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Research Article

Green Synthesis of Zinc Oxide Nanoparticles from *Coriandrum sativum* and Their Use as Fertilizer on Bengal Gram, Turkish Gram, and Green Gram Plant Growth

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Plant growth and development rely on various factors, including mineral nutrients. Some are macronutrients like nitrogen, phosphorus, and potassium, whereas some are micronutrients like iron, magnesium, zinc, and a few vitamins. This experimental attempt was to check the stimulatory effect of zinc nanoparticles on pulse plant growth. The study was conducted on the green synthesis of zinc oxide nanoparticles using *Coriandrum sativum* leaves extract. The characterization of zinc oxide nanoparticles was studied using the X-ray diffraction (XRD), scanning electron microscope (SEM), and transmission electron microscope technique (TEM). The effect of zinc oxide nanoparticles as a fertilizer on pulses plant (Bengal gram, Turkish gram, and green grams) was studied in vitro. The seed germination rate, length of root and shoot, fresh weight, dry weight, and protein and chlorophyll content were measured in different media for assessment of zinc oxide nanoparticle's growth stimulatory effects. The green synthesis of zinc oxide nanoparticles was confirmed with a size around 100 nm by transmission microscope technique. The germination rate of plants was 100% in MS media and MS media + nanoparticles. The present study found that the root length, shoot length, and weight were higher in MS media + nanoparticles followed by MS media, MS media only with nanoparticles, and MS media without zinc, respectively. It is found that the zinc oxide nanoparticles support seed germination and plant growth and also increase the protein and chlorophyll content. Significantly enhanced growth and development were evident in green gram and Turkish gram compared to that in Bengal gram in media treated with zinc oxide nanoparticles. The protein estimation results showed that the content was higher after 7 days in plants of Bengal gram (1.23 mg/ml), Turkish gram (1.19 mg/ml), and green gram (1.26 mg/ml) than that in roots and shoots. The application of MS media + ZnO nanoparticles results showed that chlorophyll content 12.6 mg/l was observed in other applications in the plant's seedlings. In contrast, the absence of zinc decreases the germination rate, plant growth, chlorophyll, and protein content. This study confirms that the green synthesis of zinc oxide nanoparticles assessed from *Coriandrum sativum* leaves holds implication and should function as an active biofertilizer.

1. Introduction

Nanotechnology is the utmost progressive field in the 21st century. Nanoparticles gained considerable attraction due to their unusual and engaging properties with various applications [1]. Nanoparticles may be prepared chemically, physically, or by a biological method. The results of 190 field trials in 15 countries worldwide showed that Zn deficiency was the foremost commonly occurring micronutrient deficiency and therefore the fourth most significant yield-limiting nutrient after nitrogen, phosphorus, and potassium [2]. Zinc deficiency, occurring in the form of chlorosis and white necrotic spots on leaves, reduces growth and inhibits photosynthesis in many plant species [3, 4]. Among the micronutrients, Zn affects the susceptibility of vegetation via drought stress. Zinc oxide nanofertilizer is the virtuous remedy of many environmental problems like loss of fertilizer, chemical leaching, pollution, and so on. The global production of nanoparticles (NPs) has been increasing tremendously. They are used in various disciplines, for example, optics, electronics, energy generation, materials science, medicine, and life sciences [4, 5].

The impact of engineered nanoparticles on the plant relies on various factors like composition of nanoparticles, concentration, size, other chemical and physical properties, and plant species [6]. The improvement of food sources and crops is receiving more attention in recent years due to high population growth; subsequently, demand for natural products for food, medicine, energy, and other biotechnological aspects is increasing [7, 8].

Nanotechnology incorporates a great potential to switch conventional agricultural practices. Nanoparticle technology is an emerging field with multiple potentialities and its applications [9]. The maximum agrochemicals applied to the crops are lost and do not reach the target spot because of numerous factors together with leaching, drifting, hydrolysis, photolysis, and microbial degradation. Nanoparticles provide a good means to distribute the fertilizers in a very controlled fashion with high site specificity [1]. Nanoparticles exhibit unique physicochemical properties and can have many unknown biological effects in agriculture [10].

Zinc is one of the essential micronutrients for the plant. Zinc is the major component of enzymes or cofactor of enzymes. Zinc oxide nanoparticles (ZnO NPs) are important for chlorophyll production, fertilization, pollen function, and germination [11].

Zinc oxide nanoparticles can be synthesized by various physical, chemical, and biological methods. The literature states that the physical process includes the use of high vacuum in processes like pulsed laser deposition, MBE (molecular beam epitaxy), and thermal evaporation [12, 13], whereas different chemical methods used for the synthesis of ZnO NPs are chemical microemulsion, wet chemical, spray pyrolysis, electrodeposition [1, 12], chemical and direct precipitation, and microwave-assisted combustion [1, 12, 14]. Among those, the biological methods are safe and eco-friendly [1]. They do not have any negative effect on the environment. ZnO NPs are an inorganic compound appearing as a white powder and can be synthesized by both chemical methods (precipitation method, vapor transport method, microwave solvothermal, and hydrothermal process) and biological methods using different plants extracts [1, 4, 15–17]. In green synthesis, the zinc oxide nanoparticles are synthesized using plant extract, fungi, bacteria, and microbes. The green synthesis of the nanoparticles reduces the chance of pollution, and it does not produce waste byproducts, which is hazardous to the environment [1, 18].

Zinc oxide nanoparticles have notable optical, physical, and antimicrobial properties and so have great potential to boost agriculture. ZnO is currently listed as a "generally recognized as safe (GRAS)" material by the Food and Drug Administration and used as an additive [19]. The biogenic fabrication of the nanoscale particles is preferable to physical and chemical processes due to its properties of energy efficiency, ease of scaling-up, low cost, low toxicity, and biocompatibility. Therefore, biogenic nanoparticles can be safely exploited in many biological applications [20, 21].

Green synthesis techniques make the utilization of rather pollutant-free chemicals for the synthesis of nanostructures. It holds the utilization of eco-friendly and safe solvents like water and natural extracts [1]. Though physical and chemical methods are speedy and easier for nanoparticles synthesis, the biogenic technique is healthier and eco-friendly [22, 23]. The most significant part of the green synthesis of nanoparticles is that the active biological compound present in the plant parts, such as enzyme itself, acts as a reducing and capping agent, thus reducing the overall cost of the synthesis process compared to the physical and chemical process of extraction and synthesis of nanoparticles [18, 24]. Plant parts like roots, leaves, stems, seeds, and fruits have been utilized for nanoparticles synthesis as their extract is rich in phytochemicals and acts as both reducing and stabilization agent [13]. Green synthesis of zinc oxide and iron oxide nanoparticles using *Sesbania grandiflora* leaf extract provides an effective route for an eco-friendly method of synthesis of nanoparticles [25].

