Evaluating the Potential of Green Synthesized Zinc Oxide Nanoparticles from the Fruit Extracts of *Balanites Aegyptiaca* as an Antimicrobial and Larvicidal Agent

Baba Mushemi Lawan*[1], Wilson Lamayi Danbature[2] and Umar Tanko Mamza[3]

[1, 3]Department of Pure and Applied Chemistry, University of Maiduguri, Nigeria

[2]Department of Chemical Sciences, Gombe State University, Nigeria

***Correspondence Author**

DOI: https://doi.org/10.51584/IJRIAS.2025.100700061

Received: 13 June 2025; Accepted: 23 July 2025; Published: 08 August 2025

ABSTRACT

This study evaluates the potential of green-synthesized zinc oxide nanoparticles (ZnO-NPs) derived from the fruit extract of *Balanites aegyptiaca* as an antimicrobial and larvicidal agent. The synthesised nanoparticles were characterized using a UV-Visible spectrophotometer, FTIR, XRD and SEM analysis. The antimicrobial potentials of the ZnO-NPs were evaluated against two Gram-positive bacteria (*Staphylococcus aureus*, *Streptococcus pyogenes*), two Gram-negative bacteria (*Salmonella typhi*, *Klebsiella pneumoniae*), and two fungal species (*Candida albicans*, *Aspergillus niger*). The ZnO-NPs have demonstrated moderate activity across Gram-positive, Gram-negative and fungal strains at the highest concentration (30 µg/ml). The larvicidal efficacy of the synthesized ZnO-NPs was tested against *Anopheles* mosquito larvae at concentrations of 40, 50, and 60 mg/L. The ZnO-NPs caused 100% mortality in third and fourth instar larvae, with LC_{50} values ranging from 35.30 to 59.47 mg/L across instars. These findings underscore the potent larvicidal and antimicrobial properties of ZnO-NPs synthesized from the fruit extract of *Balanites aegyptiaca*, with dose-dependent effects and notable efficiency against disease vectors and pathogens. The study supports the development of eco-friendly nanobiopesticides and therapeutics from medicinal plants.

Keywords: Anopheles Larvae, Antimicrobial, *Balanites aegyptiaca* (Fruit), Green Synthesis, Larvicidal, Mortality.

INTRODUCTION

Nanoparticles are defined as particles with at least one dimension measuring less than 100 nanometers, exhibiting various unique properties such as a high surface area-to-volume ratio, specific crystal structures, tunable pore sizes, and the ability to influence cellular and molecular activities in living organisms [1]. Nanoparticles (NPs) are particles engineered or manipulated at the atomic scale, typically ranging from 1 to 100 nanometers. Due to their nanoscale dimensions, they exhibit unique properties that differ significantly from those of bulk materials. Their small size also results in a relatively larger surface area compared to their bulk counterparts [2]. Nanoparticles (NPs) involve the characterization, design, and engineering of both biological and non-biological structures smaller than 100 nanometers, which exhibit unique and novel functional properties [3]. Research on nanoparticles (NPs) has gained significant attention due to their enhanced electrochemical reactivity, thermal conductivity, and nonlinear optical properties, which enable a wide range of unique applications [4]. Metal nanoparticles have recently garnered considerable interest due to their remarkable properties, including a large surface area, high stability, ease of chemical modification, effectiveness as fillers for enhanced permeability, and versatility in synthesis. These nanoparticles can be produced in sizes ranging from the micrometric to the nanometric scale using either top-down (destructive) or bottom-up (constructive) approaches. Zinc oxide (ZnO) is considered a biologically safe material that exhibits photo-oxidizing and photocatalytic effects on both chemical and biological entities [2]. Nano-sized zinc oxide (ZnO) exhibits various morphologies and has demonstrated significant antibacterial activity against a wide range of bacterial species, as reported by numerous

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

researchers [5]. Zinc oxide (ZnO) is currently being studied as an antibacterial agent in both microscale and nanoscale forms. When reduced to the nanometer scale, ZnO exhibits enhanced antimicrobial properties, enabling nano-sized particles to interact more effectively with bacterial surfaces and potentially penetrate the bacterial cell. These interactions result in unique bactericidal mechanisms. The primary mode of action is toxic interaction with bacterial cells, making nano-sized ZnO particularly valuable for antimicrobial applications, especially in the food industry [6]. Zinc oxide nanoparticles (ZnO-NPs) exhibit notable antibacterial properties, primarily due to their increased specific surface area resulting from reduced particle size, which enhances their surface reactivity [2]. Zinc oxide nanoparticles (ZnO-NPs) have attracted significant global research interest due to their broad biological activity. They are relatively non-toxic to human cells, biodegradable, and have the potential to significantly enhance the bioactivity of pharmacophores. Compared to their bulk counterparts, ZnO-NPs demonstrate superior antibacterial performance, attributed to quantum confinement and size-dependent effects. Their ability to inhibit bacterial growth through multiple mechanisms makes them highly effective in combating bacterial contamination-related diseases, particularly as conventional antibiotics face increasing challenges due to rising bacterial resistance [7]. The biosynthesis of zinc oxide nanoparticles (ZnO-NPs) using extracts from therapeutic plants, fungi, bacteria, and algae enhances their stability and biocompatibility across various biological contexts. This bio-fabrication approach also alters their physicochemical properties, contributing to their enhanced biological efficacy. Furthermore, ZnO-NPs function as effective nanocarriers for conventional drugs, owing to their cost-effectiveness, biodegradability, and biocompatibility [8]. Zinc oxide nanoparticles (ZnO-NPs) have been explored for a wide range of applications, including drug delivery systems, biosensing, gene delivery, nanomedicine, biological imaging, coatings for medical implants, electronic sensing devices, wastewater treatment, and communication technologies (9).

