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Efficacy of Green and Chemically Synthesized Nano Boron Nitride on Sunflower Germination

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ABSTRACT

This study explores the eco-friendly synthesis of nanoparticles using natural sources, specifically employing *Cassia fistula* leaf extract for the production of boron nitride nanoparticles. Characterization of the synthesized nanoparticles was performed using Raman spectroscopy and UV-visible spectroscopy to identify functional groups. Ab initio studies were conducted to investigate the electronic properties of the boron nitride nanostructures. The structural analysis through powder x-ray diffraction confirmed a hexagonal configuration of the nanoparticles. Scanning electron microscopy and transmission electron microscopy revealed particle sizes below 100 nm. Laboratory experiments demonstrated that sunflower seeds treated with 1500 ppm of green-synthesized nano boron nitride achieved the highest germination rate of 98.2%, surpassing other concentrations and chemically synthesized nanoparticles, which reached 93.9% at 2000 ppm. The control treatment yielded a germination rate of 76.2%. The eco-friendly synthesized nanoparticles exhibited superior efficacy compared to both chemically synthesized nanoparticles and conventional fertilizers.

1 | Introduction

Amid the intricate fabric of sunflower cultivation, it is *vital* to emphasize the pivotal roles of major and micronutrients. Although the former garners rightful attention, the latter group, encompassing zinc, iron, manganese, copper, and boron, profoundly contributes to sunflower physiology [1]. These micronutrients intricately interlace with enzymatic functions, serving as catalysts in reactions that orchestrate a symphony of plant activities [2]. Their significance reaches beyond their minimal quantities, extending from respiration to chlorophyll formation, photosynthesis, energy systems, and the synthesis of proteins, oils, tannins, and phenolic compounds [3].

Boron, a micronutrient essential for crops, stands out as a contributor. Its influence is profound, yet a delicate balance is required as high concentrations can be detrimental [4]. In the realm of sunflowers, boron aids in flowering, pollen germination, tube growth, and seed development. Particularly vital for this crop due to its sensitivity to boron deficiency, its application amplifies growth, enhances pollen characteristics, and facilitates vital compound translocation, culminating in increased productivity [5, 6].

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In the realm of modern agriculture, the pursuit of sustainable practices fostering higher yields has spurred innovative techniques. Nanoparticles, a promising avenue, offer solutions for enhanced crop growth while minimizing resources and environmental impact [7]. Nanotechnology's integration into agriculture spans domains such as nano-pesticides, nano-herbicides, nano-fertilizers, and nano-hydrogels [8]. Of particular interest is the application of nanoparticles to seeds, bolstering defenses against pests, and elevating germination percentages in various crops [9]. Sunflower cultivation, for instance, benefits from nano boron nitride (nBN) seed treatments that enhance germination rates and seedling establishment [10].

Considering the landscape of nano fertilizer implementation, a significant distinction emerges. Nano fertilizers synthesized through green routes outperform their commercially synthesized counterparts, aligning with sustainable practices [10, 11]. Their capacity to amplify seed germination through heightened metabolic activity resonates with the call for eco-friendly agricultural approaches, reducing the need for bulk fertilizers [12, 13].

In this experiment, different leaf extracts were used as reducing and stabilizing materials for the synthesis of nanoparticles. Five weed species (*Parthenium hysterophorus*, *Calotropis gigantea*, *Tridax procumbens*, *Alternanthera sessilis*, and *Cynodon dactylon*) and five tree species (*Cassia fistula*, *Pongamia pinnata, Azadirachta indica, Simarouba glauca*, and *Ficus benghalensis*) were used in the synthesis process. Among these weeds and tree species, *C. fistula* contains a higher amount of phenolics and is considered a good reducing and stabilizing agent [14]. If the leaf extract contains a higher amount of phenolics, it reduces the particles to nanosize [15]. To synthesize nBN, *C. fistula* leaf extractant was used. In the present study, green-synthesized boron nitride nanoparticles were characterized using different spectroscopic techniques, such as powder x-ray diffraction (PXRD), UV-visible spectrophotometry, particle size analysis, scanning electron microscope (SEM), transmission electron microscope (TEM), atomic force microscope (AFM), Fourier transformed infrared spectroscopy (FTIR), and Raman spectroscopy, to identify the size, shape, morphology, and other properties of nanoparticles.

