildephonse, H. (2016). Microencapsulation by Complex Coacervation: Methods, Techniques, Benefits, and Applications. *American Journal of Food Science and Nutrition Research*, 3(6), 188–192. <http://www.openscienceonline.com/journal/fsnr>
- Alzubaidi, A. K., Al-Kaabi, W. J., Ali, A. Al, Albukhaty, S., Al-Karagoly, H., Sulaiman, G. M., Asiri, M., & Khane, Y. (2023). Green Synthesis and Characterization of Silver Nanoparticles Using Flaxseed Extract and Evaluation of Their Antibacterial and Antioxidant Activities. *Applied Sciences (Switzerland)*, 13(4). <https://doi.org/10.3390/app13042182>
- Ameen, F., Al-Homaidan, A. A., Al-Sabri, A., Almansob, A., & AlNadhari, S. (2023). Anti-oxidant, antifungal and cytotoxic effects of silver nanoparticles synthesized using marine fungus *Cladosporium halotolerans*. *Applied Nanoscience (Switzerland)*, 13(1), 623–631. <https://doi.org/10.1007/s13204-021-01874-9>
- Ansari, M. A., & Jahan, N. (2021). Structural and Optical Properties of BaO Nanoparticles Synthesized by Facile Co-precipitation Method. *Materials Highlights*, 2(1–2), 23. <https://doi.org/10.2991/math.k.210226.001>
- Asif, M., Yasmin, R., Asif, R., Ambreen, A., Mustafa, M., & Umbreen, S. (2022). Green Synthesis of Silver Nanoparticles (AgNPs), Structural Characterization, and their Antibacterial Potential. *Dose-Response*, 20(1), 1–11. <https://doi.org/10.1177/15593258221088709>
- Awan, S., Shahzadi, K., Javad, S., Tariq, A., Ahmad, A., & Ilyas, S. (2021). A preliminary study of influence of zinc oxide nanoparticles on growth parameters of Brassica oleracea var italica. *Journal of the Saudi Society of Agricultural Sciences*, 20(1), 18–24. <https://doi.org/10.1016/j.jssas.2020.10.003>
- Bahjat, H. H., Ismail, R. A., Sulaiman, G. M., & Jabir, M. S. (2021). Magnetic Field-Assisted Laser Ablation of Titanium Dioxide Nanoparticles in Water for Antibacterial Applications. *Journal of Inorganic and Organometallic Polymers and Materials*, 31(9), 3649–3656. <https://doi.org/10.1007/s10904-021-01973-8>
- Bayala, B., Coulibaly, A. Y., Djigma, F. W., Nagalo, B. M., Baron, S., Figueredo, G., Lobaccaro, J. M. A., & Simpore, J. (2020). Chemical composition, antioxidant, anti-inflammatory and antiproliferative activities of the essential oil of *Cymbopogon nardus*, a plant used in traditional medicine. *Biomolecular Concepts*, 11(1), 86–96. <https://doi.org/10.1515/bmc-2020-0007>

- Kadir, M. L., Dageri, A., & Aslan, T. N. (2025). Nanopesticides for managing primary and secondary stored product pests: Current status and future directions. *Heliyon*, 11(4). <https://doi.org/10.1016/j.heliyon.2025.e42341>
- Karuppappan, S. K., Ramalingam, R., Mohamed Khalith, S. B., Dowlath, M. J. H., Darul Raiyaan, G. I., & Arunachalam, K. D. (2021). Characterization, antibacterial and photocatalytic evaluation of green synthesized copper oxide nanoparticles. *Biocatalysis and Agricultural Biotechnology*, 31(December 2020). <https://doi.org/10.1016/j.bcab.2020.101904>
- Lakshmnarayanan, S., Shereen, M. F., Niraimathi, K. L., Brindha, P., & Arumugam, A. (2021). One-pot green synthesis of iron oxide nanoparticles from Bauhinia tomentosa: Characterization and application towards synthesis of 1, 3 diolein. *Scientific Reports*, 11(1), 1–13. <https://doi.org/10.1038/s41598-021-87960-y>
- Mariappan, R., Ponnuswamy, V., Suresh, P., Ashok, N., Jayamurugan, P., & Chandra Bose, A. (2014). Influence of film thickness on the properties of sprayed ZnO thin films for gas sensor applications. *Superlattices and Microstructures*, 71, 238–249. <https://doi.org/10.1016/j.spmi.2014.03.029>
- Mohammed, M. A., Syeda, J. T. M., Wasan, K. M., & Wasan, E. K. (2017). An overview of chitosan nanoparticles and its application in non-parenteral drug delivery. *Pharmaceutics*, 9(4). <https://doi.org/10.3390/pharmaceutics9040053>
