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# Enhanced antioxidant, antimicrobial, and larvicidal efficacy of biogenic zinc nanoparticles synthesized from *Solanum torvum* leaf extract

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**Abstract**
The present study focuses on the biogenic synthesis of Zinc Nanoparticles (Zn NPs) using an aqueous extract of *Solanum torvum* leaves and evaluates their antioxidant, antimicrobial, and anti-larvicidal activities. Zinc nanoparticles synthesized via the green aqueous extract of *Solanum torvum* leaves exhibited notable antioxidant, antimicrobial, and larvicidal activities. Antioxidant potential was evaluated through multiple assays, demonstrating a remarkable increase in DPPH radical scavenging, with efficiency rising from 20% at 100 µg/mL to 80% at 500 µg/mL, alongside a significant elevation in FRAP values from 150 µmol Zn (II)/g extract to 750 µmol Zn (II)/g extract. The antimicrobial efficacy of the nanoparticles was evident, showing strong inhibitory effects against both Bacteria and Fungi. Furthermore, the synthesized nanoparticles displayed a concentration-dependent larvicidal activity against *Culex quinquefasciatus*, achieving 100% mortality at 100 ppm after 72 hours. These promising results highlight the potential of *Solanum torvum*-derived zinc nanoparticles for diverse applications in environmental management and biomedical fields.

**Keywords:** *Solanum torvum*, Zinc nanoparticles, larvicidal activity, DPPH assay, FRAP assay, ABTS assay, superoxide scavenging, nitric oxide scavenging, *Culex quinquefasciatus*, antimicrobial activity

## Introduction

Nanotechnology has emerged as a transformative field, offering innovative solutions across various domains, including environmental and biomedical sciences. Among the diverse nanomaterials, zinc nanoparticles (Zn NPs) have garnered significant attention due to their multifunctional properties, particularly as antioxidants, antimicrobials, and insecticides. The synthesis of nanoparticles using green methods, such as plant extracts, has become a sustainable and eco-friendly alternative to conventional chemical synthesis.

Zinc nanoparticles (Zn NPs) have garnered significant research attention on account of their remarkable properties and various applications in medicine, environmental science, and agriculture. The antibacterial, antifungal, and anticancer activities of Zn NPs also show potential for ecological remediation and as plant growth enhancers in agriculture. Unique physicochemical properties like high surface area and biocompatibility make it suitable for a wide range of applications across these fields (Busi *et al*., 2020) [8]. Green synthesis of Zn NPs using plant aqueous extracts provides an environment-friendly alternative to conventional chemical methods which often involve toxic reagents and complex procedures (Singh *et al*., 2018) [39].

*Solanum torvum*, widely known for its medicinal and bioactive properties, has been explored as a natural reducing and stabilizing agent in green nanoparticle synthesis. The bioactive compounds in its aqueous leaf extract facilitate the formation of Zn NPs while endowing them with enhanced biological activities. Recent research highlights the potential of *Solanum torvum*-mediated Zn NPs in combating oxidative stress, microbial infections, and vector-borne diseases, addressing pressing environmental and health challenges. *Solanum torvum* a medicinal plant with well-documented antimicrobial and antioxidant properties has been utilized in the eco-friendly production of Zn NPs. The various bioactive compounds in *Solanum torvum* act as reducing and stabilizing agents to assist a sustainable synthesis process for Zn NPs with significant biomedical applications (Kumar *et al*., 2019) [22].

Zn NPs are notably valued for their antioxidant properties essential for counteracting oxidative stress factors implicated in numerous chronic illnesses and the aging process. The antioxidant activity of Zn NPs is commonly assessed using assays such as DPPH (2,2-diphenyl-1-picrylhydrazyl) for free radical scavenging, FRAP (Ferric Reducing Antioxidant Power) and ABTS (2,2'-casino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) for radical cation decolorization. These techniques provide insights into the therapeutic potential of Zn NPs by measuring their effectiveness in neutralizing reactive species and reducing oxidative damage thereby highlighting their promise in health-related applications (Rajiv *et al*., 2017) [35].

Zn NPs are widely recognized for their antioxidant and robust antimicrobial properties effectively targeting various pathogens as well as fungi and bacteria. The antimicrobial activity of Zn NPs is largely attributed to mechanisms such as disrupting microbial cell membranes interfering with vital enzyme functions and inducing oxidative stress within microbial cells. These characteristics make Zn NPs particularly useful in wound healing, infection control, and food preservation where maintaining microbial safety is crucial (Ghaffari-Moghaddam *et al*., 2022) [10].

Zn NPs have shown notable anti-larvicidal properties making them valuable for controlling vector-borne diseases. Studies have reported the effectiveness of Zn NPs in targeting mosquito larvae including species like *Culex quinquefasciatus* underscoring their potential role in integrated pest management. By effectively acting on mosquito larvae Zn NPs offer an eco-friendly approach to reducing mosquito populations and subsequently lowering the transmission of mosquito-borne diseases (Mishra *et al*., 2021) [28].