Numerous researchers have successfully synthesized nBN via the green synthesis approach [16–18]. It is worth noting that variations exist not only in the plant extractants employed for the synthesis, but also in the geographical availability of the same plant species worldwide. Certain species are confined to specific regions or countries. In our specific context, we embarked on an exploration involving five weed species and five tree species, with the objective of identifying plant extracts rich in phenolic content capable of facilitating the transformation of particles into their nano counterparts.

The scientific community has indeed recognized the significance of utilizing green-synthesized nanoparticles for foliar application in diverse research endeavors [19]. However, the utilization of nanoparticles for seed treatment has remained constrained, and a discernible knowledge gap exists pertaining to their influence on root germination and ensuing root growth. Motivated by these pertinent gaps, our current study endeavors to holistically evaluate the impact of nanoparticles on both shoot and root development, specifically within the context of sunflower cultivation. Consequently, this research undertakes a comprehensive characterization of nanoparticles synthesized through diverse methodologies, shedding light on the distinct attributes of each, and underscoring their relative effectiveness.

This study serves as a *vital* bridge between past achievements and emerging inquiries within the realm of nanotechnology. By juxtaposing green and chemical synthesis pathways, it strives to unravel the nuances that underscore their respective contributions. This journey encompasses the exploration of nanoparticle efficacy and opens avenues for fostering sustainable agricultural practices through the optimal use of nanoparticles.

2 | Experimental Procedure

2.1 | Experimental Procedure for the Extraction of *C. fistula* Leaf Extractant and Green Synthesis of nBN

In this experiment, various leaf extracts were employed as reducing and stabilizing agents for the synthesis of nanoparticles. Leaf extracts from five weed species (*P. hysterophorus, C. gigantea, T. procumbens, A. sessilis*, and *C. dactylon*) and five tree species (*C. fistula, P. pinnata, A. indica, S. glauca*, and *F. benghalensis*) were utilized in the synthesis process. Among these weed and tree species, *C. fistula* was found to contain a higher amount of phenolics and was considered an effective reducing and stabilizing agent. It is noted that leaf extractants with higher phenolic content tend to reduce particles to nano size [20–22]. For the synthesis of nBN, *C. fistula* leaf extract was employed as the reducing and stabilizing agent.

2.2 | Leaf Extractant

Fresh leaves of *C. fistula* were procured from a university campus. Leaves underwent cleaning under tap water to eliminate debris, followed by several washes with distilled water. After being air-dried for a duration of 4 weeks, the leaves were ground into a fine powder utilizing a mixer grinder, subsequently sieved through a 20-mesh sieve, and stored appropriately. Subsequently, 20 g of this powdered material was combined with 400 mL of deionized water in separate 500 mL beakers. These mixtures were then subjected to heating at 65°C for 30 min. The ensuing leaf extract was isolated through a process of double filtration and centrifugation, and subsequently preserved at room temperature, maintaining separate storage for each species.

2.3 | nBN

A 9.5 g boron nitride (white graphene) (BN) was added to boiling water at 125°C with continuous stirring. The 45 mL of *C. fistula* leaf extract was then added to the solution with continuous stirring for 10 min. The heating process continued along with constant stirring for 90 min. After the stirring process keep it undisturbed for 3 h, Supernatant was collected and centrifuged at 1500 rpm for 30 min. After centrifugation, particles were freeze-dried to get boron nitride Nanosheets.

2.4 | Commercially Available/Chemical Synthesis of nBN

nBN was chemically synthesized by following the procedure of [23–25].

2.5 | Laboratory Studies

A laboratory study was conducted to analyze the germination percentage, and other parameters related to the seedling development of sunflower seeds. This analysis involved the utilization of different forms and concentrations of nBN fertilizers.

Germination test: In accordance with International Seed Testing Association [26, 27] regulations, the seed germination test for the sunflower hybrid KBSH-53 (*Helianthus annuus* L.) was conducted using non-toxic germination paper as the medium. Sunflower seeds were exposed to varying nBN concentrations, including 250, 500, 750, 1000, 2000, and 3000 ppm of green-synthesized particles (GsP) and commercially available particles (CP) and along with the control (water treated). Each treatment utilized 100 seeds, with triplicate examinations. The seeds were placed between paper towels, enclosed, and positioned within a seed germinator set at a temperature of 25°C and relative humidity of 95%. Germination percentages were calculated based on normal, deformed, and non-germinated seedlings, as well as diseased seeds, as per the procedure described in refs. [27, 28].

