



Green Synthesis of Zinc Nanoparticles from *Senna Auriculata* and Influence on Peanut Pot-Culture

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Abstract: Green synthesis of metal nanoparticles is sprouting as a new path of research in nanotechnology. In the present investigation, zinc nanoparticles were synthesized from the leaf extract of *Senna auriculata*. The present study is focused on application of zinc nanoparticles to peanut pot-culture for evaluation of soil micro-biota, soil enzyme activities, and physiological growth parameters of peanut plants. The zinc nanoparticles were characterized using Ultraviolet-Visible spectrophotometer, Inductively coupled plasma optical emission spectrophotometer, Fourier transform infrared spectrometer, Particle size analyzer, X-ray diffractometer, Scanning, and Transmission electron microscope. The optical absorption spectrum of zinc nanoparticles showed an absorbance peak around 328 nm, confirming the formation of zinc nanoparticles. The zinc nanoparticles were observed to be poly-dispersed and spherical shaped with an average size of about 22 nm and zeta potential of 80 mV. The synthesized zinc nanoparticles were applied to the peanut pot-culture in 3 different treatments, by maintaining the controls. Enhanced microbial population, and soil enzyme activities were observed along with the induced growth of peanut plants, when compared to the controls. Among the 3 treatments, treatment-1, application of 15 ml of sample solution (zinc nanoparticles), showed good results.

Keywords: Green Synthesis, Peanut Pot-Culture, *Senna Auriculata*, Soil Enzyme Activity, Soil Micro-Biota, Zinc Nanoparticles.

I. INTRODUCTION

Nanoparticles in general show exclusive optical, magnetic, electronic, catalytic, anti-inflammatory, and anti-microbial properties [1]. Metal nanoparticles usually exhibit novel properties, compared to bulk systems, due to the quantum size effects [2]. Formation of metal nanoparticles with controlled shape, size, and roughness was due to dynamic bio physicochemical interactions and colloidal forces [3].

Green synthesis of metal nanoparticles using leaf extracts is eco-friendly, safe, and non-toxic route, by which, the nanoparticles can be synthesized at low cost in less time, when compared to physical and chemical routes. The bio reduction method for the synthesis of metal nanoparticles using plant leaf extracts has been vastly expanding in recent years. Various researchers synthesized metal nanoparticles like gold [4], [5], silver [6], [7],

tungsten oxide [8], copper oxide [9], titanium dioxide [10], and zinc oxide [11] using leaf extracts of different plant species. But, the synthesis of biogenic zinc nanoparticles is scant [12]-[15]. Green Synthesis of zinc nanoparticles is of great interest because, zinc is an essential micronutrient for plants and plays a key role in growth and yield of the plants. Plants in general absorb zinc as a divalent cation (Zn^{2+}), which enhances the soil microbial and soil enzyme activities [12].

Senna auriculata is a legume in the sub-family Caesalpinioideae, which occurs in the dry regions of India and Sri Lanka. The plant contains a cardiac glucoside called sennapicrin. The leaves and the bark of *Senna auriculata* yield anthraquinones. The bark also contains tannins. Roots of the plant are used in preparing decoctions against fever, diabetes, diseases of urinary system, and constipation. Dried flowers and flower buds of these plants are used as a substitute for tea in case of diabetic patients. The powdered seed is applied to the eye in case of chronic purulent conjunctivitis. In Africa, the bark and the seeds of this plant are said to give relief against rheumatism, eye diseases, gonorrhoea, diabetes, and gout. *Senna auriculata* can also be used as an antibacterial agent [16]. *Senna* glycosides are used as laxatives in modern medicine. Several *Senna* species are used as herbal remedies in Nigeria, to treat various conditions like constipation, fungal skin infections, and hemorrhoids [17].

Soil is the basic source of all nutrients required for the plant. Phosphatases and dehydrogenases are the enzymes present in the superficial layers of soil. Phosphatases, based on their pH are classified into acidic phosphatases and alkaline phosphatases. Microorganisms present in the soil are the main sources of phosphatases [18]. Phosphatases are the enzymes, which releases inorganic phosphate moiety from organic phosphate moiety, whereas, dehydrogenases are the enzymes, which acts as the indicators of oxidative metabolism in soils. The phosphatase and dehydrogenase enzyme activities directly imply the soil fertility and are influenced by soil temperature, and moisture content.

The present investigations are aimed to synthesize phyto-genic zinc nanoparticles using the leaf extract of *Senna auriculata*, following green reduction method and to characterize the synthesized zinc nanoparticles using



different spectroscopic, and microscopic analytical techniques. The objective of the study is to conduct pot-culture experiment on peanut, by applying the green synthesized zinc nanoparticles, to study soil micro-biota, soil enzyme activities, and physiological growth parameters of peanut plants.