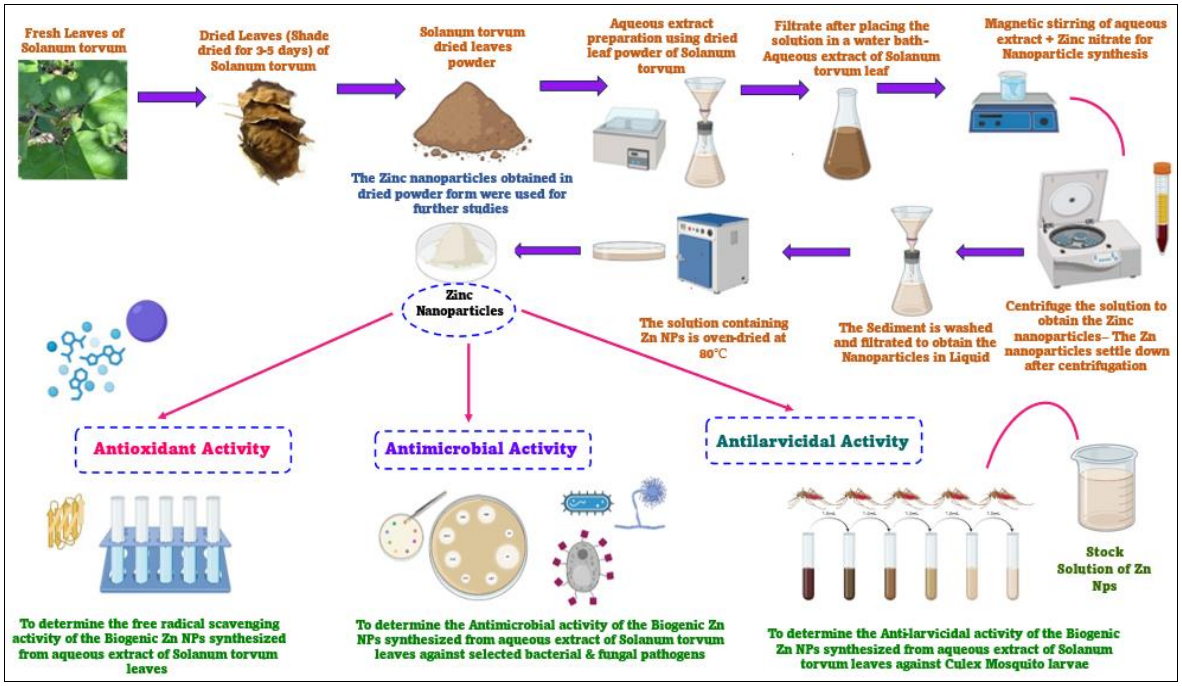


**Fig 1:** Synthesis and Application of Biogenic Zinc Nanoparticles from *Solanum torvum* Leaves for Antioxidant, Antimicrobial, and Antilarvicidal Activities

This study investigates the antioxidant, antibacterial, and larvicidal properties of Zn NPs synthesized from *Solanum torvum* leaf extract. The antioxidant capacity was assessed through DPPH and FRAP assays, revealing remarkable free radical scavenging efficiency. The antimicrobial activity was demonstrated against pathogenic bacteria like Escherichia coli and fungi such as Aspergillus niger. Furthermore, the larvicidal potential was evaluated against *Culex quinquefasciatus*, showcasing complete larval mortality at higher concentrations. These findings highlight the significant potential of *Solanum torvum*-derived Zn NPs in developing sustainable solutions for environmental and biomedical applications.

## Materials & Methods

### Collection & preparation of aqueous extract of *Solanum torvum* leaves extract

Fresh leaves of *Solanum torvum* were collected from campus, Thiruvalluvar University, Vellore, Tamil Nadu, India, and sun-dried for 20 days to ensure complete dehydration. Dried leaves were ground into a fine powder using a mortar pestle to maximize surface area for extraction. 50 g of leaf powder was mixed with 500 mL of double-distilled water and the mixture was heated, and agitated to extract bioactive compounds efficiently.

### Biogenic synthesis of Zinc nanoparticles using aqueous extract of *Solanum torvum* leaves extract

1 mM zinc acetate was dissolved in 50 mL of distilled water and magnetically agitated at room temperature (27 °C) for 3 hours. Subsequently, 25 mL of *Solanum torvum* leaf aqueous extract was added to the solution. After 10 minutes, NaOH was added drop by drop, until the particles get separated. The mixture was then centrifuged at 3000 rpm for 20 minutes, yielding a clear supernatant at room temperature. Zinc oxide nanoparticles were dried in an oven at 100-120 °C for 6 hours and stored for further analysis.