Coriander, the generic name of herb *Coriandrum sativum* generally known as Dhania in India, has been employed in the current study. It is the herb. The furthermost important role of these natural plant biomolecules like protein and enzymes tangled within the bioreduction of metal salts throughout the nanoparticle synthesis. In the present study, zinc oxide nanoparticles were synthesized by means of the leaves extract of the plant *Coriandrum sativum* [26, 27]. Zinc oxide nanoparticles are also prepared by using a plant like *Calotropis procera* (Maddar) [28], *Camellia sinensis* [29], *Acalypha indica*, Milky Latex of *Calotropis procera*, and herb *Coriandrum sativum* [30]. Rico et al. [31] and Peralta-Videa et al. [32] are the pioneers of studies dealing with the effects of nanoparticles on vascular plants. The most common monitored parameters comprise the germination rate and root/stem growth rate. Newly, the number of leaves [33] and chlorophyll content [34, 35] of exposed plants were involved as new monitored parameters for phytotoxicity tests [36].

The effect of zinc oxide nanoparticles was seen on the rice and wheat in the study, where the biomass of wheat was decreased by the treatment of nanoparticles. However, the toxic effect of zinc oxide nanoparticles was observed on rice [37]. The nanoparticles move to the plant by various means of root uptake and cuticular translocations [38]. The zinc oxide nanoparticles reduced the root growth of rice [39]. Another study observed that zinc oxide nanoparticles translocated to the upper parts of the plant. The effect of zinc oxide nanoparticles was also seen in the soybean plant. The root elongation was observed at 500 mg/L zinc oxide nanoparticle concentration [40]. A research study illustrated that the five nanoparticles (multiwalled carbon nanotubes (MWCNTs), Ag, Cu, ZnO, and Si) were tested on *Cucurbita pepo* in suspensions up to 1000 mg/L. This study found different effects from the NPS and their counterparts concerning seed germination, root elongation, and biomass [9, 41]. Another study illustrated that the effects of biogenic AgNPs application at different concentrations on seed germination, seedling growth, oxidative stress status, and antioxidant enzyme activities were studied and found that the applications of AgNPs significantly improved seed germination and growth of *Z. mays* L., *T. foenum-graecum* L., and *A. cepa* [42].

Stress caused by cadmium (Cd) and the toxicity of DDT have a direct effect on the growth and yield of the crop plants. Ultimately the greater uptake and accumulation of DDT by edible plants affect human health by contaminating the food chain. However, this study also confirmed that an exogenously applied benzene dicarboxylic acid (Bd) also successfully improved the antioxidant system and physiochemical parameters of plants in *Brassica alboglabra* [43]. A research study revealed that Cd stress decreased plant growth attributes like root diameter, root length, root weight, shoot length, leaves fresh weight, and leaves dry weight. Nonetheless, AgNPs and IAA (indole acetic acid) mitigated Cd stress by detoxifying reactive oxygen species (ROS). However, the application of AgNPs and IAA boosted plant growth through reducing the level of malondialdehyde (MDA) [44]. Another investigation revealed that Si and Fe NPs have enormous potential to mitigate Cd-induced phytotoxicity by declining Cd uptake and improving growth attributes of plant *Phaseolus lunatus* if applied in combination [45]. There is another study that found that arsenic (As) stress curtailed root and shoot length, chlorophyll (Chl.) content, and net photosynthetic rate in *Vicia faba* L. seedlings. However, the study concluded that As stress alleviation was credited to reduce As uptake in faba beans seedlings treated with a synergistic application of ZnO NPs and potassium silicate (K^+) [46].

Zinc oxide nanoparticles (ZnO NPs) are capable of making different abiotic stresses less difficult when applied to plants. The individual application of ZnO NPs and *B. fortis* IAGS 223 slightly enhanced the growth characteristics, including photosynthetic pigments, gas exchange parameters, and antioxidative system of *Cucumis melo* seedlings under Cd stress [47].

The zinc oxide nanoparticles can play a dynamic role in the germination and growth of the plant. The nanoparticles affect negatively if their concentration and time exceed. The effects of nanoparticles on different plant species can differ significantly with plant growth stages and method and duration of exposure and also depend on nanoparticle size, concentration, chemical composition, surface structure, solubility, shape, and aggregation [38, 48]. Another study showed the effect of zinc oxide nanoparticles on plants like radish, rape, ryegrass, lettuce, corn, and cucumber was studied, which showed that the germination was not fully affected by the zinc nanoparticles [1].

Hence, the study was commenced to green synthesize zinc oxide nanoparticles using *Coriandrum sativum* or coriander leaves of variety Suruchi (LCC-234) and their use as a fertilizer and for growth stimulatory effects on different pulses like Bengal gram, Turkish gram, and green gram plant growth.

2. Materials and Methods

2.1. Study Area. The present study was conducted in Pune city of India, which is situated at approximately 18°32″ north latitude and 73°51″ east longitude. The city's total area is 15.642 sq. km. Pune lies on the western margin of the Deccan plateau, at an altitude of 560 m (1,840 ft) above sea level. Pune has a tropical wet and dry climate, closely bordering upon a hot semiarid climate with average temperatures ranging between 20 and 28°C.

2.2. Required Materials for Experiment. Requirements for green synthesis of ZnO NPs are as follows: coriander leaves or plant parts (Suruchi LCC-234), double distilled water, mortar and pestle, Whatman filter paper (no. 42), 0.02M zinc acetate solution, magnetic stirrer (Q19, REMI 5-MLH Magnetic Stirrers, India), centrifuge (Remi R-4C Compact Centrifuge India), oven (U-Tech SSI-107, Star Scientific, India), X-ray diffraction (XRD), scanning electron microscope (SEM), and transmission electron microscope technique (TEM). Requirements for plant tissue culture (PTC) are as follows: seed of three plants (Bengal gram, green gram, and Turkish gram), sterile culture bottles, autoclave, Murashige and Skoog (MS) media, sterile H_2O, 2% $HgCl_2$, and 70% alcohol. Requirements for protein estimation are as follows: phosphate buffer, bovine serum albumin (BSA); solution A reagent, solution B reagent, and colorimeter. All the reagents of analytical purity grade were used and are purchased from commercial sources.

Table 1 indicates the composition of MS media and other media preparations used for plant tissue culture (PTC) in the current experimental study.

