



Novel developments of ZnO/SiO₂ nanocomposite: a nanotechnological approach towards insect vector control

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Abstract

Recently, there is increasing efforts to develop newer and effective larvicides to control mosquito vectors. This study was carried out to examine the efficacy of ZnO/SiO₂ nanocomposite synthesized using Gum Arabic against *Culex quinquefasciatus* larvae. The elemental composition, morphology, functional groups and surface plasmon resonance of the ZnO/SiO₂ nanocomposite was analyzed by Energy dispersive X-ray analysis (EDX), Scanning electron microscope (SEM), FTIR and UV-Visible spectroscopy respectively. In bioassay, larvae were exposed to three different concentrations of synthesized ZnO/SiO₂ nanocomposite. The mortality rates at concentrations of 10, 20 and 25 were found to be (70%, 80%, 86%), (56%, 64%, 84%) and (44%, 48%, 76%) for 1st, 2nd, and 3rd instar respectively. This study revealed that the synthesized ZnO/SiO₂ nanocomposite exhibit high larvicidal activity; 1st instar (LC₅₀=4.024, LC₉₀= 39.273 mg/l), 2nd instar (LC₅₀=8.767, LC₉₀=51.069 mg/l) and 3rd instar (LC₅₀=13.761, LC₉₀=81.809 mg/l)

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1. Introduction

Application of chemical insecticides in order to kill mosquito larvae or pupae in the water is known as larviciding. Larviciding is generally more effective and target-specific than adulticiding (applying chemicals to kill adult mosquitoes). The most common synthetic chemicals used in controlling mosquitoes' larvae are methoprene, pyrethroids, diflubenzuron, malathion, dichlorodiphenyltrichloroethane (DDT), organophosphate temephos,

and as well as phytochemicals [1-3]. However, synthetic chemicals (insecticides) are known to cause serious environmental problem thereby killing non-target organism and affecting human health. Moreover, continuous application of synthetic chemicals (insecticides) results in control failures due to development of resistance by the mosquitoes (vectors) [4]. Hence, it has been reported that ZnO and SiO₂ nanoparticles provides a lay down of a novel green nanotechnology to control insect pest including mosquitoes' larvae [5-8]. ZnO/SiO₂ nanocomposites have been synthesized using various techniques such as chemical vapor deposition, sputtering, chemical etching and sol gel process and they are used in different applications such as an-

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timicrobial, photonic crystals, photocatalysts, gas sensors, vacuum fluorescent display and varistors etc., [9-19]. But based on our search, there was no report on the effect of ZnO/SiO₂ nanocomposites against mosquito larvae except for the individual ZnO and SiO₂ nanoparticles.

Culex quinquefasciatus is a vector of lymphatic filariasis. The breeding site of *Culex* species includes; gutters and water retention sites having organic matter. Filariasis has been reported to be a public health problem in Africa as well as other part of the world [20-22]. Thus, to prevent mosquito bornediseases and improve the quality of public health, it is necessary to control mosquito larvae. In this study, ZnO/SiO₂ nanocomposite was synthesized using Gum Arabic and was tested against the larvae of *Culex quinquefasciatus*. The formation of ZnO/SiO₂ nanocomposite was confirmed using ultraviolet-visible (UV-Vis) spectrophotometry, Scanning electron microscopy (SEM) coupled energy dispersive X-ray (EDX) spectroscopy and Fourier transforms infrared (FTIR) spectroscopy.

2. Materials and Methods

2.1. Collection of Gum Arabic (*Acacia senegalensis*)

A fresh *A. senegalensis* extrudes were collected from Biliriri Local Government of Gombe State. The Gum extract were neatly collected and allowed to dry properly under the sun. The Gum Arabic was crushed to powder using pestle and mortar.

2.2. Synthesis of ZnO/SiO₂ Nanocomposite

One gram (1 g) of Gum Arabic was poured into a beaker containing 40 ml of distilled water which was magnetically stirred for 10 minutes at 90°C. Following this, 2 g of Zn(NO₃)₆.6H₂O and 2 g of silica gel were added and stirred for 30 minutes. Upon addition of Zn(NO₃)₆.6H₂O and silica gel the aqueous solution changed to milk colour. With time the solution became viscous. A cloudy formation at the bottom of the beaker indicated the formation of resin. The resin obtained was placed in a furnace at 450 °C for two hours to obtain ZnO/SiO₂ nanocomposite [23].