Balanites aegyptiaca (L.) Del., commonly known as the 'desert date,' is an evergreen, woody, and spiny flowering tree that can grow up to 10 meters tall. A member of the Balanitaceae family, it is widely distributed across arid regions of Africa and Southern Asia. This plant is a rich source of therapeutic compounds, including saponins, flavonoids, alkaloids, lipids, proteins, carbohydrates, and organic acids. Various parts of the tree have been traditionally used in medicine to treat a wide range of ailments [10]**.** It is well noted for its various medicinal properties, including antidiabetic, anthelmintic, antibacterial, and antiviral activities. Different parts of the plant, such as the bark, unripe fruits, and leaves, have been reported to exhibit anthelmintic, antifertility, purgative, and antidysentery properties [11].

Balanites aegyptiaca is a widely cultivated desert plant known for its versatile applications. It primarily thrives in arid and semi-arid regions across Africa, the Middle East, and South Asia. [12]. Traditionally, various parts of *Balanites aegyptiaca* have been valued for their medicinal applications in the treatment of conditions such as skin boils, leukoderma, malaria, wounds, colds, syphilis, and liver and spleen disorders. The fruit, commonly known as the desert date, is the most notable part of the tree. This drupe is pubescent when unripe and becomes yellowish and smooth upon ripening. It comprises four distinct layers: the outer skin (epicarp), the fleshy pulp (mesocarp), the woody shell (endocarp), and the inner seed (kernel). All four layers have potential uses in both industrial and pharmaceutical contexts. The edible portions—particularly the pulp and kernel—are known to yield oil. Nutritionally, the pulp is especially rich in carbohydrates (62.63%) and protein (9.19%), with lower contents of fat (2.58%) and dietary fibre (2.93%) [13]. Local inhabitants utilise the fruits of *Balanites aegyptiaca* for the treatment of various ailments. [14]. The fruit is also used in the treatment of jaundice, while the oil extracted from the seeds serves as a laxative and is traditionally employed to treat a variety of ailments, including hemorrhoids, stomach aches, jaundice, yellow fever, syphilis, and epilepsy [11].

MATERIALS AND METHODS

Collection of Plant Materials

Fruits of *Balanites aegyptiaca* were collected from the field within the premises of the University of Maiduguri, Borno State, Nigeria, and taken to the Department of Plant Science for identification and authentication. The samples were gathered during the dry season, then sorted and stored in clean polythene bags for further analysis.

Anopheles mosquito larvae were collected from various identified breeding sites within Gombe metropolis, including sewage and sullage water bodies such as cesspools, cesspits, drains, and septic tanks. A ladle and a

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

collection bottle were used for the sampling. The ladle was positioned at approximately a 45-degree angle and gently lowered into the water until one side was just beneath the surface, ensuring minimal disturbance to prevent the larvae from diving. The collected larvae were subsequently maintained and reared in the laboratory for larvicidal bioassay experiments. The collection was done based on Abba *et al.* [9].

Sample Preparation

Fruits of *Balanites aegyptiaca* were collected, thoroughly washed with distilled water, and air-dried in the shade to prevent phytochemical degradation. The mesocarp was then carefully separated from the shell

Preparation of *Balanites aegyptiaca* Fruit Extract

The aqueous extraction of *Balanites aegyptiaca* fruit was adapted from Al-Senani (2020) [15], with minor modifications. Ten grams (10 g) of the sample were dissolved in 200 mL of distilled water in a 250 mL conical flask. The mixture was heated at 60 °C for 3 hours in a water bath with constant stirring. After cooling to room temperature, the solution was filtered using Whatman No. 1 filter paper. The freshly prepared aqueous extract was then used for the synthesis of zinc oxide nanoparticles.

Synthesis of Zinc Oxide Nanoparticles.

Ten millilitres (10 mL) of *Balanites aegyptiaca* fruit extract were added to 50 mL of 0.1 M $ZnCl_2$ and 5 mL of 0.5 M NaOH. The mixture was stirred using a magnetic stirrer hot plate at 50 °C for 30 minutes, during which a noticeable colour change indicated the formation of zinc oxide nanoparticles. The nanoparticles were then separated by filtration, dried, and stored for later use [15].

Characterization of Zinc Oxide Nanoparticles and Fruit Extract

The optical properties of the synthesized zinc oxide nanoparticles and the fruit extract were analyzed using UV-Visible spectrophotometry within a wavelength range of 200–800 nm. Fourier-Transform Infrared Spectroscopy (FTIR) was employed to identify the functional groups present in the samples. X-ray Diffraction (XRD) was used to determine the crystal structure of the nanoparticles, while Scanning Electron Microscopy (SEM) was utilized to examine their morphology and particle size.