2.3. Green Synthesis of Zinc Oxide Nanoparticles. Most generally, the practical method of sample preparation of ZnO nanoparticles from leaves or flowers is where the plant parts are washed thoroughly in running tap water and then sterilized using double distilled water. Similarly, in the present study, the fresh leaves of coriander were washed with distilled water. After washing, the leaves were kept for drying at room temperature, followed by weighing and then crushing it using a mortar and pestle and grinding to organize aqueous extract. 10 grams of coriander leaves was measured and added to 5 ml of distilled water to obtain the extract. Then, the leaf extract was filtered through Whatman filter paper (no. 42) and bacterial filter (0.2 microns) to get rid of contamination. For this experiment, 50 ml of 0.02M zinc acetate solution was prepared. Aqueous leaf extract of 0.5 ml was mixed with 50 ml of zinc acetate solution by constant stirring. Then 2M NaOH was added to the mixture to keep up the pH 12. The mixture was kept for stirring for two hours during a magnetic stirrer. After stirring, the white mixture was subjected to centrifuge at 4000 rpm for five minutes. Centrifugation results in a change of colour of the mixture to pale white, (Figure 1) which is usually an indication of synthesized nanoparticles. Subsequently, the pale white precipitate was observed and was washed with distilled water followed by ethanol to get rid of any impurities from precipitate. The precipitate was collected and was dried in an oven at 50°C for half-hour as an incubation period. The pale white powder of ZnO nanoparticles was obtained. Further, this fine powder was used for characterization with X-ray diffraction (XRD), scanning electron microscope (SEM), and transmission electron microscope technique (TEM).

Table 1: Composition of MS media.

Macronutrients		Micronutrient		Vitamins		MS media	
Compound	Amount (mg/l)	Compound	Amount (mg/l)	Nicotinic acid	0.5	Agar	8 g/l
NH_4NO_3	1650	H_3BO_3	6.2	Thiamine HCL	0.1	Sucrose	30 mg/l
KNO_3	1900	$MnSO_4{\cdot}4H_2O$	22.3	Pyridoxine HCL	0.5		
$MgSO_4{\cdot}7H_2O$	370	$ZnSO_4{\cdot}7H_2O$	8.6	i-Inositol	100		
KH_2PO_4	170	KI	0.83	Glycine	2		
$CaCl_2{\cdot}2H_2O$	440	$Na_2MoO_4{\cdot}2H_2O$	0.25				
		$CuSO_4{\cdot}5H_2O$	0.025				
		$CoCl_2{\cdot}6H_2O$	0.025				
		Fe·EDTA	40				

2.4. Characterization of Green Synthesized ZnO Nanoparticles

2.4.1. X-Ray Diffraction Analysis (XRD). The formation and quality of compounds were investigated by the X-ray diffraction technique. The sample collected from the green synthesis of ZnO NPs using coriander extract was analysed using Single Crystal X-Ray Diffractometer (Bruker 9XS D8 Advance Venture model, German). X-ray diffraction (XRD) is a novel method that is employed for the determination of crystallography of the compound of interest in this experiment. In this method, scanning was done in the region of 2θ from 20° to 80°.

2.4.2. Scanning Electron Microscopy (SEM). The sample was then analysed by FESEM: FEI (Field Electron and Ion Company, FEI, Japan) Nova NanoSEM 450 scanning electron microscopy (SEM), which is a nondistractive technique. Thin-film of green synthesized ZnO NPs powder sample was prepared on carbon counted tape by adhering small amount of dried fine powder of sample on the grid; excess sample was removed with the help of blotting paper. The film on the SEM grid was allowed to dry by putting it under a mercury lamp for 5 min. The SEM analysis was used to determine the surface structure of green synthesized ZnO nanoparticles [18].

2.4.3. Transmission Electron Microscopy (TEM). Further, the sample was also analysed on transmission electron microscopy (TEM) by using 100 keV or higher (up to 1 MeV) by instrument Tecnai G2 U-Twin 200 kV Lab 6 FEI Netherlands). During this analysis, the sample was prepared in ethanol and was sonicated for 15–20 minutes to know the shape of green synthesized ZnO nanoparticles.

2.4.4. Method for Plant Tissue Culture (PTC). Moreover, for estimation of different pulses seeds germination growth and phyto physical characteristics, four different sets of autoclaved media were prepared like MS media, MS media without zinc, MS media with nanoparticles, and MS media with zinc and nanoparticles, respectively. The concentration of zinc oxide nanoparticles was kept constant as per MS media, that is, 8.6 mg/l. The seeds of pulses were superficially sterilized with sterile 2% $HgCl_2$ and sterile distilled water. Then the 5 seeds were inoculated in each medium and kept in a plant tissue culture lab for 7 and 14 days for observations for germination. After respective 7 and 14 days, a few seedlings were harvested from each of the media (Figure 2). Shoot length (SL, the distance from the leaf base to the leaf tip) and root length (RL, the distance from the root base to the root tip) were measured by measuring scale. As well, the fresh weight and dry weight of each germinated seed were weighted by the analytical balance in laboratory. The germination percentage rate was calculated based on the following formula: germination (%) = number of germinated seeds/numbers of inoculated seeds × 100%.

In this manner, the germination rate, root length, and shoot length were estimated. The protein content within the whole plant, root, and shoot was also estimated.

2.5. Method for Protein Estimation. Sample preparation for protein estimation was done after 7 and 14 days as few pulses' plants were removed from different media. The entire plant, root, and shoot were crushed in 1 ml phosphate buffer, respectively. The quality set of bovine serum albumin (BSA) was prepared for protein estimation. A test tube with distilled water was referred to as blank. The reaction set was prepared by 1 ml of sample +4.5 ml of reagent I +4.5 ml of reagent II. The set was incubated at room temperature for half-hour. Then the absorbance was engaged at 660 nm on a UV-visible spectrophotometer.

2.6. Method for Chlorophyll Estimation. The extract of fresh leaves was homogenized with 80% acetone. Calcium carbonate was added to stabilize the chlorophyll content. Then it was filtered through Whatman filter paper till the residue became colourless. The filtrate was made up to 10 ml, and readings were taken on UV/vis spectrophotometer at 663 nm and 645 nm, respectively.

Customarily, we have estimated this experiment with 3 replicates; each replicate has like 10 seedlings/sample or treatment (so total number of samples $n = 30$/treatment). Then we average the results of these 10 samples to get 1 number/replicate and use these 3 numbers/treatments to perform statistical analysis.

3. Results

3.1. Colour Change. Zinc was confirmed by colour change of the reaction mixture from pale yellow to pale white (Figure 1).