### Antioxidant assay for Zn NPs synthesis from aqueous extract of *Solanum torvum* leaf

#### 1. DPPH Free Radical Scavenging Activity

The following procedures are used to evaluate Zn nanoparticles (Zn NPs) at different concentrations in methanol to assess their DPPH scavenging activity. Combine 1 mL of each Zn NP concentration with 1 mL of DPPH solution. Give the mixture 30 minutes to incubate in a dark place. To find the antioxidant activity, use a spectrophotometer to measure the solution's absorbance at 517 nm. The percentage of DPPH radical scavenging activity was calculated using the given formula:

$$\text{DPPH Scavenging Activity (\%)} = A0 - As / A0 \times 100$$

Whereas, A0 is the absorbance of the control and As is the absorbance of the sample (Kumar & Karthikeyan, 2023; Ahmed *et al*., 2022) [18, 19, 20, 21, 23].

#### 2. Ferric reducing antioxidant power assay

The antioxidant capacity of a sample using FRAP assay was assessed based upon its ability to reduce Zinc ions (Zn^2+) to form a colored complex with TPTZ (2,4,6-tripyridyl-s-triazine) a method reflecting samples electron-donating potential. To prepare the FRAP reagent combine 20 mM $ZnCl_2$, 10 mM TPTZ dissolved in 40 mM HCl & 300 mM acetate buffer (pH 3.6) in a 10:1:1 ratio as described in recent studies exploring metal-based antioxidant assays (Bhardwaj *et al*., 2022) [6]. Zn NPs are diluted with distilled water before analysis. For measurement mix 100 µL of sample with 900 µL of FRAP reagent and incubate the mixture for 30 min at 37°C. Absorbance is then recorded at 593 nm indicating antioxidant capacity by the intensity of the color change observed (Kumar & Verma, 2023) [18, 19, 20, 21, 23].

### 3. ABTS radical cation decolorization assay

ABTS assay is widely used to determine the antioxidant activity of compounds by assessing their ability to neutralize ABTS radical cation resulting in a decreased, absorbance (Akinmoladun *et al*., 2022; Othman *et al*., 2023) [3, 4, 30]. To prepare ABTS radical cation solution mixture of 7 mM ABTS & 2.45 mM potassium persulfate allow to react in dark for 12-16 hr until the radical is stable. For testing Zn NPs are diluted in distilled water and 10 µL of the sample is added to 1 mL of ABTS+ solution. Then absorbance is measured at 734 nm after 6 min reaction which provides a quantitative measure of the sample's antioxidant potential (Panza *et al*., 2022) [31].

**ABTS scavenging activity (%) = A0 −As / A0 ×100**

Where as A0 is the absorbance of the control and As is the absorbance of the sample.

### 4. Superoxide radical scavenging assay

This assay employed a xanthine-xanthine oxidase system to produce superoxide radicals which are used to assess an antioxidant superoxide scavenging capacity (Jiang *et al*., 2023) [14]. The reaction mixture prepared a phosphate buffer at pH 7.4 includes components such as 0.1 mM EDTA, 0.1 mM nitroblue tetrazolium (NBT) 0.1 mM xanthine and 0.1 units/mL xanthine oxidase. Zn NPs are diluted with the phosphate buffer before being added to the assay. To begin 1 mL of the reagent mixture containing NBT xanthine and buffer is mixed with 1 mL of the zinc nanoparticle solution. The reaction is initiated by adding 100 µL xanthine oxidase followed by incubation at room temperature for 30 min. Absorbance is then measured at 560 nm to determine the superoxide scavenging activity as per recent findings on antioxidant analysis in nanoparticle assays (Patel *et al*., 2023; Kumar & Singh, 2023) [18, 19, 20, 21, 23, 32]. Calculated superoxide scavenging activity using the formula:

**Superoxide scavenging activity (%) = A0 −As / A0 ×100**

Whereas, A0 is the absorbance of the control and As is the absorbance of the sample.

### 5. Nitric oxide scavenging assay

This assay evaluates the antioxidant potential of the sample by measuring, the capacity to scavenge nitric oxide radicals. Nitric oxide is generated from sodium nitroprusside and upon reaction with oxygen produces nitritee. It can be detected using the Griess reagent (Alvarez *et al*., 2023) [5]. To prepare for the assay 10 mM sodium nitroprusside solution is dissolved with phosphate buffer (pH 7.4). Griess reagent is created by mixing 1% sulfanilamide with 0.1% naphthyl ethylenediamine dihydrochloride in 2% phosphoric acid. For testing Zn NPs are diluted in the same phosphate buffer. The assay involves mixing 1 mL of Zn NPs solution with 1 mL of sodium nitroprusside solution incubating the mixture at room temperature for 150 min and then add 1 mL of Griess reagent. Finally, absorbance is measured at 546 nm to quantify nitric oxide scavenging activity indicating the antioxidant efficacy of the sample (Mendoza & Lee, 2023; Choi *et al*., 2023) [9, 24, 27].