2.3. Characterization of the Green synthesized ZnO/SiO₂ nanocomposite

ZnO/SiO₂ Nanocomposite was characterized using Ultraviolet-visible Spectroscopy, Fourier transformed infrared spectroscopy (FT-IR) and Scanning Electron Microscopy (SEM) coupled with energy dispersed x-ray techniques.

2.4. Collection of *Culex quinquefasciatus* larvae

Culex quinquefasciatus mosquito larvae were collected from different areas of Gombe metropolis. Using ladle and a collection bottle, the ladle was lowered into the water (breeding site) at an angle of about 45° until one side is just below the surface of the water. While dipping, care was taken not to disturb the larvae which may cause them to swim downward. The larvae were maintained and fed in the laboratory with glucose for the larvicidal bioassay. The collection was done based on previous literature [23].

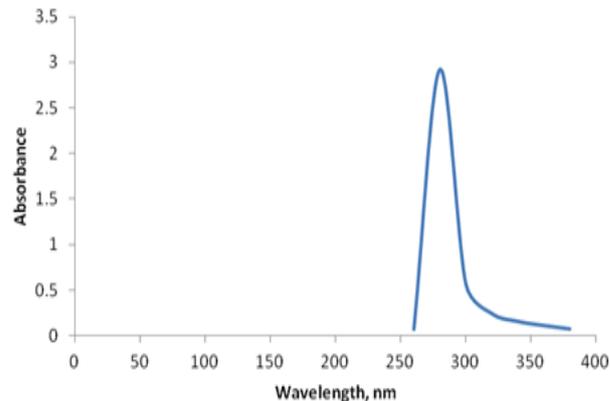


Figure 1. UV-Visible spectrum for ZnO/SiO₂ nanocomposite.

2.5. Larvicidal Activity of ZnO/SiO₂ Nanocomposite

The test was carried out according to our previous work [24]. 0.1g of ZnO/SiO₂ nanocomposite was weighed and diluted with distilled water in a 1000 ml volumetric flask and shaken to obtain 100 mg/L concentration. The bioassay was done by placing different instars (1st – 3rd) of the larvae into 200 ml of plastic container with four replicates and a control in each of the instars, each replicate comprised of twenty-five larvae. 100 ml of dechlorinated water was added in each of the replicates. Finally, 10 mg/L, 20 mg/L and 25 mg/L of the ZnO/SiO₂ Nanocomposite concentrations were inoculated into each of the replicates. And percentage mortality was calculated as follows:

2.6. Statistical Analysis

Percentage mortality, Probit analysis, Chi square and Correlation analysis were calculated and tabulated using (SPSS, 2016).

3. Result and Discussion

3.1. Ultraviolet visible analysis

Absorption spectrum of synthesized ZnO/SiO₂ nanocomposite at different wave lengths ranging from 260 to 380 nm revealed the maximum absorption wavelength of 280 nm, (Figure 1). Elsewhere, maximum absorption wavelength of 300 nm was reported for CaO/SiO₂ nanocomposite [25]. This optical property is in the same range with the one in the current.

3.2. FT-IR Analysis

Figure 2 depict the FT-IR spectrum of ZnO/SiO₂ nanocomposite analyzed from 450-4000 cm⁻¹ which exhibited prominent peaks at 3457.75, 1654.65, 1067.44, 701.43, and 455.97 cm⁻¹. The band at 1067.44 cm⁻¹ corresponds to asymmetric stretching vibration of Si-O-Si bond. The peaks at 701.43 cm⁻¹ corresponds to Si-OH bond [9-19,26-28]. The band at 3457.75 cm⁻¹ indicates HO-H stretching mode for silanol group and adsorbed water. And band at 1654.65 cm⁻¹ indicates bending mode of adsorbed water. The Zn-O and Si-O bond is indicated by the peak at 455.97 cm⁻¹ [919, 25-27]. Thus, this information confirmed the formation of ZnO/SiO₂ nanocomposite.