II. EXPERIMENTAL

A. Study site and soil sampling

Experimental work was carried out at Tirupati, and Bangalore. Tirupati was located at 13.65°N 79.42°E. Monsoon remains moderate and summer experiences temperatures ranging from 35 °C to 40 °C. In winter, the minimum temperatures will be between 18 °C and 20 °C. Summer usually occurs from March to June, and rains occur in July, followed by winter, which lasts until the end of February. Bangalore was located at 12°58'N 77°34'E. Bangalore has a tropical savanna climate with distinct wet and dry seasons. Due to its high elevation, Bangalore usually enjoys a more moderate climate throughout the year. The coolest month is December, with an average low temperature of 15 °C, and the hottest month is April, with an average high temperature of 36 °C. Soil for the pot-culture experiment was collected from Indian Institute of Horticultural research, Bangalore, India. The soil used for the experiment was red soil (loams) with pH of 6.7.

B. Preparation of leaf extract and green synthesis of zinc nanoparticles

Fresh leaves of *Senna auriculata* were collected from the fields of Regional Agricultural Research Station, Acharya NG Ranga Agricultural University, Tirupati, India. The leaves (500 gm.) were thoroughly washed with double distilled water and dried. After drying, the leaves were made into powder and sieved (0.5 mm.). 3 gm. of powder was dissolved in 100 ml. of distilled water, boiled for 15 min. at 65° C and filtered (leaf extract). For the green synthesis process, 10 ml. of leaf extract and 90 ml. of 0.005 molar zinc nitrate solution were taken in 1: 9 ratio (sample). The solution was heated using a hot plate up to observation of color change from pale yellow color to dark honey color (65 °C). Later, the sample was centrifuged (REMI K.70) at 18,000 rpm for 15 min and the supernatant is stored at -20 °C.

C. Characterization of zinc nanoparticles

The absorption spectrum was recorded using Shimadzu, 4650 UV-Visible Spectrophotometer in the wavelength range 200 nm – 800 nm. Fourier transform infrared spectra were recorded for the leaf extract of *Senna auriculata* and for the sample solution using Bruker Tensor, 27 in the wave number range 400 – 4,000 cm⁻¹. The particle size distribution, and zeta potential spectra were recorded using Particle size analyzer (Horiba, Nanoparticle SZ-100). 4 ml. of the sample solution was taken for particle size analysis (in a quartz cell) and 1 ml. of the sample solution was taken for zeta potential measurement (in an electrode cell). The micro structural properties were studied using Scanning electron microscope (Carlzeiss EVO 50), and Transmission

electron microscope (HITACHI, H-7500). The X-ray diffraction analysis was performed using Siefert X-ray diffractometer, model 3003.

D. Pot-culture experiment on peanut

Pot-culture experiment was carried out on *Arachis hypogea* L (peanut). 20 pots (15 cm. x 12 cm. x 12 cm.) were raised as 5 replications for which, the sample was added (at the time of sowing seeds) to 15 pots and 5 pots were maintained as controls. Soil microbial population, acidic phosphatase activity, alkaline phosphatase activity, and dehydrogenase activity (soil enzyme activities) were estimated along with the physiological growth parameters of peanut plants in two regular time intervals of 30 days and 60 days of sowing period in 3 different treatments by maintaining controls.

Treatment – 1: 15 ml. of sample solution.

Treatment – 2: 10 ml. of sample solution.

Treatment – 3: 5 ml. of sample solution.

Control : Without adding any sample.

Serial dilution method and spread plate technique were used for the estimation of microbial population present in the soil. For bacteria - nutrient agar media, for fungi – potato dextrose agar media, and for actinomycetes - kennight and munnaier's media were prepared. 3 gm. of soil was taken from each peanut pot (60 days of sowing period) to prepare the master solutions. 0.1 ml. of the prepared dilutions was added to the petri-dishes, which include 10⁻⁵ dilution for bacteria, 10⁻² dilution for fungi and 10⁻³ dilution for actinomycetes. The Petri-dishes of bacteria and fungi were incubated at 23⁰C for 3 days, and actinomycetes were incubated at 23⁰ C for 5 days. Later, the microbial population (colony count) was estimated after the incubation period.

3 gm. of soil was taken from each peanut pot for the estimation of soil phosphatase (acidic and alkaline) activities, and soil dehydrogenase activity. Phosphatase activity was performed as described by Tabatabai and Bremner, 1969 [19], and dehydrogenase activity was performed as described by Thalmann, 1968 [20]. The soil enzyme activity analysis was carried out in two regular time intervals of 30 days and 60 days of sowing period.

Physiological growth parameters like plant height, number of leaves, and leaf surface ratio (leaf length and breadth) were recorded in two regular time intervals of 30 days and 60 days of sowing period. The root length, shoot length, fresh weight of shoots, fresh weight of roots, dry weight of shoots, dry weight of roots, and the total biomass were recorded after 60 days of sowing period. After 60 days of sowing period, peanut plants from all the pots were removed and each plant was differentiated into its root, and shoot. Fresh weights of roots and shoots were measured immediately after differentiating the plants into roots, and shoots. Dry weights were measured after incubating the roots, and shoots in an oven for 36 hrs. at 65°C.