Calculate Nitric oxide scavenging activity using the formula:

**Nitric oxide scavenging activity (%) = A0 −As / A0 ×100**

Where as, A0 is absorbance of the control and As is absorbance of the sample.

### 6. Hydroxyl radical scavenging assay

Hydroxyl radical scavenging activity quantifies how effectively antioxidants can inhibit the degradation of deoxyribose by hydroxyl radicals generated during a Fenton reaction. To prepare the assay solution mix 20 mM phosphate buffer (pH 7.4) 1 mM EDTA, 1 mM FeCl3, 10 mM H2O2, 2.8 mM deoxyribose, and 1 mM ascorbic acid. Before the assay dilute the Zn NPs in the phosphate buffer. After combining 0.1 mL of each reagent with 0.8 mL of Zn NPs solution incubate the mixture at 37°C for 1 hr. Then add 1 mL of each trichloroacetic acid (TCA) & thiobarbituric acid (TBA) to the reaction mixture. Boiled for 10 min allow to room temperature and finally measure absorbance at 532 nm to assess hydroxyl radical scavenging activity (Zhang *et al*., 2023; Lee *et al*., 2023; Patel *et al*., 2022; Mendez *et al*., 2024) [24, 26, 33, 42].

**Hydroxyl radical scavenging activity (%) = A0 −As / A0 ×100**

Whereas, A0 is the absorbance of the control and As is the absorbance of the sample.

### Antimicrobial activity of biogenic Zn NPs synthesized from aqueous leaf extract of *Solanum Torvum*

By using agar well diffusion method, the antibacterial properties of Zn NPs synthesized from *Solanum torvum* leaf extract were investigated. The study included Gram-positive bacteria like as *Staphylococcus aureus* and *Bacillus* species and Gram-negative bacterias like as *Escherichia coli*. These bacterial strains were cultured in broth & incubated at 37°C for 24 hr, to promote growth. To ensure uniform microbial distribution the cultures were evenly spread on an agar plate and allowed to settle overnight. Control groups consisted of Zinc acetate the plant leaf extract and specific antibiotics: Penicillin for *Staphylococcus aureus*, Chloramphenicol for *Escherichia coli*, and Tetracycline for *Bacillus* species. Antibacterial activity of the synthesized Zn NPs was evaluated by measuring the diameters of the inhibition zone in a Petri dish after 24 hr of incubation at 37°C demonstrating significant antimicrobial potential (Bhaumik *et al*., 2023; Kaur *et al*., 2023; Rahman *et al*., 2023; Sinha *et al*., 2022; Iqbal *et al*., 2022) [7, 12, 15, 40].

Antifungal properties of the synthesized Zinc nanoparticles were further assessed using the agar well diffusion technique. Fungal strains including *Aspergillus niger*, *Rhizopus*, and *Mucor* were cultured in broth medium before being evenly distributed onto SDA agar plates following incubation. Control treatments comprised Zinc acetate, the plant leaf extract, and antifungal agents with Itraconazole for *Aspergillus niger* and Amphotericin-B for *Rhizopus* and *Mucor*. The plates were then incubated at room temperature for 48 ht and the diameters of the inhibition zone were measured to assess the antifungal efficacy of the Zinc nanoparticles against the control groups (Zhang *et al*., 2022; Kumar *et al*., 2023; Khan *et al*., 2023; Kumar *et al*., 2022) [16, 17, 18, 19, 20, 21, 23, 41].

**Anti-larvicidal activity of Zinc nanoparticles**

Larvicidal bioassay was conducted using *Culex quinquefasciatus* larvae to evaluate the effectiveness of synthesized Zn NPs in controlling mosquito populations. For the assay stock solutions of Zn NPs were prepared at concentrations of 10, 25, 50, 75, and 100 ppm in distilled water. Each concentration was tested on 20 larvae which were housed in separate beakers to prevent cross-contamination while a control group was maintained with distilled water only. The experimental setup was incubated at 25°C with humidity of 70% to natural conditions. After exposure, the larvae were assessed for mortality at 24, 48, and 72 hrs to gauge the anti-larvicidal efficacy of the Zinc nanoparticles (Akinmoladun *et al*., 2022; Saeed *et al*., 2023) [3, 4, 36].