Antimicrobial Activity

The antimicrobial activity of the synthesized zinc oxide nanoparticles was evaluated against selected bacterial and fungal pathogens using the agar well diffusion method. This widely used laboratory technique assesses the ability of a substance to inhibit microbial growth, and is commonly applied in testing the antimicrobial efficacy of plant- and microbe-derived extracts. To conduct the assay, a bacterial suspension was evenly spread onto the surface of an agar plate. Wells were then created in the agar using a sterile borer, and the nanoparticle solution was introduced into each well. The plates were incubated, and subsequently observed for clear zones of inhibition surrounding the wells. The diameters of these zones were measured to quantify antimicrobial activity. An increase in the size of the inhibition zone with rising nanoparticle concentration indicated enhanced antimicrobial effectiveness.

Larvicidal Activity

The larvicidal activity was assessed following the method described by Abba et al. [9], with slight modifications. A 0.1 g sample of zinc oxide nanoparticles was dissolved in distilled water using a 1000 mL volumetric flask to prepare a stock solution with a concentration of 100 mg/L. The bioassay was conducted by introducing different larval instars (1st to 4th) into 200 mL plastic cups, with four replicates and a control group for each instar, each containing twenty-five larvae. To each replicate, 100 mL of dechlorinated water was added. Zinc oxide nanoparticles were then introduced at concentrations of 40 mg/L, 50 mg/L, and 60 mg/L. Larval mortality was recorded, and the percentage mortality was calculated using the following formula: $\text{Percentage Mortality} = \frac{\text{Number of Dead Larvae}}{\text{Number of Introduced Larvae}} \text{ X } 100$

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

RESULTS AND DISCUSSIONS

Electronic Spectra Results of Zinc Oxide Nanoparticles and Fruit Extract

The UV–Visible spectra for fruit extract and ZnO nanoparticles are presented in Figures 1A and 1B. ZnO nanoparticle displayed an absorbance band at 348 nm, and the fruit extract shows an absorbance band at 308 nm. The movement of the absorbance band to a higher wavelength suggests a reduction in size from bulk molecules to the nanoscale. This is due to the surface Plasmon vibration and excitation of bio-reduction and capping or stabilising agents present in the fruit extract [16]. This also corresponds to the work done by Naranjan *et al*. [17] and Preeti [18], which suggested the possibility of finding the Plasmon band of zinc oxide nanoparticles in the range of 300-400nm.

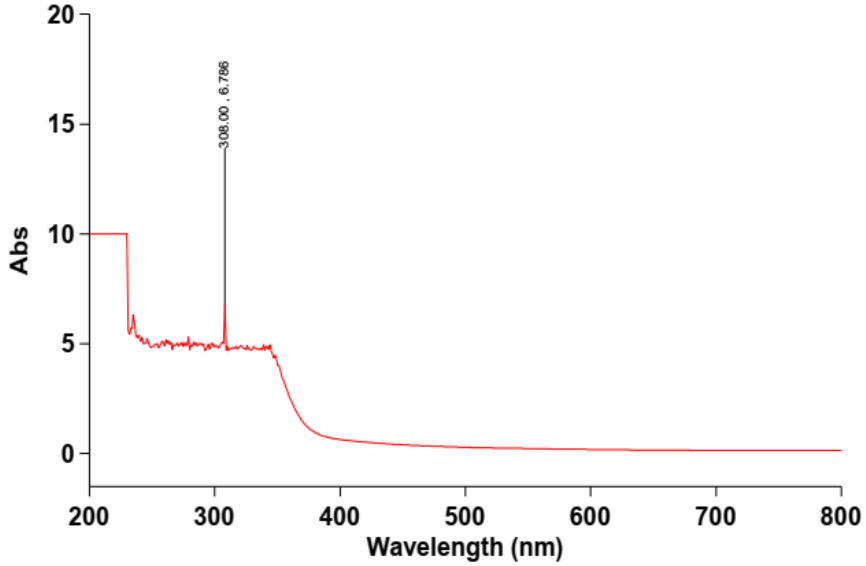

Figure 1A: Electronic Spectrum of *Balanites aegyptiaca* Fruit Extract

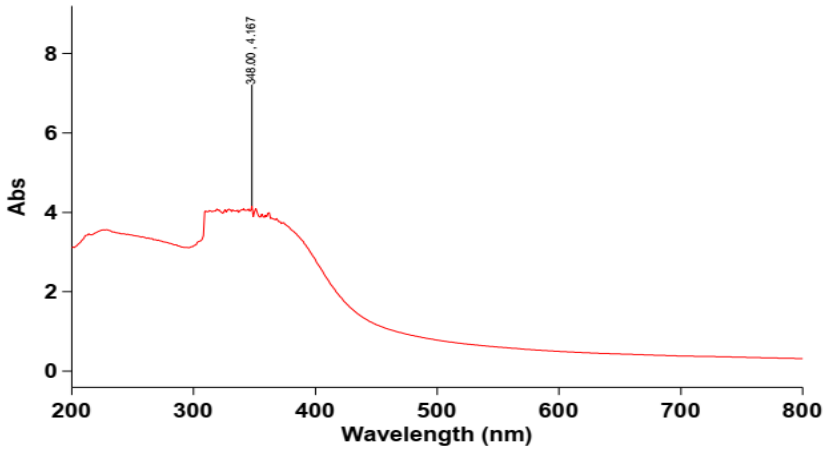

Figure 1B: Electronic Spectrum of ZnO Nanoparticles Synthesized Using Fruit Extract