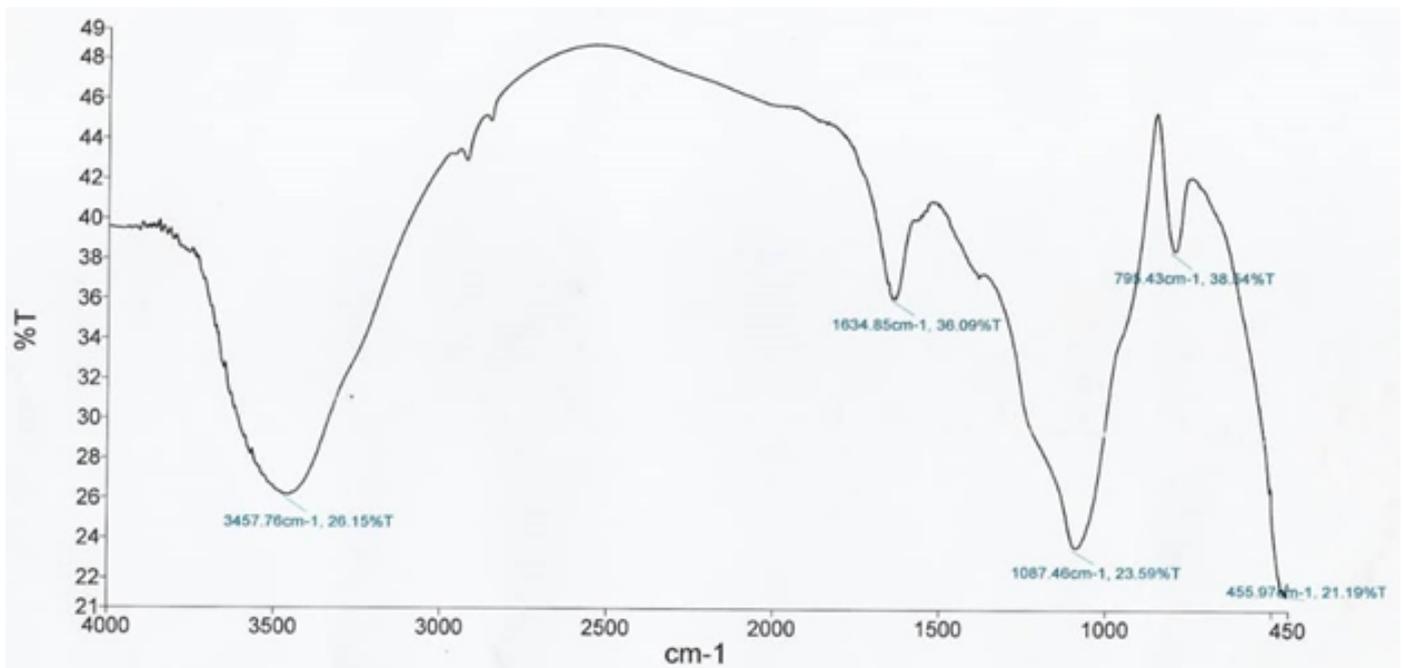


Figure 2. FT-IR spectrum of ZnO/SiO₂ Nanocomposite.

Table 1. Larvicidal activity of synthesized ZnO/SiO₂ nanocomposite on *Culex quinquefasciatus* larvae. LC₅₀ ; lethal concentration that kills 50% of larvae, LC₉₀ ; lethal concentration that kills 90% of larvae, r: correlation coefficient; χ^2 ; chi square

Instars	Conc (mg/l)	Mortality %	% Mortality	LC50 (mg/l)	LC ₉₀ (mg/l)	χ^2	r
1 st Instar	10	17.5	70	4.024	39.273	0.076	0.999
	20	20	80				
	25	21.5	86				
2 nd Instar	10	14	56	8.767	51.069	1.543	0.908
	20	16	64				
	25	19	84				
3 rd Instar	10	11	44	13.761	81.809	2.75	0.826
	20	12	48				
	25	19	76				