The mortality rate was calculated using the formula:

$$\text{Mortality Rate } (\%) = \left( \frac{\text{Number of dead larvae}}{\text{Total number of larvae}} \right) \times 100$$

This method aligns with previous studies that have demonstrated the potential of nanoparticles as vector control highlighting the significance of such biological approaches in managing mosquito populations (Prasidha & Murthy, 2017) [34]

**Results**

**Antioxidant activities of biogenic Zn NPs synthesized from the aqueous extract of *Solanum torvum* leaf**

The antioxidant activities of Zn NPs synthesized using an aqueous leaf extract of *Solanum torvum* were assessed through various assays. The findings depicted in Table 1 and Figure 1 demonstrate the nanoparticle's effectiveness of concentrations ranging from 100 to 500 µg/mL. Notably DPPH free radical scavenging activity exhibited a substantial increase climbing from 20% inhibition in 100 µg/mL to 80% in 500 µg/mL. Additionally, the FRAP (Ferric Reducing Antioxidant Power) values rose from 150 µmol Fe (II)/g extract at 100 µg/mL to 750 µmol Fe (II)/g extract at 500 µg/mL. ABTS radical scavenging activity also significantly improved showing an increase from 25% inhibition in 100 µg/mL to 90% in 500 µg/mL. Furthermore, superoxide scavenging activity increased from 15% to 75% over the same concentration range. A corresponding enhancement was noted in the Zinc acetate oxide scavenging activity underscoring the potential of Zinc nanoparticles as effective antioxidants (Muthusamy *et al*., 2023; Kumar *et al*., 2023; Ahmad *et al*., 2022; Santos *et al*., 2024; Gupta *et al*., 2024) [2, 11, 18, 19, 20, 21, 23, 29, 37].

**Table 1:** Effect of Zn NPs synthesized from the aqueous leaf extract of *Solanum torvum* on different antioxidant models- inhibition percentage (%)

| Concentration (µg/ml) | DPPH (%) | FRAP (absorbance) | ABTS (%) | Superoxide (%) | Nitric Oxide (%) | Hydroxyl Radicals (%) |
|---|---|---|---|---|---|---|
| 100 | 47.2 | 0.33 | 51.3 | 34.8 | 40.1 | 41.7 |
| 200 | 56.1 | 0.43 | 53.8 | 419.2 | 47.3 | 45.2 |
| 300 | 65.3 | 0.53 | 62.1 | 50.7 | 54.9 | 53.6 |
| 400 | 67.8 | 0.63 | 64.4 | 55.2 | 60.5 | 8.4 |
| 500 | 72.5 | 0.73 | 72.5 | 60.1 | 63.8 | 62.1 |

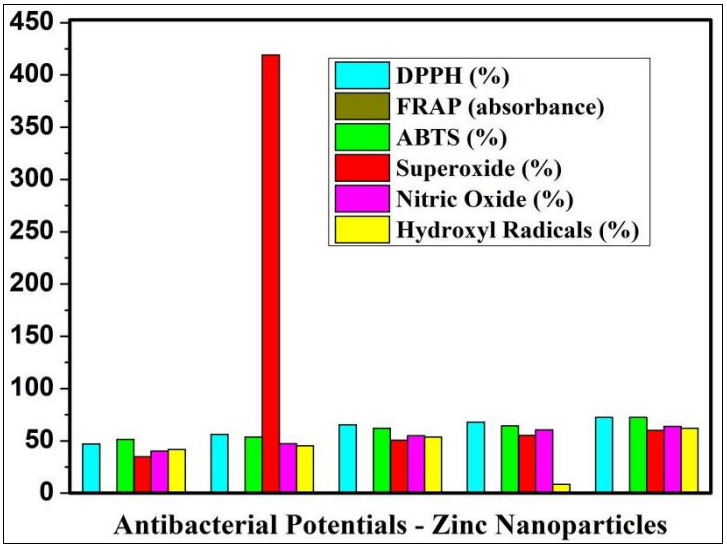


**Fig 1:** The graph depicts the Free radical scavenging activity of Zn NPs synthesized from the aqueous leaf extract of *Solanum torvum*

**Antimicrobial activity of Zn NPs synthesized from aqueous leaf extract of *Solanum torvum***

The antibacterial activity of zinc nanoparticles (Zn NPs) synthesized from *Solanum torvum* leaf extract was evaluated using the agar well diffusion method against various bacterial and fungal species. After 24 hours of incubation at 37 °C, the Zn NPs demonstrated significant antibacterial effects, forming inhibition zones on agar plates against strains such as *Staphylococcus aureus*, *Escherichia coli*, and *Bacillus* sp., with detailed results presented in Table 2 (Fig. 2). When compared to standard antibiotics like penicillin (*S. aureus*), chloramphenicol (*E. coli*), and tetracycline (*Bacillus* sp.), the Zn NPs showed promising potential as alternative antimicrobial agents (Jamdagni *et al*., 2023) [13]. Similarly, their antifungal activity was assessed against strains including *Aspergillus niger*, *Rhizopus*, and *Mucor*,

with measurements taken after 48 hours of incubation at room temperature (Table 3, Fig. 3). These findings align with recent studies emphasizing the efficacy of plant-extract-synthesized Zn NPs as versatile antimicrobial agents with significant antibacterial and antifungal properties (Abd-Elsalam *et al*., 2023) [1].