III. RESULTS AND DISCUSSION

A. Spectroscopy

Fig.1 shows the absorption spectrum of zinc nanoparticles recorded in the wavelength range 200 nm –

800 nm. The absorption peak of zinc nanoparticles was observed at a wavelength of 328 nm. The absorption edge for zinc oxide nanoparticles were normally observed at a wavelength of about 360 nm [21], whereas for zinc nanoparticles it will be in the wavelength range of 230-330 nm. [22], [23].

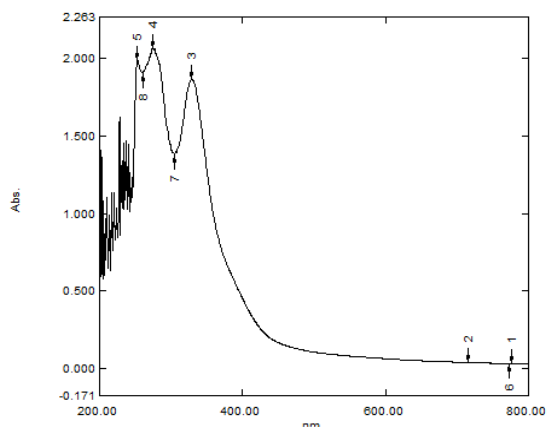


Figure.1. Absorption spectrum of the zinc nanoparticles synthesized from the leaf extract of *Senna auriculata*.

Thus, from the absorption spectrum, the formation of zinc nanoparticles was confirmed. The zinc content was estimated as 344 ppm (344 mg/L.) from Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES - Perkin Elmer Optima 8000) [12].

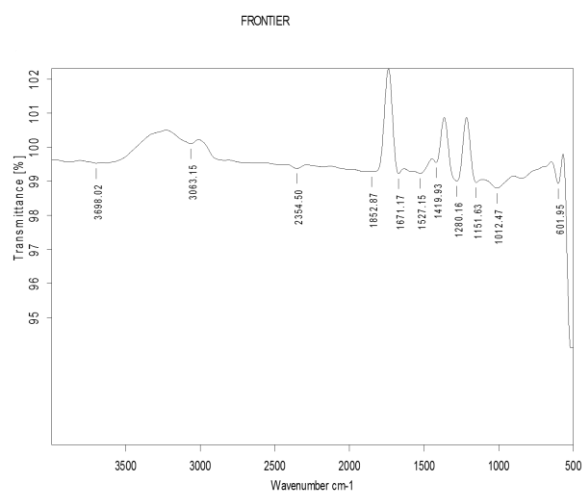


Figure.2(a). FTIR spectrum of the leaf extract (*Senna auriculata*).

Fig. 2a. shows the infrared spectrum recorded for the leaf extract of *Senna auriculata*. The functional groups of alcohols, phenols, alkenes, alkynes, phenyls, carbonyls, nitro compounds, and amines were identified from the Fourier transform infrared (FTIR) spectrum of *Senna auriculata* leaf extract. The spectrum showed the bands at 3698, 3063, 2354, 1852, 1671, 1527, 1419, 1280, 1151, 1012, and 601 cm^{-1} . Strong band of -C=O- stretch (carbonyls) was recorded at 1671cm^{-1} , and medium bands of -N=O- symmetric stretch (nitro compounds), and C-N stretch (amines) were recorded at 1280 and 1151cm^{-1} .

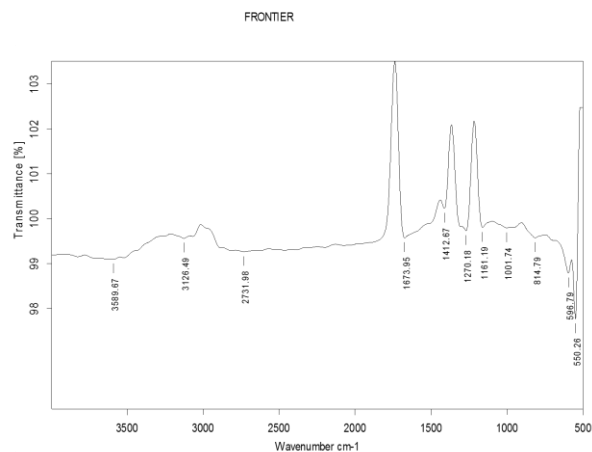


Figure. 2(b). FTIR spectrum of zinc nanoparticles.

Fig. 2b. shows the infrared spectrum recorded for the zinc nanoparticles, synthesized from the leaf extract of *Senna auriculata*. Alcohols, phenols, carboxylic acids, aromatics, nitriles, carboxylic acids, aldehydes, ketones, esters, aromatic amines, and alkyl halides were the functional groups identified from the spectrum showed the bands at 3589, 3126, 2731, 1673, 1270, 1161, 1001, 814, 596, and 550cm^{-1} . Strong band of -C=O- stretch (aldehydes, and ketones) was recorded at 1674cm^{-1} , and medium bands of -C-N- stretch (aromatic amines), and $\text{-CH}_2\text{-X}$ stretch (alkyl halides) were recorded at 1161 and 550cm^{-1} .