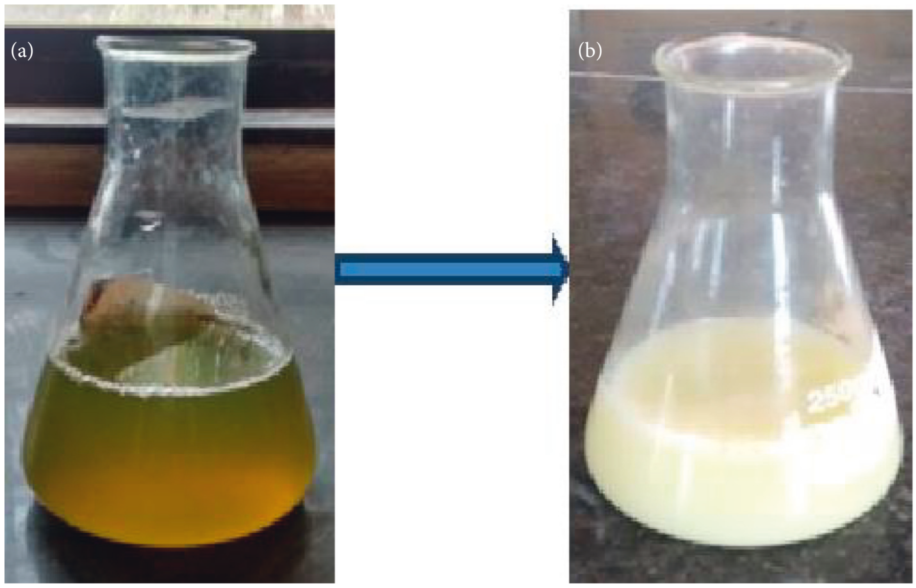

Figure 1: Synthesis of nanoparticles. (a) Leaf's extract + zinc acetate. (b) Leaf's extract + zinc acetate after 2 hrs.

Figure 2: Inoculation of pulses seeds on 1st day and Growth after 14th days.

3.2. Synthesis of Zinc Oxide Nanoparticles: XRD, SEM, and TEM. The biological approach for the formation of ZnO nanoparticles using Dhania (*Coriandrum sativum*) at room temperature was recorded. The X-ray diffraction (XRD) pattern discloses the formation of ZnO nanoparticles, which shows crystallinity structure with no impurity peaks present. As illustrated in Figure 3, the XRD pattern of ZnO nanoparticles powder embedded in coriander matrix synthesized by coprecipitation method.

The biological method of synthesis of nanoparticles is more efficient, eco-friendly, and simple to handle. The XRD result shows the utmost peak at a specific wavelength for every substance. The precise peak is a typical characteristic of that substance. For zinc oxide nanoparticles, the maximum peak is at 2-theta values 31°, 34°, and 36°. The scattered X-rays constructively interfere with each other, and this interference was calculated using Bragg's Law or the Debye-Scherrer equation to determine various characteristics of the crystalline material, where D is the crystal size, λ is the wavelength of X-ray, θ is the Braggs angle in radians, and β is the full width at half maximum of the peak in radians. The scale size of zinc oxide nanoparticles was calculated by the following formula [17, 29, 49, 50]:

$$D = k * \frac{\lambda}{\beta \cos \theta}. \quad (1)$$

The size of zinc oxide nanoparticles crystallites was detected within the range of 78 to 84 nm.

SEM was employed to analyse the structure of zinc oxide nanoparticles that were formed from coriander leaf extracts. SEM images have shown individual ZnO nanoparticles as well as a number of aggregates. Figure 4 shows the SEM image of the particles which are nanosized in nature as embedded in the sample treated within coriander leaves extract. The SEM result shows the flex at different magnifications as depicted within Figure 4.

A TEM image was recorded by liquifying the as-synthesized powder sample in ethanol and so placed a drop ethanolic solution on the surface of the copper grid. As indicated in Figure 5, TEM image shows ZnO nanoparticles with an interplanar distance of 0.31 nm. TEM pattern exhibits that those nanoparticles have a size of 100 nm and are rod-shaped and polycrystalline in nature.

After characterization through XRD, SEM, and TEM, the effect of those ZnO nanoparticles was seen on the plants like Bengal gram, Turkish gram, and green gram. The seed

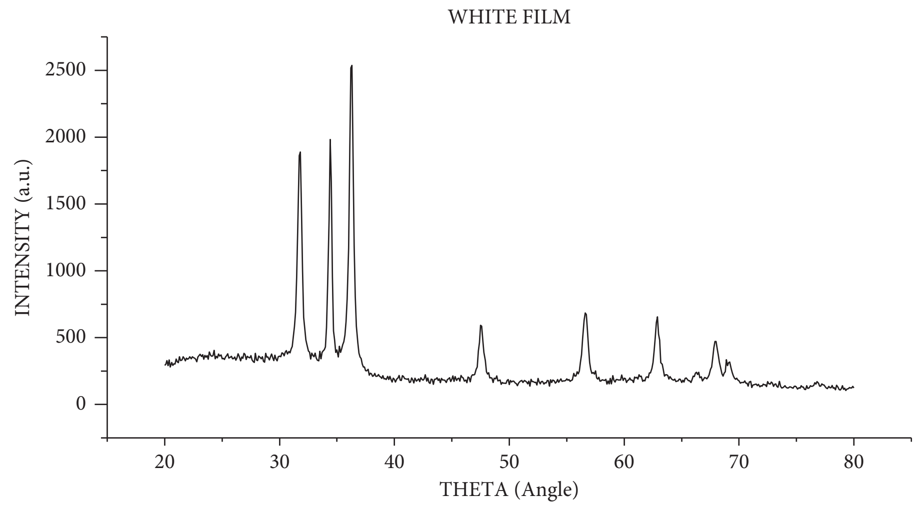

Figure 3: XRD image showing typical peak for zinc nanoparticles.

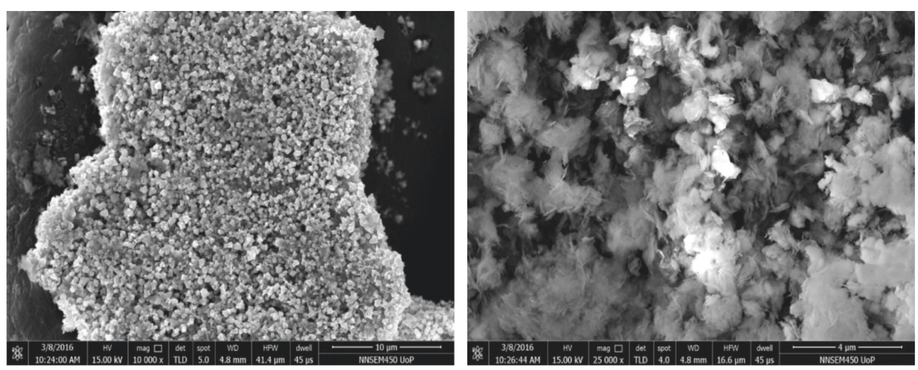

Figure 4: SEM images at different magnifications.

germination rate, length of root and shoot, fresh weight, dry weight and protein, and chlorophyll content were assessed.

3.3. Germination Rate of Plants. The germination rate of plants was 100% in MS media and MS media + nanoparticles and 80% in MS media only with nanoparticles and 50% in MS media without zinc (Table 2).

3.4. Length of Plant Parts. The results from Table 3 indicate that the ZnO nanoparticles were taken up by Bengal gram and Turkish gram roots with a very low translocation to the shoots, whereas in green gram, the ZnO NPs were taken up by shoots, and a very low amount was utilized in roots.