Fourier Transform Infrared (FTIR) Results of Fruit Extract and Zinc Oxide Nanoparticles

The FTIR spectrum of *Balanites aegyptiaca* fruit extract and ZnO nanoparticles are presented in Figures 2A and 2B. The absorption bands observed for fruit extract were 3268 cm^{-1}, 2120 cm^{-1} and 1638 cm^{-1} indicating OH stretching, C=C stretching and C=O stretching respectively. While for the ZnO nanoparticles synthesized from the fruit extract, the following bands were observed at 3563 cm^{-1}, 3436 cm^{-1}, 2922 cm^{-1}, 2108 cm^{-1}, 1606 cm^{-1}, 1423 cm^{-1}, 1263 cm^{-1}, 1028 cm^{-1}, 818 cm^{-1} and 701 cm^{-1}. These bands are absent in the spectra of the extract, signifying the formation of nanoparticles (19). The band at 3563 cm^{-1}, 3436 cm^{-1} are due to OH alcohol/ phenols,

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

2922 cm^{-1} is for C=C stretching for alkenes, 2108 cm^{-1} is for C-O alcohol, 1606 cm^{-1} for C=C alkenes, 1423 cm^{-1} for CH_3 bending and C-C is for ring aromatic, 1263 cm^{-1} is for C-N aromatic amines, 1028 cm^{-1} is for C-O stretching due to alcohol, and 818 cm^{-1} and 701 cm^{-1} are due to C-Br alkyl halides.

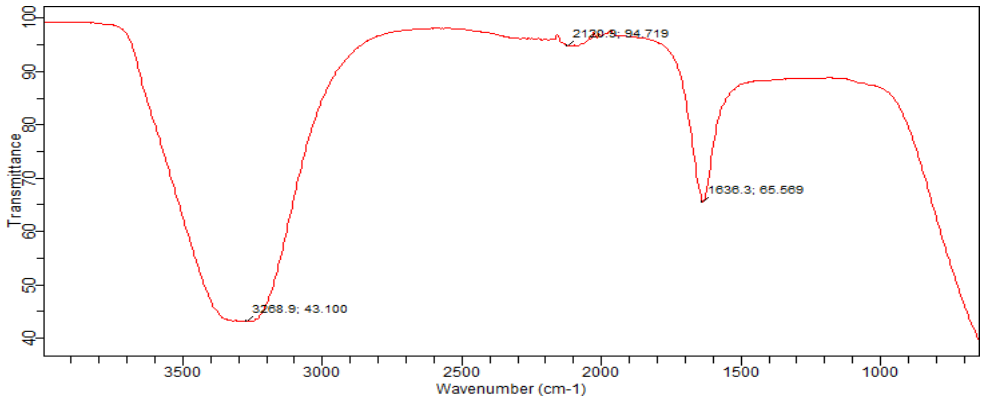

Figure 2A: FTIR Spectrum of Balanites aegyptiaca Fruit Extract

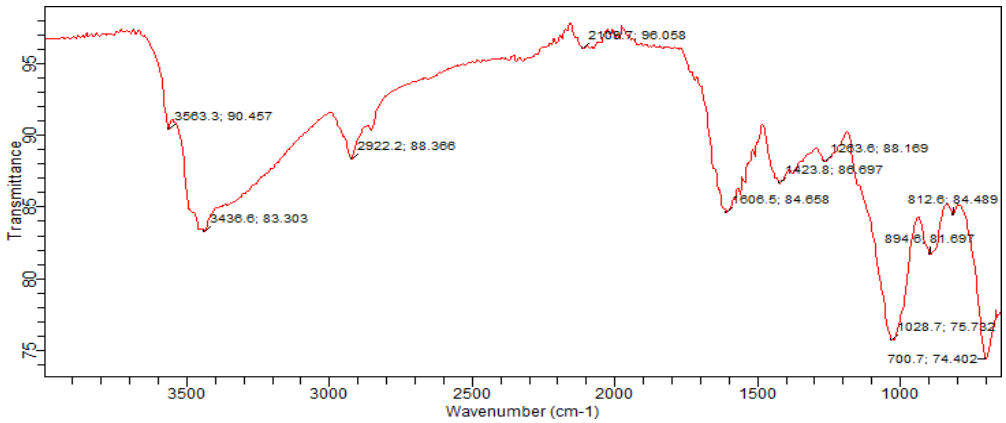

Figure 2B: FTIR Spectrum of ZnO Nanoparticles Synthesized Using Fruit Extract

XRD Results of ZnO Nanoparticle Synthesized from The Fruit

The XRD result for the ZnO nanoparticle synthesized from the fruit is presented in Figure 3. It was observed that five prominent peaks were observed at 2θ=12.89º, 21.67º,33.46 º, 43.47 º and 52.51 º with respect to the plane of (111), (201), (211), (221) and (311) respectively. It shows Face Centered Cubic (FCC) structure and the average crystalline size of 46.77 nm and it corresponds to the literature reported by Yangma and Jinhou (2020) [20].