The FTIR spectra recorded for *Senna auriculata* leaf extract, and zinc nanoparticles (sample) showed a change in wave number of the functional groups due to the bio-reduction, and stabilization of metal group – Zn [12]. When the spectrum of *Senna auriculata* leaf extract was compared with the spectrum of zinc nanoparticles, stretching of bands corresponding to the functional groups of aldehydes, and ketones (H-C=O); nitriles ($\text{C}\equiv\text{N}$); carboxylic acids, and esters (-C=O-); aromatic amines ($\text{NH}_2\text{-ring}$), and alkyl halides ($\text{-CH}_2\text{-X}$) were observed from the spectrum of zinc nanoparticles.

The principle involved in the bio-reduction process of metal nanoparticles is due to the interaction of biological components present in the samples [24]. Here, the infrared spectroscopy studies confirmed that, the flavonoids (carboxylic acids, and esters; aldehydes, and ketones; aromatic compounds, and amines and phenols), and the terpenoids (carbonyl groups) present in the leaves extracts bind to the metal (Zn), and bio-reduced the metal zinc to zinc nanoparticles, by stabilizing the metal group zinc. Thus, the bio-molecules present in the leaves extracts are responsible for formation, and stabilization of zinc nanoparticles in the aqueous medium.

B. Particle analyzer studies and microscopy

The particle size, and zeta potential spectra recorded for the zinc nanoparticles are shown in Fig. 3 & Fig. 4. The estimated average particle size, and zeta potentials were 22 nm and 80 mV respectively. Zeta potential here, explained the dispersion stability of zinc nanoparticles, and the degree of repulsion between the particles present in colloidal solution.

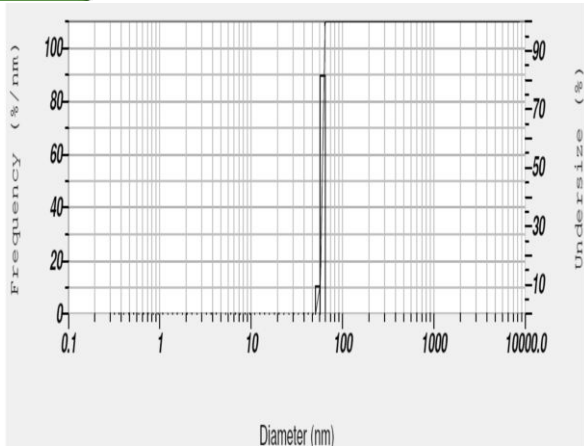


Figure. 3. Particle size distribution spectrum of zinc nanoparticles

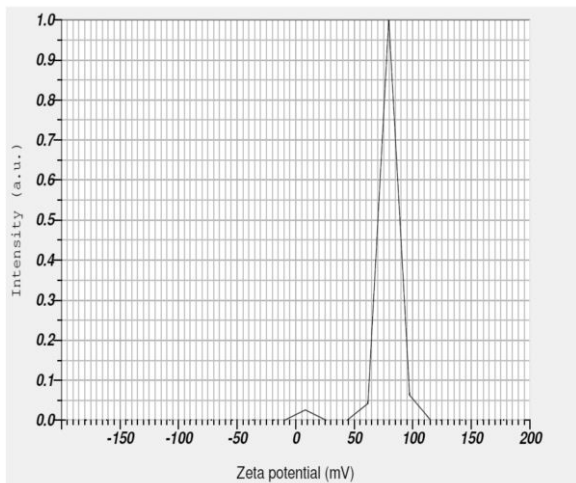


Figure. 4. Zeta potential spectrum of zinc nanoparticles.

In the Horiba SZ-100, light source interacts with sample cell, and scatters light in all the directions. The scattered light was collected at either 90° or 173° depending on the scattering angle, and position of the cell. The system automatically selects the optimum scattering angle, and the cell position depending on the sample concentration and intensity. Charge of the particle (negative/positive) was determined by the direction of the motion of particles, and magnitude of the charge was determined by speed of the motion of particles. Here, the reported zeta potential result can be used as an indicator of stability of zinc nanoparticles. The size distribution profile of nanoparticles in solution depends on the particle core size, surface structures, particle concentration, and the type of ions in the medium [12].

Fig.5 shows the X-ray diffraction pattern of zinc nanoparticles. The XRD pattern of zinc nanoparticles exhibited the characteristic Bragg peaks with diffraction intensities at 19° , 36° , 39° , 43° , and 54° (2θ angles) corresponding to (hkl) values of (1 0 1), (2 0 1), (2 0 2), (2 0 3), and (3 0 0), representing hexagonal closely packed (hcp) structure of zinc nanoparticles. Broadening of peaks was due to the presence of nano-sized particles (zinc nanoparticles). The other minor peaks observed from the

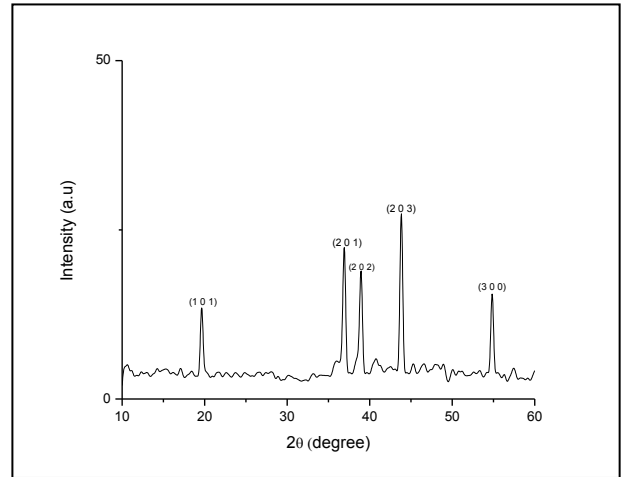


Figure.5. XRD pattern of zinc nanoparticles.