3.5. Weight of Plants. Tables 3 and 4 results showed that the root, shoot length, and weight were higher in MS media + nanoparticles followed by MS media, MS media only with nanoparticles, and MS media without zinc, respectively. Significantly enhanced growth and development were evident in green gram and Turkish gram compared to those in Bengal gram in media treated with ZnO nanoparticles (Tables 3 and 4).

3.6. Protein Estimation. Figures 6–9 show that the protein content of the whole plant, root, and shoot was estimated separately. The protein content was higher in pulse plant than that in shoot and root (Figures 6–9).

3.7. Chlorophyll Content Estimation. Figure 10 indicates that less chlorophyll content was present within the media without zinc, whereas high content of chlorophyll was present in media + nanoparticles. The overall protein content and chlorophyll content are lower in plant from the media without zinc and higher within the plant from the MS media + nanoparticles (Figures 6–10).

4. Discussion

Zinc (Zn) is one of the utmost important and essential trace elements for plants, although its requirement is small in amounts; Zn deficiencies in plants are common throughout the globe [51]. These deficiencies within the crop are treated with the addition of zinc oxide nanoparticles [52], which makes it one among the encouraging fertilizers and potential substitutes to traditional water-soluble Zn fertilizers, which are easily lost by raining runoff and leaching [53, 54]. The low concentration of

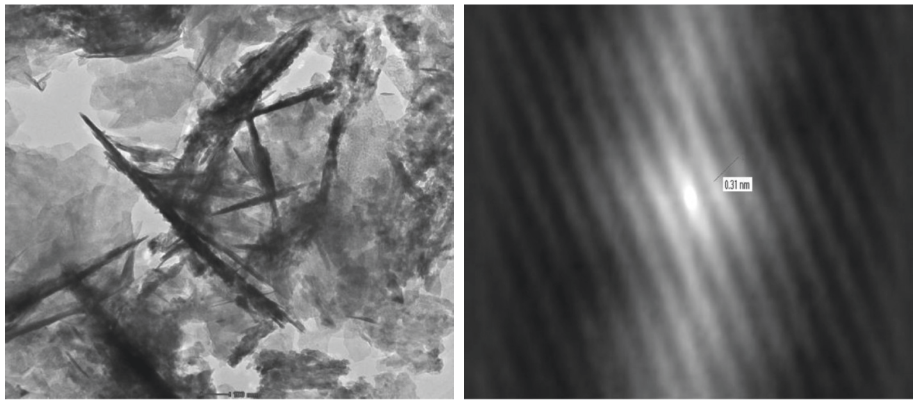

Figure 5: TEM images showing rod-shaped nanoparticles.

Table 2: Germination rate after 7 and 14 days.

Media	Seed name	Seeds planted (no.)	Seeds germinated (no.)	Germination percentage (%)
Germination rate after 7 days, the 1st set				
MS media	Bengal gram	5	5	100
	Turkish gram	5	4	80
MS media without zinc	Bengal gram	5	—	—
	Turkish gram	5	1	20
MS media only with nanoparticles	Bengal gram	5	—	—
	Turkish gram	5	2	40
MS media + Zn nanoparticles	Bengal gram	5	4	80
	Turkish gram	5	4	80
Germination rate after 7 days, the 2nd set				
MS media	Bengal gram	5	5	100
	Green gram	5	5	100
MS media without zinc	Bengal gram	5	3	60
	Green gram	5	4	80
MS media only with nanoparticles	Bengal gram	5	4	80
	Green gram	5	5	100
MS media + Zn nanoparticles	Bengal gram	5	5	100
	Green gram	5	5	100
Germination rate after 14 days, the 1st set				
MS media	Bengal gram	5	5	100
	Turkish gram	5	3	60
MS media without zinc	Bengal gram	5	2	40
	Turkish gram	5	—	—
MS media only with nanoparticles	Bengal gram	5	3	60
	Turkish gram	5	—	—
MS media + Zn nanoparticles	Bengal gram	5	5	100
	Turkish gram	5	4	80
Germination rate after 14 days, the 2nd set				
MS media	Bengal gram	5	5	100
	Green gram	5	5	100
MS media without zinc	Bengal gram	5	3	60
	Green gram	5	3	60
MS media only with nanoparticles	Bengal gram	5	5	100
	Green gram	5	5	100
MS media + Zn nanoparticles	Bengal gram	5	5	100
	Green gram	5	5	100

ZnO nanoparticles is effective for crops for improvements in growth and development [55], without disturbing the soil microbes like nitrogen-fixing microbes and methane-oxidizing microbes because of higher levels of ZnO NPs [56].

The nanofertilizers are effectively utilized in ensuring efficient macronutrients in potatoes and barley [57]. It is found that they can increase crop production by 6 to 17% [57]. Nanofertilizers such as nanoparticles of zinc oxide, silicon dioxide, and titanium oxide are shown innovative

Table 3: Average of root length and shoot length measured in several media.

Set	Seeds name	Plant part	MS media (cm)	MS media without zinc (cm)	MS media with only nanoparticles (cm)	MS media + Zn nanoparticles (cm)
1st 7th day	Bengal gram	Root	1.6	0	0	1.58
		Shoot	1	0	0	1.14
	Turkish gram	Root	0.92	0.4	0.14	4.15
		Shoot	5.75	0	0	4.92
2nd 7th day	Bengal gram	Root	1.34	0.4	2.32	1.94
		Shoot	1.31	0	1.76	1.2
	Green gram	Root	4.38	2.32	4.48	5
		Shoot	10.04	6.8	9.7	10
1st 14th day	Bengal gram	Root	1.64	0.84	0.8	2.74
		Shoot	1.02	0	0.26	2.04
	Turkish gram	Root	0.62	0	0	3.2
		Shoot	5.15	0	0	5.52
2nd 14th day	Bengal gram	Root	2.7	2.06	3.08	2.52
		Shoot	2.28	1.98	2.94	1.02
	Green gram	Root	3.7	2.5	3.38	5.9
		Shoot	8.1	6.6	13	9.5

Note. The average was calculated based on 5 seeds for each type of plant.

Table 4: Weight of plants after 7 and 14 days.