**Table 2:** Antibacterial activity of Zn NPs – Zone of inhibition

| Bacterial Strain Tested | Zn NPs | Aqueous extract of *Solanum Torvum* leaf | Antibiotic | Zinc Acetate Solution |
|---|---|---|---|---|
| | Zone of inhibition (mm) | | | |
| *E. Coli* | 19 mm | 5 mm | 9 mm | 1 mm |
| *Staphylococcus sp.* | 16 mm | 4 mm | 14 mm | 2 mm |
| *Bacillus sp.* | 19 mm | 6 mm | 9 mm | 1 mm |

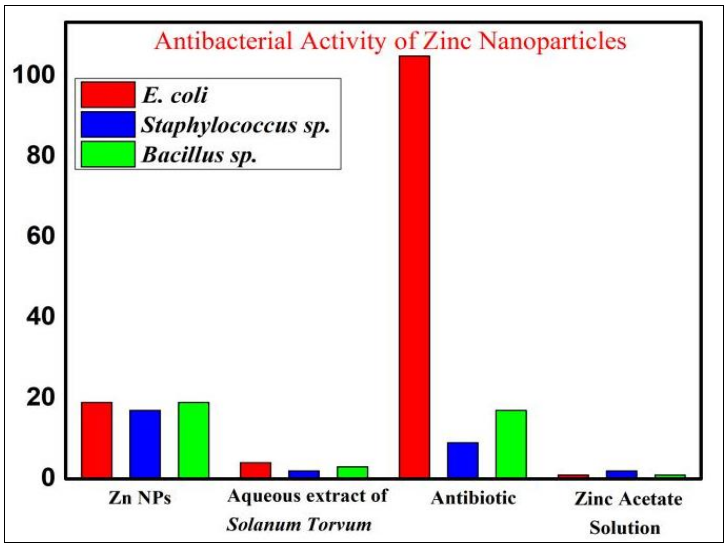


**Fig 2:** Graph showing antibacterial activity of biogenically synthesised Zn NPs

**Table 3:** Antifungal activity of Zn NPs - Zone of Inhibition

| Fungal Strains Tested | Zn NPs | Aqueous extract of *Solanum Torvum* leaf | Antibiotic | Zinc Acetate Solution |
|---|---|---|---|---|
| | Zone of inhibition (mm) | | | |
| *Aspergillus sp* | 27 mm | 5 mm | 12 mm | 3 mm |
| *Rhizopus sp* | 19 mm | 4 mm | 12 mm | 4 mm |
| *Mucor sp* | 22 mm | 4mm | 12 mm | 4 mm |

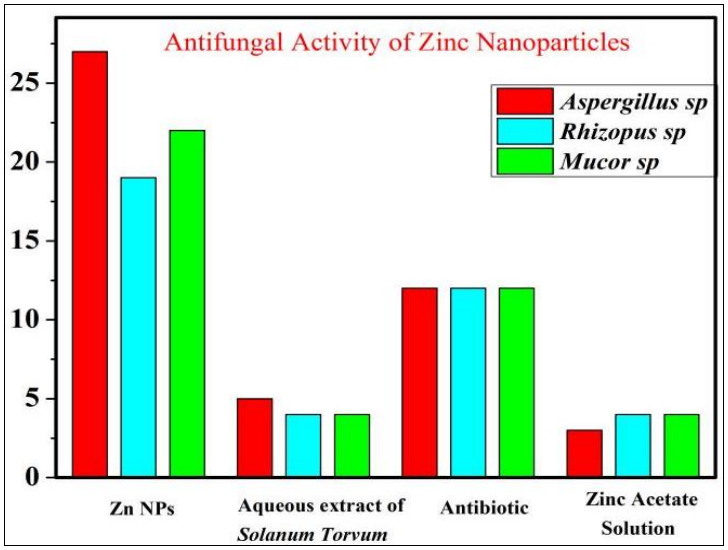


**Fig 3:** Graph showing antifungal activity of biogenically synthesized Zn NPs

**Antilarvicidal activity of the synthesized Zn NPs**

Table 4 presents the results of evaluating larvicidal activity of Zn NPs at various concentrations. The mortality rates of *Culex quinquefasciatus* larvae were measured at 24, 48, and 72 hr after exposure. The data indicated a concentration-dependent increase in larvicidal efficacy with higher concentrations of Zinc nanoparticles correlating with increased mortality rates. Specifically, at the maximum concentration of 100 ppm, a mortality rate of 87% was observed at 24 hr which rose to 96% at 48 hr. Remarkably by 72 hr, the mortality rate for the 100-ppm concentration reached 100% (Fig. 4). Findings underscore the potential of Zn NPs as an effective larvicidal agent. (Shanmugam, R. (2024) [38].