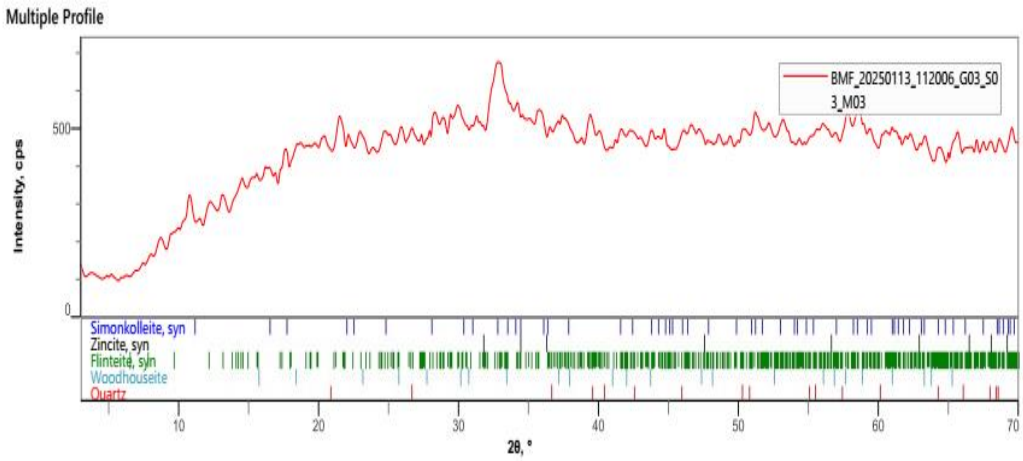

Figure 3: XRD Result of ZnO Nanoparticle Synthesized Using Fruit Extract

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

SEM Analysis of Zinc Oxide Nanoparticle Synthesized from The Fruit

The SEM result for the ZnO nanoparticles synthesized from the fruits are presented in Figure 4. The morphology of the green synthesized ZnO nanoparticles shows that the particles have monodispersed granular and partially agglomerated morphology. The result obtained is in agreement with the previous works done by Dominic *et al*. (2020) [21] and Hassan *et al.* (2019) [22].

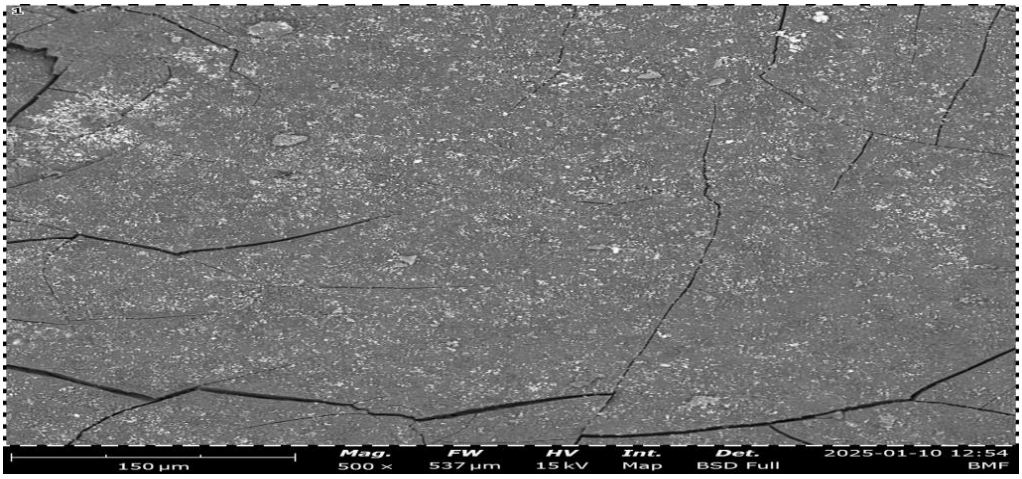

Figure 4: SEM Result of ZnO Nanoparticle Synthesized Using Fruit Extract

Antimicrobial Activity Results

The antimicrobial activity test result for zinc oxide nanoparticle synthesized from the fruit of *Balanites aegyptiaca* are presented in Table 1. The results have shown dose dependent effect across the micro-organisms studied. From the results, the Gram-positive bacteria (*Streptococcus pyogene* and *Staphylococcus aureus*) have showed highest sensitivity with 18.00±0.00 mm and 17.00±0.00 mm zone of inhibition respectively as compared to standard drug Augmentin (23.00±0.00 mm and 24.00±0.00 mm) at the highest concentration of (30 µg/ml). The Gram – negative bacteria (*Salmonella typhi*) has shown moderate sensitivity with 15.00±0.00 mm zone of inhibition as compared to standard drug Augmentin (22.00±0.00) at the highest concentration of (30 µg/ml). The fungal strain (*Candida albicans*) has showed a remarkable susceptibility effect with (16.00±0.00 mm) zone of inhibition compared to the standard drug (fulcin) with 20.00±0.00 mm zone of inhibition. The fungal strain (*Aspergillus niger*) has shown resistance across the zinc oxide nanoparticle treated. This corresponds to that obtained by Zacchaeus *et al*. (2018) [23] which shows an activity of 29, 18 and 12 mm at concentration 100, 150 and 250 mg/L respectively.