Media	Fresh weight (gm)		Dry weight (gm)	
	Bengal gram	Turkish gram	Bengal gram	Turkish gram
Weight of plant after 7 days, the 1st set				
MS media	0.42	0.09	0.22	0.02
MS media without zinc	0.41	0.09	0.21	0.02
MS media with only nanoparticles	0.39	0.10	0.25	0.04
MS media + Zn nanoparticles	0.45	0.12	0.30	0.03
Weight of plant after 7 days, the 2nd set				
MS media	0.37	0.21	0.12	0.01
MS media without zinc	0.31	0.20	0.12	0.10
MS media with only nanoparticles	0.42	0.25	0.21	0.10
MS media + Zn nanoparticles	0.47	0.28	0.21	0.17
Weight of plant after 14 days, the 1st set				
MS media	0.50	0.15	0.26	0.02
MS media without zinc	0.40	0.04	0.19	0.01
MS media with only nanoparticles	0.58	0.12	0.22	0.02
MS media + Zn nanoparticles	0.65	0.22	0.28	0.03
Weight of plant after 14 days, the 2nd set				
MS media	0.67	0.19	0.39	0.01
MS media without zinc	0.65	0.10	0.40	0.01
MS media with only nanoparticles	0.87	0.23	0.63	0.10
MS media + Zn nanoparticles	0.44	0.19	0.21	0.01

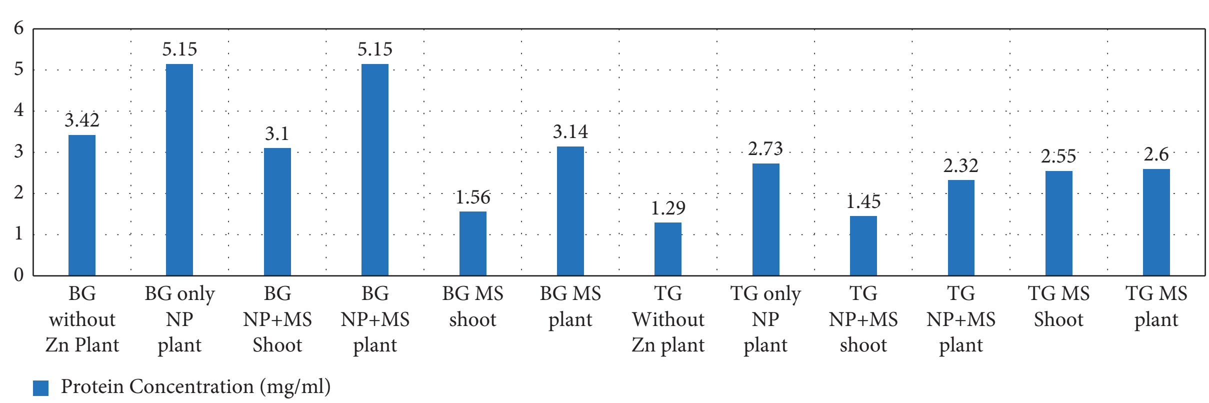

Figure 6: Protein estimation after 7 days, the 1st set. BG: Bengal gram, TG: Turkish gram, and GG: green gram.

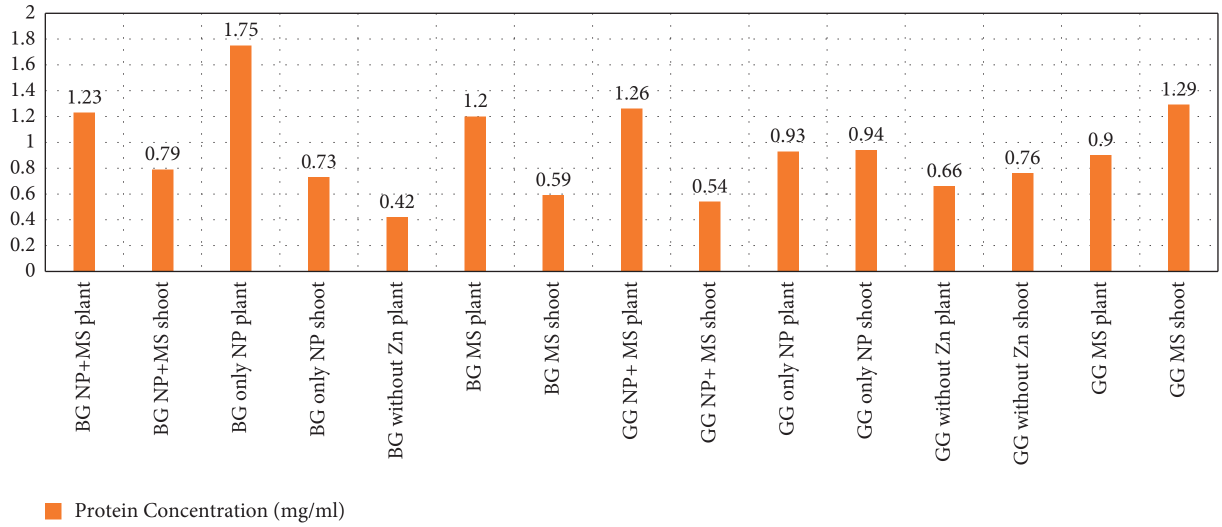

Figure 7: Protein estimation after 7 days, the 2nd set. BG: Bengal gram and GG: green gram.

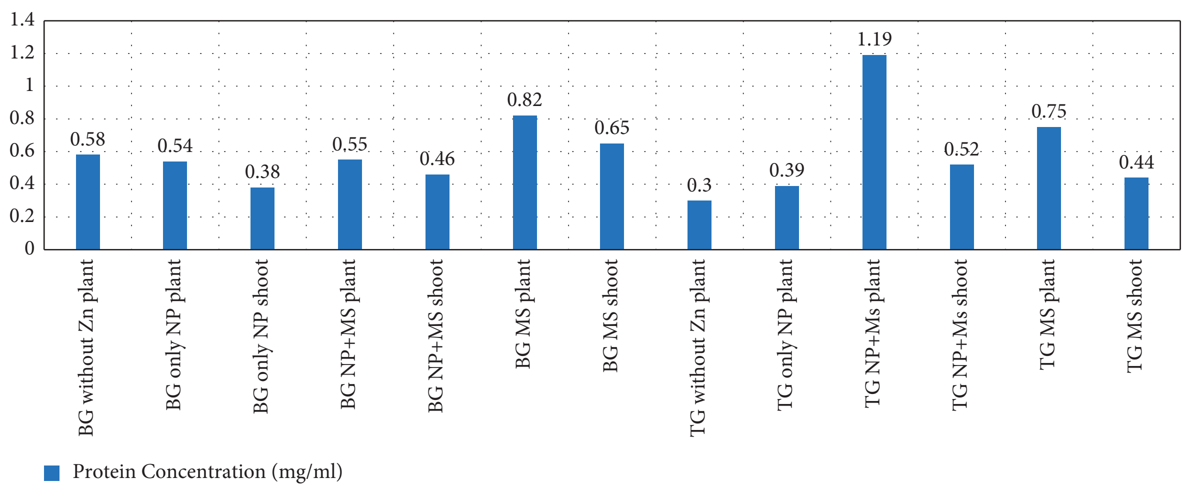

Figure 8: Protein estimation after 14 days, the 1st set. BG: Bengal gram and TG: Turkish gram.