- Mulwandari, M., & Sirajuddin, M. I. (2022). *Heliyon Direct synthesis of lemongrass (Cymbopogon citratus L.) essential oil - silver nanoparticles (EO-AgNPs) as biopesticides and application for lichen inhibition on stones*. 8(December 2021). <https://doi.org/10.1016/j.heliyon.2022.e09701>
- Noveriza, R., Mariana, M., & Yuliani, S. (2017). Keefektifan Formula Nanoemulsi Minyak Serai Wangi Terhadap Potyvirus Penyebab Penyakit Mosaik Pada Tanaman Nilam. *Buletin Penelitian Tanaman Rempah Dan Obat*, 28(1), 47. <https://doi.org/10.21082/bullitro.v28n1.2017.47-56>
- Nurmansyah. (2010). EFEKTIVITAS MINYAK SERAIWANGI DAN FRAKSI SITRONELLAL TERHADAP PERTUMBUHAN JAMUR *Phytophthora palmivora* PENYEBAB PENYAKIT BUSUK BUAH KAKAO. *Jurnal Buletin Litro*, 21(1), 43–52. <http://ejournal.litbang.pertanian.go.id/index.php/bultro/article/view/1881>
- Nzilu, D. M., Madivoli, E. S., Makhanu, D. S., Wanakai, S. I., Kiprono, G. K., & Kareru, P. G. (2023). Green synthesis of copper oxide nanoparticles and its efficiency in degradation of rifampicin antibiotic. *Scientific Reports*, 13(1), 1–18. <https://doi.org/10.1038/s41598-023-41119-z>
- Pellis, A., Guebitz, G. M., & Nyanhongo, G. S. (2022). Chitosan: Sources, Processing and Modification Techniques. *Gels*, 8(7), 5–25. <https://doi.org/10.3390/gels8070393>
- Pertiwi, I., Zaman, N. N., Arifki, H. H., Silalahi, K., Wenni, & Wathoni, N. (2023). Farmaka Farmaka. *Farmaka*, 16(1), 310–321.
- Pochapski, D. J., Carvalho Dos Santos, C., Leite, G. W., Pulcinelli, S. H., & Santilli, C. V. (2021). Zeta Potential and Colloidal Stability Predictions for Inorganic Nanoparticle Dispersions: Effects of Experimental Conditions and Electrokinetic Models on the Interpretation of Results. *Langmuir*, 37(45), 13379–13389. <https://doi.org/10.1021/acs.langmuir.1c02056>
- Sari, R. N., Saridewi, N., & Shofwatunnisa, S. (2017). Biosynthesis and Characterization of ZnO Nanoparticles with Extract of Green Seaweed Caulerpa sp. *Jurnal Perikanan Universitas Gadjah Mada*, 19(1), 17. <https://doi.org/10.22146/jfs.24488>
- Shangguan, W., Chen, H., Zhao, P., Cao, C., Yu, M., Huang, Q., & Cao, L. (2024). Scenario-oriented nanopesticides: Shaping nanopesticides for future agriculture. *Advanced Agrochem*, 3(4), 265–278. <https://doi.org/10.1016/j.aac.2024.07.002>
- Sharma, D., Afzal, S., & Singh, N. K. (2021). Nanoprimering with phytosynthesized zinc oxide nanoparticles for promoting germination and starch metabolism in rice seeds. *Journal of Biotechnology*, 336(December 2020), 64–75. <https://doi.org/10.1016/j.jbiotec.2021.06.014>
- Suryani, A., Sjoftan, O., & Widodo, E. (2025). *Evaluation of Scanning Electron Microscopy (SEM) Test and Flavonoid Nanoparticles from Herbal Dreg as an Additive in Layer Chicken Feed* (Issue Icesai 2024). Atlantis Press International BV. <https://doi.org/10.2991/978-94-6463-670-3>
- Sutanto, Y. S., Harti, A. S., Puspawati, N., & Sutanto, M. (2022). The Effectiveness Antimicrobial of Polysaccharide Gel from Durian Peel Ethanol Extract and Chitosan Gel. *Open Access Macedonian Journal of Medical Sciences*, 10(A), 982–987. <https://doi.org/10.3889/oamjms.2022.9974>
- Van Bavel, N., Issler, T., Pang, L., Anikovskiy, M., & Prenner, E. J. (2023). 15 Pdf. *Molecules*, 28(11), 1–14.
- Veena, V., Sharanagouda, H., & Lagashetty, A. (2024). Encapsulated Coragen-ZnO nanopesticide for effective photo-controlled release and synergistic activity. *Next Research*, 1(1), 100016. <https://doi.org/10.1016/j.nexres.2024.100016>
- Younas, U., Hassan, S. T., Ali, F., Hassan, F., Saeed, Z., Pervaiz, M., Khan, S., Jannat, F. T., Bibi, S., Sadiqa, A., Ali, Z., Iqbal, S., Ghfar, A. A., Ouladsmame, M., Al-Anazy, M. M., & Ali, S. (2021). Radical scavenging and catalytic activity of fe-cu bimetallic nanoparticles synthesized from ixora finlaysoniana extract. *Coatings*, 11(7), 1–12. <https://doi.org/10.3390/coatings11070813>