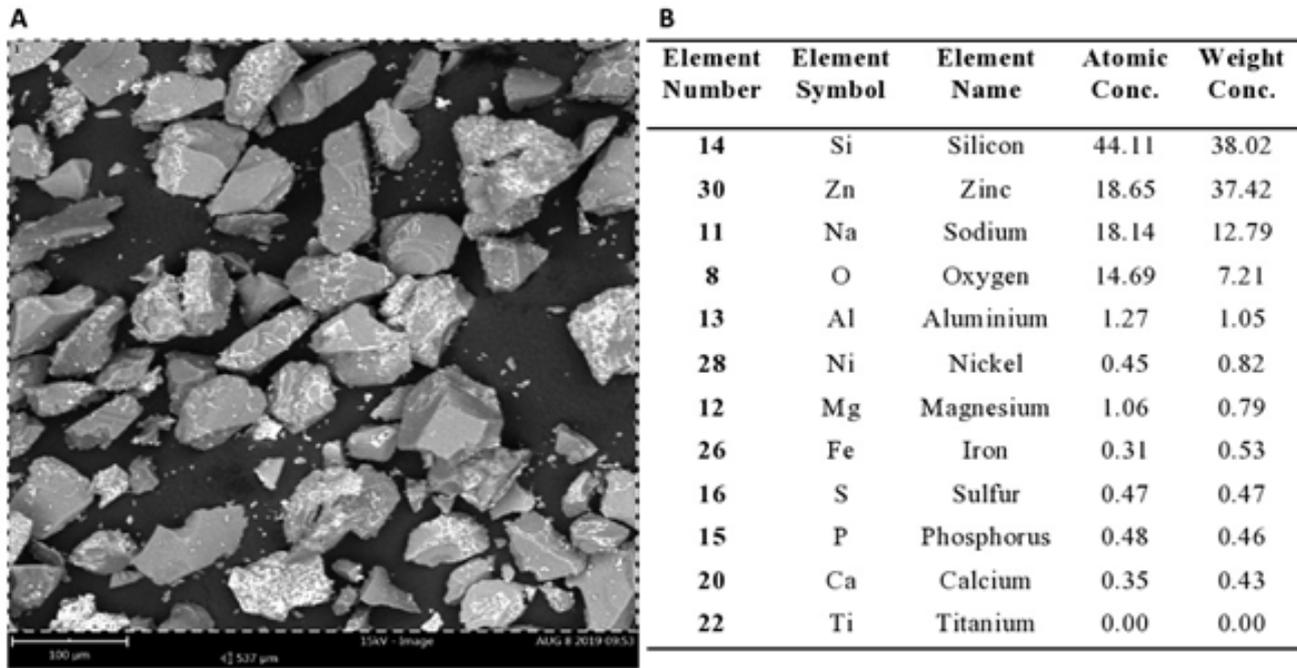
3.3. SEM/EDX Analysis

Figure 3A depict SEM image, 3B depict elemental data and 3C depict EDX spectrum of ZnO/SiO₂ nanocomposite. The SEM image showed large and dispersed particles of silica coated ZnO nanoparticles. The EDX spectrum showed different element apart from the expected Zn, Si and O. The presence of other element is due to Gum Arabic used in the synthesis because Gum Arabic has been reported to contained; Al, Ba, Ca, Fe, K, Mg, Mn, P, S and Sr [28]. From Figure 3B, percentage composition of Si, Zn and O were 38.02, 37.42 and 7.21 % respectively.