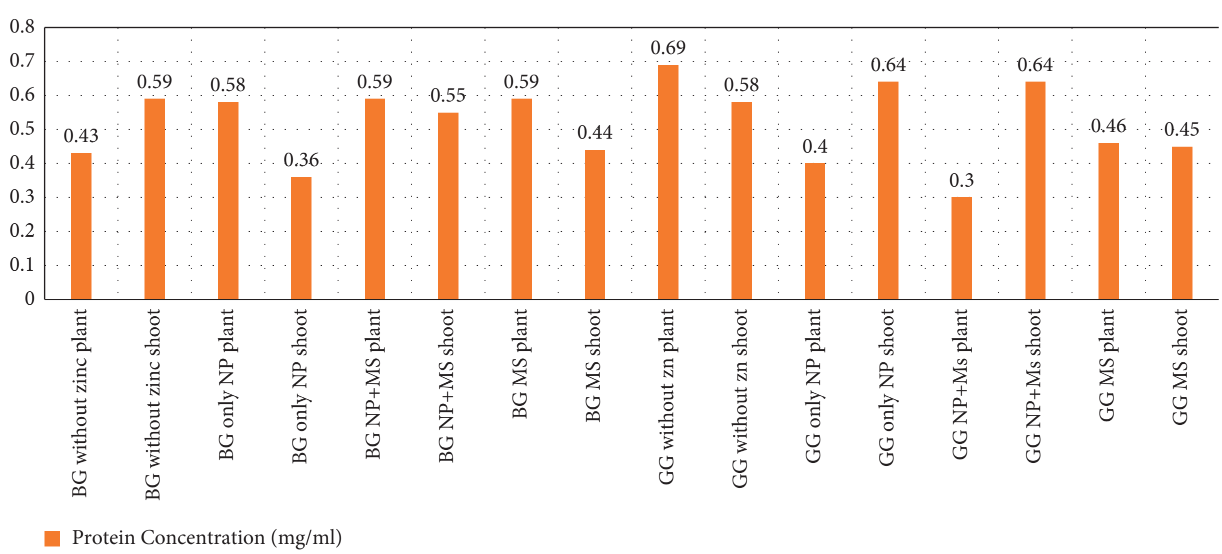

Figure 9: Protein estimation after 14 days, the 2nd set. BG: Bengal gram and GG: green gram.

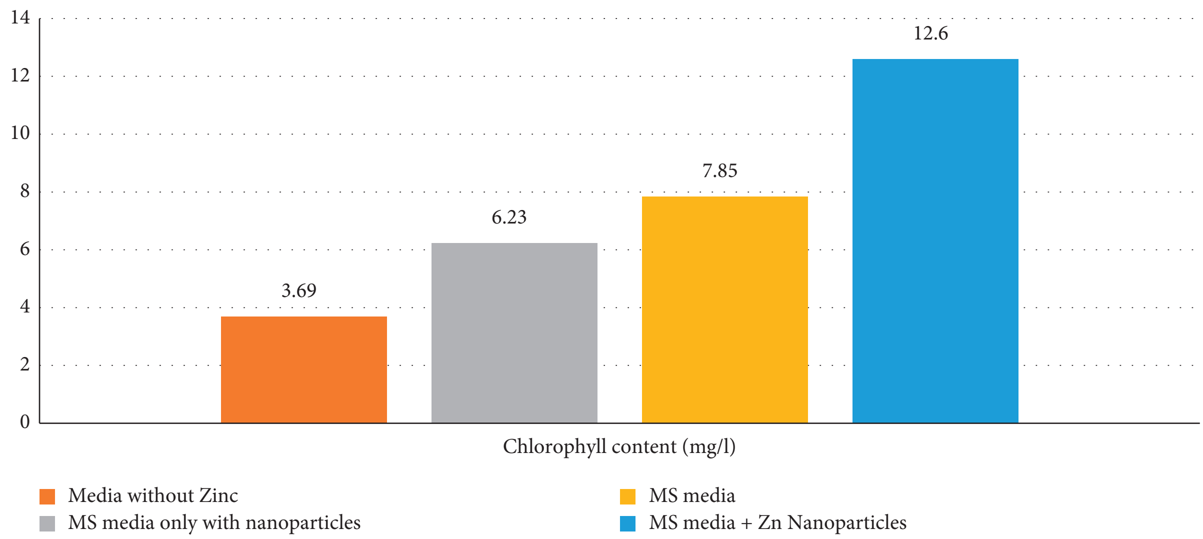

Figure 10: Chlorophyll content in several media.

performance in improving seed germination, length of shoot, and even healthy seedlings [58]. However, the nanofertilizer formulations needed consequential product performance characteristics such as stability, time-controlled release, and reduced toxicity [59].

The present study tried to determine the impact of ZnO nanoparticles on seed germination, plant growth, chlorophyll production, and protein estimation in pulses grown in media treated with ZnO nanoparticles. The present study's SEM result coincides with results already reported, which shows the formation of spherical-shaped zinc oxide nanoparticles and aggregated molecules in *Calotropis* leaf extract [60]. Another research investigated green synthesized AgNPs characterized by XRD, TEM, and FTIR analysis findings demonstrated the successful green synthesis of crystalline, spherical Ag-NPs with a particle size of 13–40 nm [21]. The toxicity of rod-shaped particles is greater than that of spherical-shaped particles. Previous studies carried out by various investigators showed that spherical nanoparticles are highly stable thermodynamically due to preservation by a sufficient number of biomolecules [61, 62]. Another research investigation showed the influence of ZnO NPs with the size of 20 nm and at a concentration of 0, 10, 20, 30, and 40 mgL^{-1} on seed germination in onion (*Allium cepa* L.). The ZnO NPs promoted seed germination at lower concentrations but reduced it at higher concentrations [4, 63].

The nano-based oxides of a few foliar fertilizers such as manganese, iron, and zinc are reported effective in squash (*Cucurbita pepo* L.) to boost vegetative characteristics, level of chlorophyll pigments, and overall yield of the plants. Similar to the present study, the result from fenugreek and tomato seeds, the germination was found to enhance by 25 and 14%, respectively, with nanofertilizer dosage [58]. Similarly, seed germination, root elongation, and biomass increases were observed in nanoparticles (multiwalled carbon nanotubes (MWCNTs)) with ZnO particles [9, 41]. The study conducted on the application of silver nanoparticles noted that they significantly enhanced seed germination and antioxidant machinery and improved the easy growth characteristics in both monocot and dicot crops. This study also showed that germination and growth parameters (germination%, shoot length, root length, and seedling fresh weight) increased significantly ($p < 0.001$) with increased AgNPs concentration [42].

Plants can rapidly absorb nanofertilizers. Nano-encapsulated slow-release fertilizers can save fertilizer consumption and curtail environmental pollution [1]. Nanoparticles of many metal oxides can play an imperative role in promoting the growth and yield of plants. Zinc oxide nanoparticles have likely to boost the yield and growth of food crops. One of the advantages of this ZnO nanofertilizer is that it can be used in very small amounts. Nanopowders can be effectively used as fertilizers and pesticides as well [64, 65]. Green synthesized ZnO NPs were given as the nutrient source for the growth of the sesame plant with different concentrations (1, 3, 5, 7, and 9 mg/ml). The concentration of 5 mg/ml of ZnO NPs reveals significant ($p < 0.05$) growth in root and shoot development of the plant when compared to the control [66].