Significant enhancements in germination parameters were observed during the initial laboratory trials within the range of 1000 to 2000 ppm for nBN. In the subsequent series of experiments, both commercially available and green synthesized nanoparticles of boron nitride (1000, 1250, 1500, 1750, 2000, and 2250 ppm) concentrations were tested along with the control (water treated). Each treatment was replicated three times in the laboratory, with observations recorded for normal, abnormal, dead, and diseased seeds. Germination percentages were noted twice, at 5 days and 10 days after sowing

2.5.1 | Germination Percentage

The number of germinated seedlings for each treatment was recorded visually. The germination percentage was estimated using the following formula:

$$\text{Germination}\,(\%) = \frac{\text{no. of germinated seeds}}{\text{Total no. of seeds kept for germination}} \times 100.$$

2.5.2 | Mean Days of Germination ($\bar{t}$)

The mean number of days required for total germination for a particular treatment was calculated using the following formula [9]:

$$\bar{t} = \frac{N_1T_1 + N_2T_2 + \cdots + N_kT_k}{N_1 + N_2 + \cdots + N_k}.$$

where $\bar{t}$ = time in days starting from day "0" and N = is the number of seeds completing germination on the day "t".

2.5.3 | Co-Efficient of Velocity of Germination (CVG)

The coefficient velocity of germination as influenced by different treatments was calculated using the following formula [9]:

$$CVG = \frac{N_1 + N_2 + \cdots + N_k}{N_1T_1 + N_2T_2 + \cdots + N_kT_k\, N_1} \times 100$$

where "N" is the number of germinating seeds within the consecutive intervals of time "T" and "T" is the time between the beginning of the test and the end of the particular intervals of measurement.

2.5.4 | Mean Daily Germination (MDG)

The final germination percentage at the end of the test divided by the number of days was expressed as the mean daily germination, as described by [9].

2.5.5 | Statistical Analysis and Interpretation of Data

The data gathered from studies at various phenological phases were statistically analyzed. In the laboratory experiment, the level of significance in the "F" and "t" tests was 5% ($p = 0.05$) or (F-test *) and 1% ($p = 0.01$) or (F-test **).

3 | Result and Discussion

3.1 | Characterization of Nanoparticles

3.1.1 | Powder X-ray Diffraction (PXRD)

All strident diffraction peaks obtained after Rietveld refinement are in indenture with JCPDS card 00-034-0421 for boron nitride. Boron Nitride has a hexagonal structure with phase purity in the P63/mmc space group (Figure 1). No impurity peaks were observed, confirming the high crystallinity.

Using the Debye Scherrer reckoning, the typical crystallite size of the ready sample was considered as follows:

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

where, β is the full width at half maximum, θ is the glancing angle, D is the average crystal size, $\lambda = 1.5418$ Å is the wavelength of the x-rays used, and $k = 0.89$ is the shape factor. The average crystallite size was institute to be nearly 38.9 nm for boron nitride.

BN crystallized in a hexagonal crystal system with the space group P63/mmc. The two-dimensional structure consists of two BN sheets oriented in the Z-direction. The B^{3+} ion is bonded to three equivalent N^{3-} atoms in a trigonal planar geometry, while N^{3-} is bonded to three equivalent B^{3+} atoms in trigonal planar geometry. Table 1 shows the refinement outcomes for all structures. In the hexagonal structure, the atomic sites of B (4b; 0, 0.25, 0.625) and N (4a; 0, 0.25, 0.125) were refined using the pseudo-Voigt function