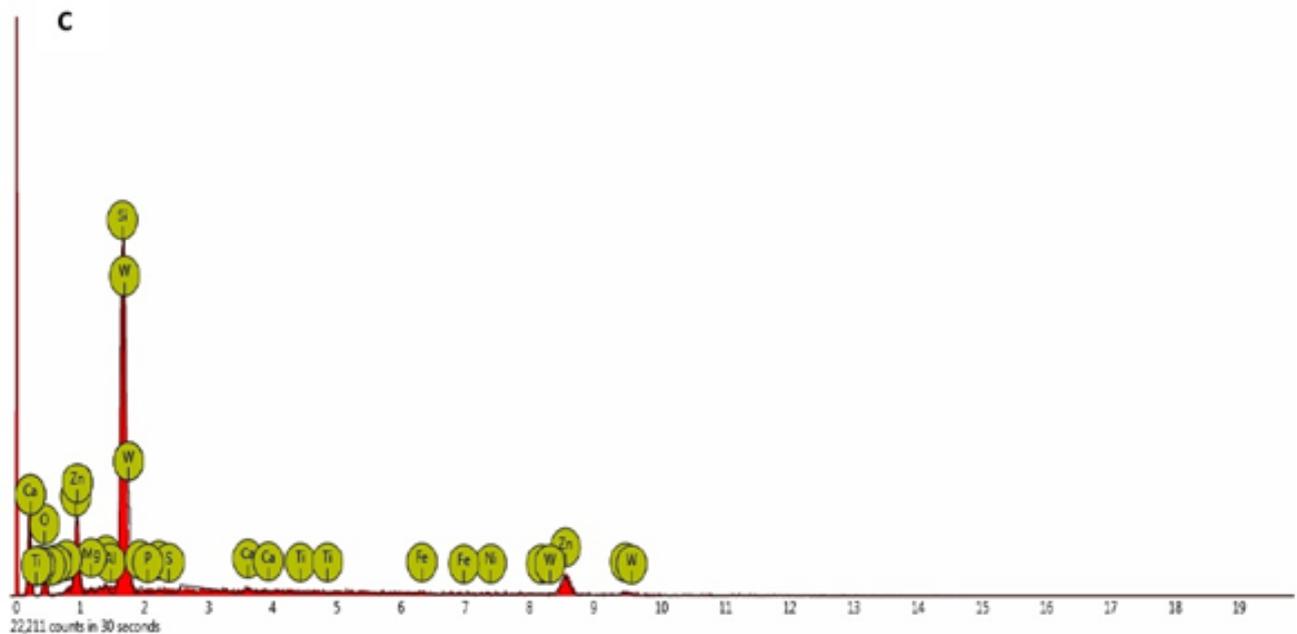
3.4. Larvicidal test result:

The exposure of *Culex quinquefasciatus* larvae to different concentrations of the synthesized ZnO/SiO₂ nanocomposite for 24hrs demonstrates their larvicidal efficacy. Table 1 show that larval mortality significantly increased with the increase in concentrations of ZnO/SiO₂ nanocomposite. The mortality rates of

concentrations; 10, 20 and 25 mg/l for 1st instar were 70%, 80%, 86%, 2nd instar were 56%, 64%, 84%, and 3rd instar were 44%, 48% and 76% respectively. This study revealed that the synthesized ZnO/SiO₂ nanocomposite larvicidal activity decreases from 1st instar to 3rd instar. Thus, lethal concentrations of the nanocomposite on the larvae of *Culex quinquefasciatus* were found to be (LC₅₀=4.024 mg/l, LC₉₀= 39.273 mg/l), (LC₅₀=8.767 mg/l, LC₉₀=51.069 mg/l) and (LC₅₀=13.761 mg/l, LC₉₀=81.809 mg/l) for 1st, 2nd, and 3rd instar respectively. In our previous studies, Ag-Co and Cu/Ni bimetallic nanoparticles were synthesized through green pathway and it larvicidal activities were tested against *Culex quinquefasciatus* larvae. The LC₅₀ for 1st, 2nd, and 3rd instars were 5.237, 9.310 and 13.626 mg/l respectively [29]. And the LC₅₀ for 1st, 2nd, and 3rd instars were 14.75, 18.25 and 18.50 mg/l respectively [30]. Hence, ZnO/SiO₂ nanocomposite proved to be more effective against *Culex quinquefasciatus* larvae than Ag-Co and Cu/Ni bimetallic nanoparticles as reported by [29-30].



FOV: 537 µm, Mode: 15kV - Image, Detector: BSD



Disabled elements: Sr

Figure 3. (A) SEM image (B) elemental result and (C) EDX spectrum of the synthesized ZnO/SiO₂ nanocomposite

4. Conclusion

In this research, ZnO/SiO₂ was synthesized using Gum Arabic and characterized by UV-Visible, FTIR, SEM and EDX techniques. The larvicidal activity of ZnO/SiO₂ nanocomposite was tested against *Culex quinquefasciatus* larvae using desired

concentrations which showed significant results. This study showed that, the application of ZnO/SiO₂ nanocomposite can serve as a replacement of insecticide in mosquito vector control.

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