Table 4.3: Antimicrobial Susceptibility Test of ZnO-NP of *Balanites aegyptiaca* Fruit

	Concentration (mg/ml)/ Mean Zone of Inhibition in diameter (mm)					
S/N	**Organism**	**30**	**20**	**10**	**Aug. (30µg/ml)**	**Ful. (50µg/ml)**
1	Staphylococcus aureus	17.00 ± 0.00^{a}	12.00 ± 0.00^{b}	8.00 ± 0.00^{c}	24.00 ± 0.00^{d}	-
2	Streptococcus pyogenes	18.00 ± 0.00^{a}	12.33 ± 0.33^{b}	8.00 ± 0.00^{c}	23.00 ± 0.00^{d}	-
5	Klebsiella pneumonia	11.00 ± 0.00^{a}	7.00 ± 0.00^{b}	0.00 ± 0.00^{c}	20.00 ± 0.00^{d}	-
6	Salmonella typhi	15.00 ± 0.00^{a}	10.00 ± 0.00^{b}	00.00 ± 0.00^{c}	22.00 ± 0.00^{d}	-
7	Aspergillus niger	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}	-	21.00 ± 0.00^{b}
8	Candida albicans	16.00 ± 0.00^{a}	10.00 ± 0.000^{b}	0.00 ± 0.00^{c}	-	20.00 ± 0.00^{d}

Key: Aug = Augmentin, Ful = Fulcin

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

Larvicidal Test Activity of ZnO Nanoparticle Synthesized from The Fruit

Table 2 shows the larvicidal activity of ZnO nanoparticle synthesized from the fruit of *Balanites aegyptiaca* on Anopheles' larvae. The results shows that the percentage mortality of the first instar larvae at 40, 50 and 60 mg/L concentrations of ZnO nanoparticle are 100, 100 and 100% respectively. The second instar showed 92, 100 and 100% mortality when tested with 40, 50 and 60 mg/L concentrations of the nanoparticle respectively. For the third instar larvae, the percentage mortality for the 40, 50 and 60 mg/L concentrations were 74, 100 and 100% respectively. While for the fourth instar, the mortality at 40, 50 and 60 mg/L concentrations were 64, 84 and 100% respectively. This agrees with the findings of Bello *et al*. [24] and Shehu *et al.* [25], where they reported a high toxicity of Cu Nanoparticles and ZnO – CuO nanoporous composite against the larvae of anopheles and malaria vector after exposure for 24 hours. Overall, the highest mortality was observed in the first, instar (100%) at the concentration of 40, 50 and 60 mg/L, second instar (100%) at concentrations 50 and 60 mg/L, third instar (100%) at concentrations 50 and 60 mg/L, fourth instar (100%) at concentration of 60 mg/L, while the lowest was found in the fourth instar (64%) at 40 mg/L concentration. Wilson *et al.* [26] and Danbature *et al* [27] reported that the first instar larvae are more susceptible to nanoparticles and the susceptibility decreases with the growing larval instars subjected to the same concentration of nanoparticles. In a similar work reported by Sharon *et al*. [28], the first instar larva of *Aedes aegypti* showed high susceptible to copper nanoparticles than the 2^{nd}, 3^{rd} and 4^{th} larval instars. This revealed that the more matured the larva, the less susceptible they are to nanoparticles. This is due to the fact that most juvenile larvae are more delicate and therefore easily intoxicated by nanoparticles [9]. The calculated LC_{50} values were 59.47, 52.74, 37.15 and 35.30 mg/L for the first to fourth instar larvae respectively. The findings of Bello *et al*. (2015) [24] revealed that the larvicidal activity of bio – synthesized Copper nanoparticles of African spinach on Anopheles' larvae (LC_{50} = 47.20 mg/L), a lower LC_{50} compared to the findings of the present work. On the other hand, Rawani *et al.* [29] reported the larvicidal activity of silver Nanoparticles which showed LC_{50} value of 1.59 ppm for berries dry leaves and fresh leaves against the larvae of *Anopheles stephensi*. These variations may be attributed to several factors such as the reducing agent (species of plant or parts) used in the synthesis, the type of metal and the mode of action [9]. The mortality rate recorded in this work showed that the activity of the ZnO nanoparticle synthesized from the fruit of *Balanites aegyptiaca* on the Anopheles Mosquito larvae is dose-dependent as reported by other works [9], [25], [26], [27], [30], [31], and [32].