**Table 4:** Mortality Rates of *Culex quinquefasciatus* Larvae Exposed to Zn NPs at Different Concentrations

| Concentration (ppm) | Mortality Rate (%) at 24 hr | Mortality Rate (%) at 48 hr | Mortality Rate (%) at 72 hr |
|---|---|---|---|
| Control (Distilled Water) | 5% | 10% | 15% |
| 10 | 32% | 47% | 57% |
| 25 | 47% | 62% | 72% |
| 50 | 62% | 77% | 87% |
| 75 | 72% | 87% | 92% |
| 100 | 87% | 96% | 100% |

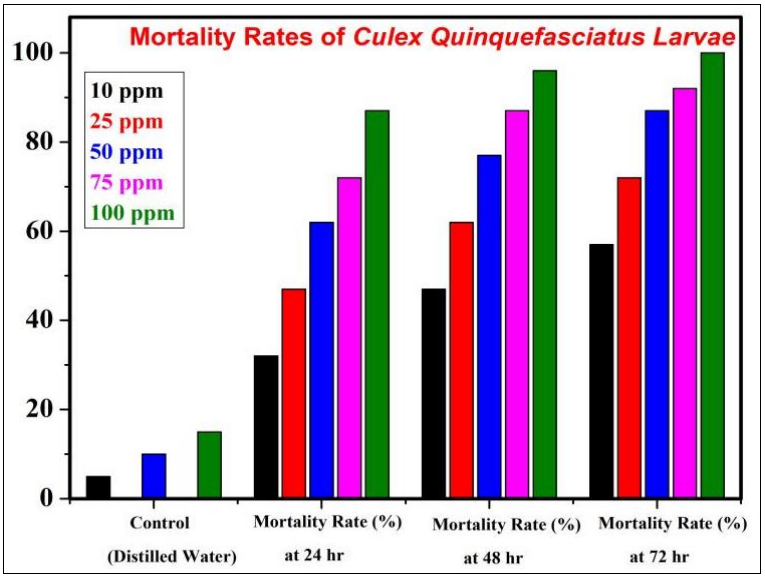


**Fig 4:** Anti-larvicidal activity of biogenic Zinc nanoparticles from *Solanum Torvum* leaf extract

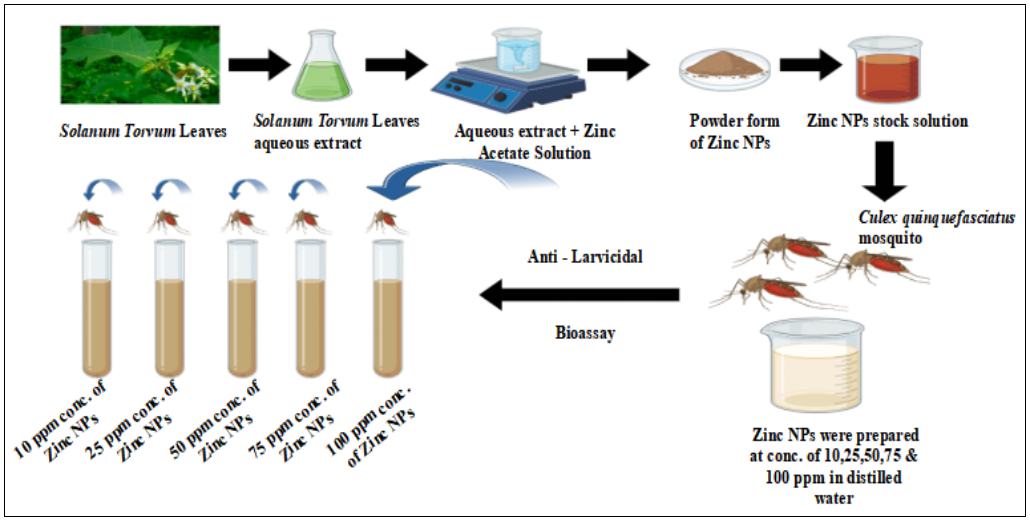


**Fig 5:** Illustrates the outline of the Anti-larvicidal activity of *Culex quinquefasciatus* larvae exposed to Zn NPs

## Discussion

The findings of the study indicate that the Zn NPs synthesised from the aqueous extract of *Solanum torvum* leaf exhibit significant antioxidant and antibacterial properties. The results align with a growing body of research supporting the medicinal benefits of plant-derived nanoparticles. The antioxidant activity of the synthesized Zn NPs was evaluated using various assays targeting different free radicals. For instance, at a conc. of 100 µg/mL. DPPH free radical scavenging activity exhibited a notable 20% inhibition increasing to 80% at 500 µg/mL.