XRD pattern were due to the presence of biological materials in the leaf extract of *Senna auriculata*. The average particle size of zinc nanoparticles was calculated as 22 nm from XRD spectrum, using Debye formulae.

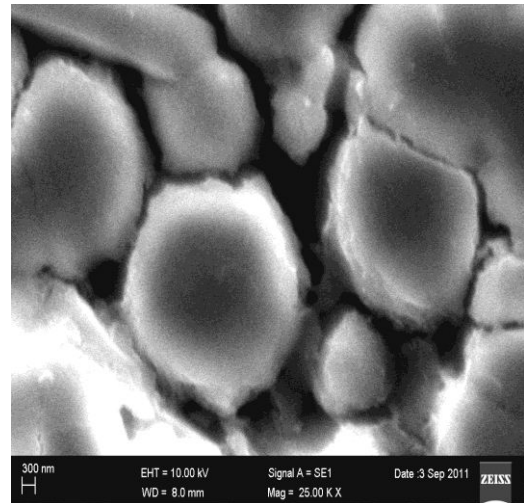


Figure.6. Scanning electron microscopic image of zinc nanoparticles (300 nm).

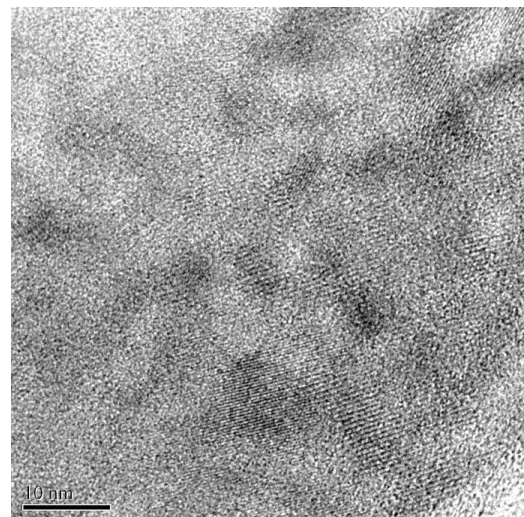


Figure.(7a).Transmission electron microscopic image of zinc nanoparticles (10 nm).

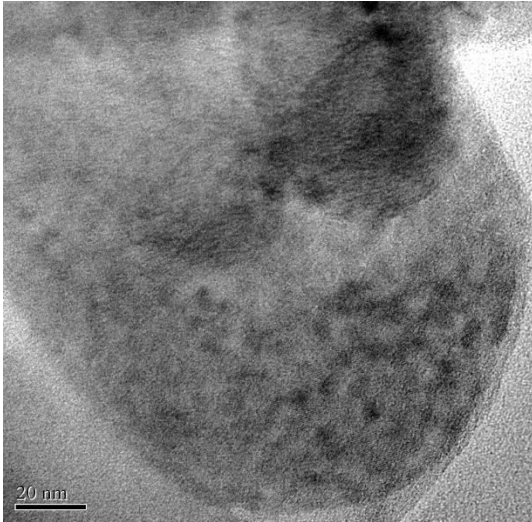


Figure.(7b).Transmission electron microscopic image of zinc nanoparticles (20 nm).

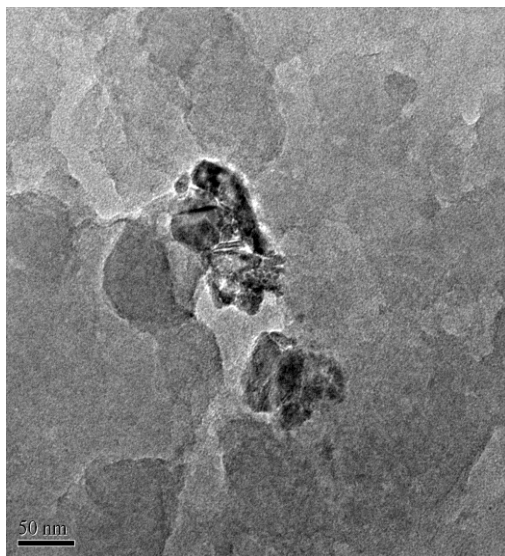


Figure.(7c).Transmission electron microscopic image of zinc nanoparticles (50 nm).