Table 2: Larvicidal Activity of ZnO Nanoparticle Synthesized from The Fruit Against first to fourth Instars Larvae of Anopheles Mosquito

Anopheles	**S/N**	**Conc. (mg/L)**	**% Mortality At 48 Hours**	**LC_{50} (mg/L)**	**R^2**
First	1	40	100		
Instar	2	50	100	59.47	0.970
	3	60	100		
Second	1	40	92		
Instar	2	50	100	52.74	0.981
	3	60	100		
Third	1	40	74		
Instar	2	50	100	37.15	0.960
	3	60	100		
Fourth	1	40	64		

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue VII July 2025

Instar	2	50	84	35.30	0.943
	3	60	100		

REFERENCES

1. Alsamadany, H., and El-zohri, M. (2024). Bioscience Research Green Synthesis of Phytogenic Nanoparticles Using Plant Extracts and their Promising Roles in Sustainable Agriculture : Innovative Scientific Information & Science Network, **21**(4), 738–749.
2. Sirelkhatim, A., Mahmud, S., and Seeni, A. (2015). Review on Zinc Oxide Nanoparticles : Antibacterial Activity and Toxicity Mechanism. Nano-Micro Letters, **7**, 219–242. https://doi.org/10.1007/s40820-015-0040-x
3. Khan, I., Saeed, K., and Khan, I. (2017). Nanoparticles : Properties, Applications and Toxicities. Arabian Journal of Chemistry. https://doi.org/10.1016/j.arabjc.2017.05.011
4. Agarwal, H., Kumar, S. V., and Rajeshkumar, S. Resource-Efficient Technologies Review Article. A Review on Green Synthesis of Zinc Oxide Nanoparticles – An Eco-Friendly Approach. Resource-Efficient Technologies, **3**(4), 406–413. https://doi.org/10.1016/j.reffit.2017.03.002
5. Raghupathi, K. R., Koodali, R. T., and Manna, A. C. (2011). Size-Dependent Bacterial Growth Inhibition and Mechanism of Antibacterial Activity of Zinc Oxide Nanoparticles. American Chemical Society Publications, **27**, 4020–4028.
6. Webster, T. J. (2012). Antimicrobial applications of Nanotechnology : Methods and Literature. International Journal of Nanomedicine, **7**, 2767–2781.
7. Huq, A., Apu, A. I., and Rahman, M. (2023). Bioactive ZnO Nanoparticles : Biosynthesis, Characterization and Potential Antimicrobial Applications. Pharmaceutics, **15**(2634), 1–22.
8. Mandal, A. K., Katuwal, S., Tettey, F., Gupta, A., Bhattarai, S., Jaisi, S., Bhandari, D. P., Shah, A. K., Bhattarai, N., and Parajuli, N. (2022). Current Research on Zinc Oxide Nanoparticles : Synthesis, Characterization, and Biomedical Applications. MDPI (Nanomaterials), **12**(3066), 1–31.
9. Abba, E., Shehu, Z., Wilson, D., and Poloma, K. (2021). Novel Developments of ZnO / SiO2 Nanocomposite : A Nanotechnological Approach Towards Insect Vector Control. Journal of the Nigerian Society of Physical Sciences, 3, 262–266. https://doi.org/10.46481/jnsps.2021.198
10. Al Thobati, S., and Zeid, I. A. (2018). Medicinal Properties of Desert Date Plants (Balanites aegyptiaca) -An Overview. Global Journal of Pharmacology, **12**(1), 1–12. https://doi.org/10.5829/idosi.gjp.2018.01.12
11. Kabbashi, A. S. (2015). Activity, Cytoxicity and Phytochemicals of Ethanolic Fruit Extract of Balanites aegyptiaca (L .). World Journal of Pharmaceutical Research, **4**(3), 1–21.
12. Teklu, B., Kumari, S., and Vidavalur, S. (2023). Green Synthesis of Copper Oxide Nanoparticles Using Balanites aegyptiaca Stem Bark Extract and Investigation of Antibacterial Activity. Results in Chemistry, 6(September), 101152. https://doi.org/10.1016/j.rechem.2023.101152
13. Achaglinkame, M. A., Aderibigbe, R. O., Hensel, O., Sturm, B., and Korese, J. K. (2019). Nutritional Characteristics of Four Underutilized Edible Wild Fruits of Dietary Interest in Ghana. Foods, **8**(104), 1–12. https://doi.org/10.3390/foods8030104
14. Murthy, H. N., Yadav, G. G., Dewir, Y. H., & Ibrahim, A. (2021). Phytochemicals and Biological Activity of Desert Date (Balanites aegyptiaca (L.) Delile). MDPI (Plants), **10**(32), 1–22.
15. Al-senani, G. M. (2020). Synthesis of ZnO-NPs Using a Convolvulus arvensis Leaf Extract and Proving Its Efficiency as an Inhibitor of Carbon Steel Corrosion. MDPI (Materials), **13**(890), 1–16.
16. Neamah, S. A., Albukhaty, S., Falih, I. Q., Dewir, Y. H., and Mahood, H. B. (2023). Biosynthesis of Zinc Oxide Nanoparticles Using Capparis Spinosa L . Fruit Extract : Characterization , Biocompatibility, and Antioxidant Activity. MDPI (Apploied Sciences), **13**(6604), 1–14.
17. Naranjan, B, Saha, S, Chaaraborty, M, Maiti, M, Das, S, Basu, S and Nandy, P. (2015) Green Synthesis of Zinc Oxides Nanoparticles Using Hibiscus Subdariffa Leaf Extract, Effect of Tempreture on Synthesis, Antibacterial Activity and Antidiabetic Activity. Royalsociety of chemistry. **3**(8),1-9
18. Preeti, R. (2017). Green-Synthesis of Silver Nanoparticles, Their Characterization and Microbial Potential" PhD. Thesis (published) Submitted to the Department of Molecular and Cellular Engineering.