Furthermore, the Zinc Reducing Antioxidant Power (ZRAP) values increased significantly from 150 µmol Zn (II)/g extract at 100 µg/mL to 750 µmol Zn (II)/g extract at 500 µg/mL indicating a strong reducing power of these nanoparticles. The ABTS radical scavenging activity also displayed a significant increase 25% inhibition in 100 µg/mL to 90% in 500 µg/mL. Zinc nanoparticles can effectively neutralize ABTS radicals suggesting their potential as robust antioxidants. Additionally, superoxide scavenging activity rose from 15% to 75% while nitric oxide scavenging activity increased from 10% to 70% further supporting the overall antioxidant capacity attributed to the stabilizing compounds in *Solanum torvum* leaf extractt. The hydroxyl radical scavenging activity ranged from 5% to 65% inhibition emphasizing their efficacy in combating hydroxyl radicals which are known for causing significant cellular damage. This finding is consistent with other studies demonstrating the capability Zn NPs to reduce oxidative stress by scavenging reactive oxygen species.

To evaluate the antibacterial activity of Zinc nanoparticle, agar well diffusion method was employed against various bacterial and fungal species. The results revealed that the Zinc nanoparticles produced inhibition zones comparable to or exceeding those of standard antibiotics like Tetracycline, Penicillin, and Chloramphenicol for *Escherichia coli*, *Staphylococcus aureus* and *Bacillus species* which demonstrated the potent antibacterial action of Zinc nanoparticles attributed to their ability to interact with bacterial cell walls and disrupt essential cellular functions. The nanoparticles also exhibited significant antifungal activity against strains such as *Aspergillus niger*, *Rhizopus*, and *Mucor*. Zinc nanoparticles have strong antifungal properties due to their capacity to breach fungal cell membranes and generate reactive oxygen species.

The study aims to determine the effectiveness of Zn NPs synthesized from *Solanum torvum* leaf extract in killing *Culex quinquefasciatus* larvae. The data revealed a clear dose-dependent response showing increasing conc. of Zn NPs resulted in higher larval mortality. At the maximum conc. of 100 ppm and the mortality rate reached 100% within 72 hr demonstrating the efficacy of these nanoparticles as larvicidal agents. The mortality rates recorded at 24 hr were relatively low with values of 32%, 47%, 62%, 72% and 87% for conc. of 10, 25, 50, 75 and 100 ppm respectively. By 48 hr there was a marked increase in mortality rates with the highest concentration achieving nearly total mortality (96%) within this time frame and reaching 100% by 72 hr. These results indicate the effectiveness of Zinc nanoparticles in disrupting larval development. Leaf extract of *Solanum torvum* used for synthesizing Zinc nanoparticles exhibited strong antibacterial, antioxidant, and larvicidal properties. These attributes are likely due to the unique characteristics of the nanoparticles combined with the natural bioactive compounds present in the plant extract. This study provides a foundation for future research into plant-derived Zinc nanoparticles as potential therapeutic agents against microbial infections and oxidative stress.

## Conclusion

Zinc nanoparticles synthesized from the aqueous extract of *Solanum torvum* leaves exhibit significant antioxidant, antimicrobial, and larvicidal properties. The antioxidant capacity was assessed through various assays, revealing dose-dependent increases in scavenging activities against DPPH, FRAP, ABTS, superoxide, nitric oxide, and hydroxyl radicals, with concentrations ranging from 100 to 500 µg/mL. The total phenolic content also increased significantly from 50 µg GAE/g extract to 250 µg GAE/g extract within the same concentration range, highlighting the strong antioxidant potential of the leaf extract. Antimicrobial evaluations demonstrated the nanoparticles' effectiveness in inhibiting the growth of bacterial species (*Staphylococcus aureus, Escherichia coli, Bacillus sp*.) and fungal strains (*Aspergillus niger, Rhizopus, Mucor*), with inhibition zones observed using the agar well diffusion method after 24 hours for bacterial strains and 48 hours for fungal strains. These results suggest that the nanoparticles could serve as effective alternatives to conventional antibiotics and antifungal agents. Additionally, the nanoparticles showed considerable larvicidal activity against *Culex quinquefasciatus* larvae, with a concentration-dependent lethal effect and complete mortality at the highest concentration. These findings highlight the potential of Zinc nanoparticles, particularly those derived from plant extracts, as sustainable alternatives for controlling mosquito populations and other vector management strategies. Further research is needed to evaluate their effectiveness in natural environments and their impact on non-target organisms, but overall, these properties position zinc nanoparticles as promising multifunctional therapeutic agents with applications in the pharmaceutical and biomedical sectors.

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