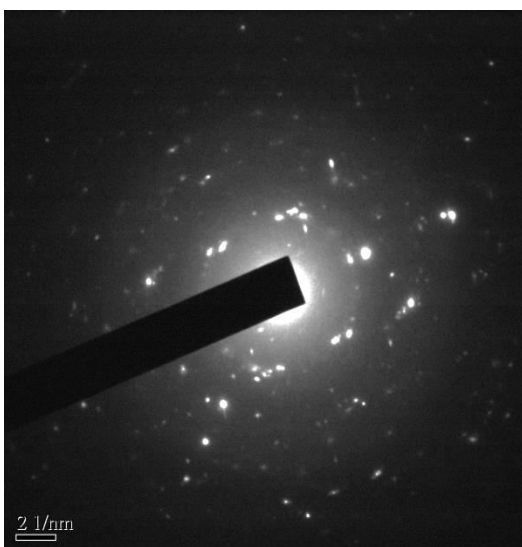


Figure.(7d).Transmission electron microscopic image of zinc nanoparticles (scattering beam).

The particle size, and shape of zinc nanoparticles were studied using scanning electron microscope, and transmission electron microscope. Fig.6 shows the scanning electron micrograph of zinc nanoparticles. Fig.7a, Fig.7b, Fig.7c and Fig.7d shows the transmission electron micrographs of zinc nanoparticles. The scanning, and transmission electron microscopic studies revealed that, the synthesized zinc nanoparticles were poly-dispersed, and spherically shaped, with an average particle size of 22 nm. Fig.7d shows the transmission electron diffraction spectral image of zinc nanoparticles confirming the formation of hexagonal close packed crystalline structure.

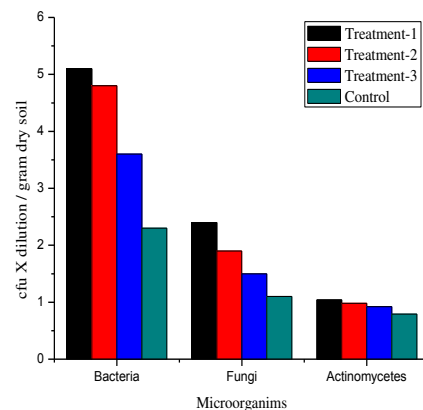


Figure.8. Estimation of soil microbial activity by applying the zinc nanoparticles.

C. Soil micro-biota

Colony count of bacteria, fungi, and actinomycetes were estimated for the three treatments (treatments 1, 2 and 3) along with the control. The bacterial population was found to be significantly higher ($2.5 - 5.0 \times 10^5 \text{ g}^{-1}$ dry soil) in nanoparticles treated samples compared to the control ($1.7 \times 10^5 \text{ g}^{-1}$ dry soil). Similarly, the nanoparticles treated samples showed higher fungi ($1.1 - 1.7 \times 10^3 \text{ g}^{-1}$ dry soil) compared to the control ($0.9 \times 10^3 \text{ g}^{-1}$ dry soil), and higher actinomycetes ($0.51 - 0.99 \times 10^3 \text{ g}^{-1}$ dry soil) compared to the control ($0.44 \times 10^3 \text{ g}^{-1}$ dry soil). The results presented in Table.I. show the number of colony forming units of bacteria, fungi and actinomycetes, with respect to the *Senna auriculata* leaves extracted zinc nanoparticles applied treatments and controls (average value of 5 replications). Table. I. revealed that, the microbial population was observed to be significantly high for the *Senna auriculata* leaves extracted zinc nanoparticles applied treatments, when compared to the controls. The estimation of soil microbial population revealed that, the leaf extracted zinc nanoparticles induced the microbial population of soil rhizosphere for the 3 treatments. Among the 3 treatments, treatment-1 showed higher values than treatments 2 and 3 as greater volume of sample was added to treatment -1 (15 ml.) than to treatment -2 (10 ml.), and to treatment - 3 (5 ml.) (Fig.8). The results were represented using the \pm Standard Deviations (SD) of five replications [25].

Table. I. Estimation of Soil micro-biota.

S.No.	Bacteria	Fungi	Actinomycetes
	10^5	10^2	10^3
(cfu x dilution g-1 dry soil)			
T1	5.1 ± 0.07	2.4 ± 0.03	1.04 ± 0.01
T2	4.8 ± 0.07	1.9 ± 0.03	0.98 ± 0.01
T3	3.6 ± 0.07	1.5 ± 0.03	0.92 ± 0.01
Control	2.3 ± 0.07	1.1 ± 0.03	0.79 ± 0.01
CD (< 5 %)	0.16	0.07	0.02

T1 = Treatment - 1, T2 = Treatment - 2 and T3 = Treatment - 3.

All values are ± SD (standard error) of 5 replications.

CD = Critical difference at 5% level.