A previous study also showed that similar results of the ZnO nanoparticles were taken up by Bengal gram and Turkish gram roots with a very low translocation to the shoots [50, 67]. Similar to another research findings, the results from peanut are promoted seed germination, plant growth with root and stem growth [68]. The harvest of wheat plants grown from seeds that were treated with metal nanoparticles on an average increased by 20–25% [69]. Biologically synthesized ZnO nanoparticles are quickly transported through the plant and included in the metabolic processes. Mung bean (green gram) seed germination in the lowest concentration (20 mg) of ZnO suspension solution showed good shoot and root growth results [70]. A previous study also observed in mung (*Vigna radiata* (L.). R. Wilczek) that an increase in the ZnO NPs concentration resulted in an increase in root and shoot elongation [4, 71]. Analogous results of seed germination, shoot development, and root elongation are observed in the present study among the seeds of mung beans (green gram), Bengal gram, and Turkey gram with ZnO NPs. Another research's results demonstrate that cadmium toxicity exhibited deleterious effects over *Phaseolus lunatus* plants. Root length, shoot length, and dry weight of roots and shoots were found the lowest in Cd-treated plants. However, the application of iron oxide nanoparticles and silicon improved the growth, morphology, and biomass of the plants as compared with the control plants [45].

The effect of zinc nanoparticles on herbaceous plants was studied. The tomato seeds were treated over a range of zinc concentrations (0–1000 mg/kg). The germination rate was not affected, and it promotes the growth up to a certain concentration, that is, 250 mg/kg. No effects were found beyond that chlorophyll content and dry biomass, and also the number of flowers is increased after treatment of zinc oxide nanoparticles [72]. Another research study revealed that the applications of ZnO NPs ($40\,mgL^{-1}$) significantly enhanced the total chlorophyll content, available soil nitrogen and phosphorus, neutral detergent fibre (NDFs), and cellulose contents and improved the total soil microbial counts and soil enzyme activities (dehydrogenase, acid, and alkaline phosphate enzyme activities) in the maize crop [73]. One study suggests that the solubility of Zn^{2+} in Zn fertilizers plays an important role in the agronomic effectiveness of the fertilizers. On the basis of thermodynamics, ZnO nanoparticles should dissolve faster, to a greater extent, than bulk ZnO particles (equivalent spherical diameter >100 nm). These novel solubility features of ZnO NPs might be exploited to improve the efficiency of Zn nanofertilizers [36, 53]. Moreover, no differences were found between the action of ZnO NPs and ZnO SMPs, which confirmed the comparable chemical purity of the samples and suggested that the most important factor influencing seed germination was in fact the concentration of zinc ions, not the particle size. The different sizes of particles affected only the initial zinc solubility but did not contribute to the change in the final concentration of zinc ions and their influence on the tested in onion seeds [4].

The green synthesis of ZnO nanoparticles is much safer and environmentally friendly compared to chemical synthesis. As far as the usage of ZnO NPs is concerned, nanoparticles play a noteworthy role in agriculture, where a colloidal solution of ZnO NPs is used as nanofertilizers. Application of those zinc oxide nanoparticles to crops surges their growth and yield. As food demand is increasing day by day, the production of staple food crops is considerably low. Further, the research study is the need of the era to commercialize metal nanoparticles for sustainable agriculture [1]. Moreover, ZnO NPs are expected to be the ideal prospect for a Zn fertilizer in agriculture, enhancing crop productivity since the efficiency of both surface and chelate of Zn for soil, and foliar application is low [4, 68]. Also, they present a broad antifungal and antibacterial action and could be applied to control the spread of and infections by a variety of plant pathogens [4, 74, 75].

ZnO nanoparticles have captivated research focus and a lot of work particularly on various plant sources. For instance, the leaf extract of *Calotropis gigantea* using $ZnNO_3$ salt produced nanoparticles of size 30–35 nm [60]. As the requirement of nanofertilizers is incredibly small compared to chemical fertilizers, they will reduce the risk of environmental and human health hazards. The efficiency of nanoparticles was observed in lettuce and cucumber seed germinations [76, 77]. The present study where the green synthesized approach showed that the environmentally benign and renewable coriander leaves extract can be used as an effective stabilizing and reducing agent for the synthesis of ZnO nanoparticles. The present study also suggests that the plant-based zinc oxide nanoparticle can have huge applications in the field of food and agriculture, pharmaceutical, and cosmetic industries and thus become a major research area [13].

The present study is based on the colloidal solution of ZnO nanoparticles is used as fertilizer for the fast growth of pulses seeds and development in seed germination up to its development specifically in the laboratory. This type of nanofertilizer is a plant nutrient that is more than a conventionally used fertilizer and will be better used than chemical fertilizers [18]. This simple and cost-effective green synthesis approach for the formation of ZnO nanoparticles has proven to be suitable for application in agriculture. Further, this study can be developed to check the ZnO nanoparticles extracted from coriander leaves that might be utilized for tree seedlings at the nursery level and more. Green synthesized zinc nanoparticles have a potential role in the form of nanofertilizers in this current research study, and this work may help other researchers in the future development of study on zinc oxide nanoparticles for plant growth, plant breeding, and agriculture development.

5. Conclusions

The zinc oxide nanoparticle was synthesized by the biological method using *Coriandrum sativum* leaves extract successfully. The green synthesis method is eco-friendly as compared to the other methods such as physical and chemical. The X-ray diffraction, scanning electron microscopy, and transmission electron microscopy were accustomed to confirming the synthesis of ZnO nanoparticles, and also the results indicated that further optimization of the method is required to urge pure nanoparticles. Study results indicated from the TEM pattern exhibits that those nanoparticles have a size of 100 nm and are rod-shaped and polycrystalline in nature; synthesis of ZnO nanoparticles using coriander leaves is an alternative to chemical synthesis and can be helpful as bio-nano-fertilizers. However, the findings of many such experiments vary depending on NPs type, shape, concentration, and plant genotype. In the present study, the effect of zinc oxide nanoparticles on seed germination and plant growth was carried out using Bengal gram, Turkish gram, and green gram. The result revealed that the deficiency of zinc decreases the rate of seed germination. Significantly enhanced growth and development were evident in green gram and Turkish gram compared to those in Bengal gram in media treated with ZnO nanoparticles. The absence of zinc also affects plant growth, chlorophyll, and protein content. The zinc oxide nanoparticle, together with MS media, aided the seed germination, plant growth, chlorophyll, and protein content. Thus, the nanoparticle shows a synergistic effect on the plants.

Data Availability

All the data used to support the findings and conclusions of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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