Jacob Institute of Biotechnology and Bioengineering Samhiggin Bottom University of Agriculture, Technology and Science, Allahabad India

19. Perumal, P., Sathakkathulla, N. A., Kumaran, K., Ravikumar, R., Selvaraj, J. J., Nagendran, V., Gurusamy, M., Shaik, N., Prabhakaran, S. G., Palanichamy, V. S., Ganesan, V., Thiraviam, P. P., Gunalan, S., & Rathinasamy, S. (2024). Green Synthesis of Zinc Oxide Nanoparticles Using Aqueous Extract of Shilajit and their Anticancer Activity against HeLa Cells. Scientific Reports, **14**(2204), 1–11. https://doi.org/10.1038/s41598-024-52217-x
20. Yangma, Y. and Jinhou, J. (2020). Preparation and Antibacterial Activity of Nano Copper Oxides Loaded Zeolite 10X" International Journal of Molecular Science**, 23**(8421):1-10.
21. Dominic, G. N., Basson, K. A, Shandu, S. E., Jabulani, M. S. S. and Rajasekhar, V.S. P. (2020) Biosynthesis, Characterization, and Application of Iron Nanoparticles: In Dye Removal and as Antimicrobial Agent Water Air Soil Pollut **2**:231:130
22. Hassan, K., Muhammmad, H. B. M and Abbas, P. (2019) Investigating Photocatalytic Performance of Natural Zeolite-TiO_2 Composites" Micro and Nano letters **14**(6):669-672.
23. Zacchaeus S., Danbature W.L, Maisanda A, Sabo and Musa M. S. (2018) "Synthesis, Characterization and Antibacterial Activity of Kaolin Gum Arabic Nanocomposite on Escherichia-coli and pseudomonas aureginosa. Research Journal of Nanoscieence and Engineering; **2** (2), 23-29.
24. A. M. Bello, E. Karu, S. Abubakar and R. Atiko (2025). "Larvicidal Activity of Amaranthus Hybridus Extract and Bio-synthesized Copper Nanoparticles against Mosquito Vectors". Journal of Science and Technology. **30**(5), 91 – 100. https://doi.org/10.20428/jst.v30i5.2829
25. Shehu Z., Abba E., Wilson D. L., Poloma K. Y., Adamu Z. A. and Namau Z. K., (2020). "Bio-fabrication of ZnO-CuO Nanoporous Composite and its Application as Nanolarvicidal Agent for Malaria Vectors". Journal of Pharmaceutical Research International. **32**(34), 31–39. doi:10.9734/JPRI/2020/v32i3430962.
26. Wilson L D, Zaccheus S, Abigail JM, Buhari M, Muhammad MA and Musa AB (2020). "Green Synthesis, Characterization and Larvicidal Activity of Cu/Ni Bimetallic Nanoparticles Using Fruit Extract of Palmyra palm". International Journal of Chemistry and Material Research. **8**(1):20-25.
27. Danbature, W. L., Yoro, M., Nasiru, Y. P. and Zaccheus, S. (2022). Synthesis, Characterization and Catalytic Application of Magnetic Iron Nanoparticles (Fe3O4) in Biodiesel Production from Mahogany Khaya Senegalensis Seed Oil" Online Journal of Chemistry, **1**:85-9
28. Sharon EA, Velayutham K, and Ramanibai R. (2018). "Biosynthesis of Copper Nanoparticles using Artocarpus Heterophyllus against Dengue Vector Aedes aegypti". International Journal of Life-Sciences Scientific Reserch. **4**(4):1872- 1879
29. Rawani, A., Ghosh, A. and Chandra, G. (2013)." Mosquito Larvicidal and Antimicrobial Activity of Synthesized Nano-Crystalline Silver Particles Using Leaves and Green Berry Extract of Solanum nigrum L. (Solanaceae: Solanales)". Acta Tropica.**128**(3):613 622.
30. Shanmugasundaram T. and Balagurunathan R. (2015). "Mosquito Larvicidal Activity of Silver Nanoparticles Synthesized Using Actinobacterium, Streptomyces sp. M25 against Anopheles Subpictus, Culex quinquefasciatus and Aedes aegypti". Journal of Parasitic Diseases. **39**(4): 677–684.
31. Murugan K, Benelli G, Ayyappan S, Dinesh D, Panneerselvam C, Nicoletti M, Hwang JS, Mahesh KP, Subramaniam J, and Suresh U. (2015). "Toxicity of Seaweed-Synthesised Silver Nanoparticles Against the Filariasis Vector Culex Quinquefasciatus and its Impact on Predation Efficiency of the Cyclopoid Crustacean Mesocyclops Longisetus". Parasitology Research. **114**:2243 2253.
32. Raman, N, Sudharsan, S, Veerakumar, V, Pravin, N., and Vithiya, K. (2012). "Pithecellobium dulce mediated extra-cellular green synthesis of larvicidal silver nanoparticles". Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. **96**:1031 1037.