D. Soil enzymatic activity

Acidic phosphatase activity, alkaline phosphatase activity, and dehydrogenase activity were estimated in 3 treatments (Treatments 1-3) along with control after 30 days and 60 days of sowing period. Soil enzyme activities

were found to be increased in response to all treatments against the control. Here, the green synthesized zinc nanoparticles induced the enzyme activity in all the 3 treatments compared to the control, when compared to Sunghyun et al., 2011 [26], where they have synthesized the nanoparticles following chemical route. The enzyme activities were also observed to be increased from 30 days to 60 days period of sowing. Table. II exhibits the acid phosphatase activity, alkaline phosphatase activity and dehydrogenase activity values recorded for the *Senna auriculata* leaves extracted zinc nanoparticles applied treatments and controls in two regular time intervals of 30 days and 60 days of sowing period. Table. II clearly shows that, the soil enzyme activities were high for the treatments when compared to the controls and increased from 30 days of sowing period to 60 days of sowing period.

Table. II. Effect of zinc nanoparticles on soil enzyme activities.

S.No.	Acidic phosphatase activity		Alkaline phosphatase activity		Dehydrogenase activity	
	(µg of p-nitrophenol released g-1 of soil h-1)		(µg of p-nitrophenol released g-1 of soil h-1)		(µg of TPF released g-1 of soil h-1)	
	30 days	60 days	30 days	60 days	30 days	60 days
T1	16.42 ± 0.16	18.22 ± 0.22	17.18 ± 0.18	19.65 ± 0.21	2.14 ± 0.03	7.27 ± 0.07
T2	15.82 ± 0.16	17.74 ± 0.22	15.73 ± 0.18	18.39 ± 0.21	1.30 ± 0.03	6.52 ± 0.07
T3	14.17 ± 0.16	17.37 ± 0.22	14.99 ± 0.18	16.76 ± 0.21	1.12 ± 0.03	6.43 ± 0.07
Control	13.65 ± 0.16	12.71 ± 0.22	12.85 ± 0.18	14.09 ± 0.21	1.03 ± 0.03	6.15 ± 0.07
CD (< 5 %)	0.35	0.49	0.4	0.47	0.06	0.16

The measured soil phosphatases (acid and alkaline), and dehydrogenases were cell bound. The soil phosphatase activity was inhibited by citrate phosphate buffer, which was based on the determination of p- nitrophenol (p-nitrophenol released after the incubation of oil with p-nitrophenol phosphate for 1 hour at 37 °C). Dehydrogenase activity was based on the estimation of triphenyl tetrazolium chloride, which is an artificial electron acceptor. The reduction rate of triphenyl tetrazolium chloride to triphenyl formazan in soils occurred after incubation at 30 °C for 24 hours [12].

Soil enzyme activity of different treatments showed similar mode of increase like soil microbial activity. Here, the raise in soil microbial activity was accompanied with the raise in soil enzyme activity, and thus, the soil enzyme and the soil microbial activities were correlated assays [27]. As the sample (zinc nanoparticles) was applied to the peanut pot-culture in greater volume for treatment-1 (15 ml.) compared to treatment-2 (10 ml.), and treatment-3 (5 ml.), the raise in values of enzyme activities was observed from treatment-3 to treatment-2, and from treatment-2 to treatment-1. Here, the pot-culture experiment on peanut confirmed the increase in soil enzyme activity, by the application of green synthesized zinc nanoparticles. This confirms that, the bio-reduction route is potential, non-toxic, and enhances the soil enzyme activity.

E. Influence of nanoparticles on the growth of peanut plants (physiological traits.)

The physiological growth parameters like number of leaves, height of the plant, leaf surface ratio (ratio of leaf length to leaf breadth), root length, shoot length, fresh weight of roots, dry weight of roots, fresh weight of

shoots, dry weight of shoots, and total biomass were recorded for the 3 treatments along with the control and the data is shown in Table. III. And Table. IV. From treatment-3 to treatment-1, leaf length was increased from 2.54 cm to 2.82 cm (increased by 11.02%) after 30 days of sowing period, and from 2.27 cm to 3.02 cm (33.04%) after 60 days of sowing period. Leaf breadth increased from 1.22 cm to 1.45 cm (30 days, 18.85%), and from 1.14 cm to 1.68 cm (60 days, 47.37%). Number of leaves increased from 52 to 68 (30 days, 30.77%), and from 100 to 116 (60 days, 16%), and plant height increased from 28.90 cm to 37.50 cm (30 days, 29.76%), and from 46.20 cm to 56.93 cm (60 days, 23.22%). Table. III. shows that, the leaf count, plant height and the leaf surface ratio recorded for the *Senna auriculata* leaves extracted zinc nanoparticles applied treatments and controls in two regular time intervals of 30 days and 60 days of sowing period. It was observed that the growth parameters were significantly high for the *Senna auriculata* leaves extracted zinc nanoparticles applied treatments, when compared to the controls and also increased from 30 days of sowing period to 60 days of sowing period. From treatment-3 to treatment-1, root length was increased from 12.05 cm to 13.18 cm (7.77%), shoot length increased from 34.15 cm to 43.75 cm (28.11%), fresh weight of root increased from 0.52 gm. to 0.61 gm. (17.31%), dry weight of root increased from 0.18 gm. to 0.29 gm. (61.11%), fresh weight of shoot increased from 12.14 gm. to 12.75 gm. (5.02%), dry weight of shoot increased from 4.71 gm. to 4.92 gm. (4.46%), and the total biomass was increased from 4.89 gm. to 5.21 gm. (6.54%) after 60 days of sowing period against the control. Table. IV. shows the

growth parameters of root length, shoot length, fresh weight of root, fresh weight of shoot, dry weight of root, dry weight of shoot and the total biomass of the peanut plants (*Senna auriculata* leaves extracted zinc nanoparticles applied treatments and controls) recorded at

60 days of sowing period. The *Senna auriculata* leaves extracted zinc nanoparticles applied treatments showed significantly higher values, when compared to the controls.

Table.III. Effect of zinc nanoparticles on physiological parameters of peanut plants under pot-culture experiment.

S.No.	30 days				60 days			
	Leaf length (cm/plant)	Leaf breadth (cm/plant)	No. of leaves (/plant)	Plant height (cm/plant)	Leaf length (cm/plant)	Leaf breadth (cm/plant)	No. of leaves (/plant)	Plant height (cm/plant)
T1	2.82 ± 0.03	1.45 ± 0.02	68 ± 0.81	37.50 ± 0.52	3.02 ± 0.03	1.68 ± 0.02	116 ± 1.59	56.93 ± 0.25
T2	2.61 ± 0.03	1.23 ± 0.02	64 ± 0.81	34.20 ± 0.52	2.81 ± 0.03	1.38 ± 0.02	104 ± 1.59	55.80 ± 0.25
T3	2.54 ± 0.03	1.22 ± 0.02	52 ± 0.81	28.90 ± 0.52	2.27 ± 0.03	1.27 ± 0.02	100 ± 1.59	46.20 ± 0.25
Control	1.98 ± 0.03	1.07 ± 0.02	42 ± 0.81	18.30 ± 0.52	2.25 ± 0.03	1.19 ± 0.02	61 ± 1.59	18.83 ± 0.25
CD (<5%)	0.07	0.03	1.76	1.13	0.07	0.04	3.47	0.55

Table. IV. Effect of zinc nanoparticles on root and shoot length, fresh and dry weight of roots and shoots and total biomass.

S.No	Root length (cm)	Shoot length (cm)	Shoot weight		Root weight		Total biomass (gm.)
			Fresh weight (gm.)	Dry weight (gm.)	Fresh weight (gm.)	Dry weight (gm.)	
T-1	13.18 ± 0.04	43.75 ± 0.21	12.75 ± 0.38	4.92 ± 0.15	0.61 ± 0.02	0.29 ± 0.01	5.21 ± 0.05
T-2	12.23 ± 0.04	43.57 ± 0.21	12.38 ± 0.38	4.75 ± 0.15	0.57 ± 0.02	0.22 ± 0.01	4.97 ± 0.05
T-3	12.05 ± 0.04	34.15 ± 0.21	12.14 ± 0.38	4.71 ± 0.15	0.52 ± 0.02	0.18 ± 0.01	4.89 ± 0.05
Control	8.12 ± 0.04	10.71 ± 0.21	10.98 ± 0.38	4.41 ± 0.15	0.47 ± 0.02	0.11 ± 0.01	4.52 ± 0.05
CD (< 5 %)	0.09	0.46	0.84	0.32	0.04	0.03	0.12

The physiological growth parameters were observed to be increased from treatment – 3 to treatment -1 against the control. Among the three treatments, treatment-1 showed higher values for all the growth parameters against the control because for treatment-1, greater volume of sample (15 ml.) was applied when compared to treatment-2 (10 ml.), and treatment-3 (5 ml.). The measured physiological traits concluded that the zinc nanoparticles (treatments.) induced the growth of the peanut plants compared to the control, and increased from 30 days to 60 days of sowing period.

IV. CONCLUSION

Bio-reduction method is a quite interesting field of nano-biotechnology for the synthesis of non-toxic, eco-friendly, and stable metal nanoparticles. In the current study, zinc nanoparticles have been successfully synthesized using *Senna auriculata* leaf extract following green synthesis route. The optical absorption edge of zinc nanoparticles was observed at a wavelength of 328 nm. The zeta potential was measured as 80 mV with average particle size of 22 nm. The X-ray diffraction pattern was in agreement to previous reports, corresponding to the hexagonal closely packed structure of zinc. The zinc content was estimated as 344 ppm (0.005 Molar). The microscopy studies revealed spherical shaped and poly-dispersed zinc nanoparticles with an average size of 22 nm. The infrared spectroscopic studies showed broad peaks and strong bands for aldehydes, ketones, carboxylic acids, nitriles, esters, aromatic amines, and alkyl halides. The zinc nanoparticles (applied in 3 treatments) induced soil microbial population, soil enzyme activities, and physiological growth parameters of peanut plants, when applied to the pot-culture of peanut, and among the three

treatments, treatment-1 showed higher values. Thus, the green synthesis is a simple, cost effective, and industrially viable technique for the large-scale preparation of zinc nanoparticles. The application of green synthesized zinc nanoparticles to the agricultural crop fields may yield good results.

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