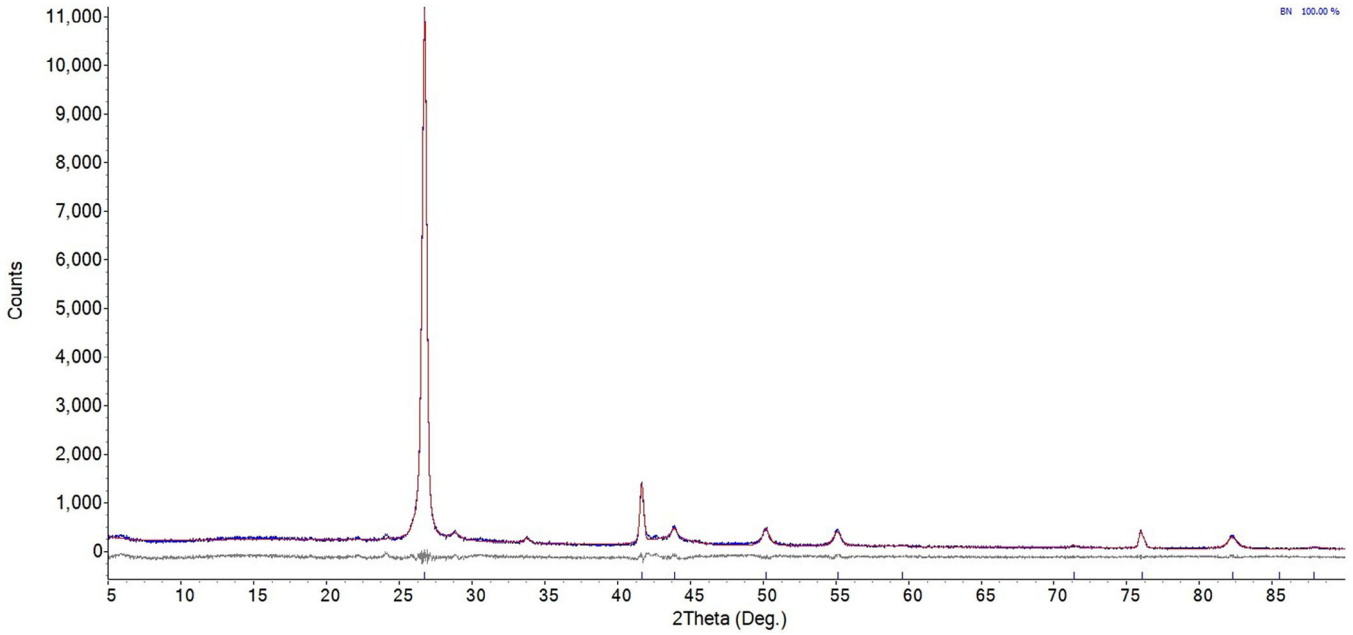


FIGURE 1 | PXRD Rietveld refinement pattern of boron nitride nanoparticle. PXRD, powder x-ray diffraction.

TABLE 1 | The Refinement results for all parameters.

Phase			**Boron nitride**			
Crystal system			*Hexagonal*			
Space group			*P63/mmc (194)*			
Lattice parameters (Å)						
a			2.500 (2)			
b			2.500 (2)			
c			6.662 (4)			
α, β, γ			90, 90, 120			
Cell volume (Å^3)			36.086 (2)			
Atomic coordinates						
Atoms	**X**	**y**	**z**	**B**	**Occ.**	**Np**
B	0.333	0.666	0.250	1.0	1.0	6
N	0.333	0.666	0.750	1.0	1.0	6
Refined parameters						
R_{exp}	**R_{wp}**	**R_p**	**GooF**	**Crystallite size (nm)**	**Density (g/cm^3)**	**Strain**
6.36	9.34	6.72	1.47	38.9	6.852	0.00108

to model the peak profiles with six coefficient polynomials to designate the background [21, 28].

3.1.2 | Computational Details

Periodic compactness functional theory designs were performed in the CRYSTAL17 code using PBE hybrid functionals [5, 29, 30]. The Monk horst-pack mesh has a shrinking factor of six in the reciprocal space of the Brillouin zone of the primitive cell. The thresholds controlling the accuracy were set to 10^{-7} for ITOL1–ITOL4 and 10^{-14} for ITOL5. For all geometry optimizations, the self-consistent field convergence (SCF) on the energy was set to 10^{-8} hartree. Figure 2 depicts the electron density (ρ) and deformation density ($\Delta\rho$) of nBN resulting from the crystalline density. The deformation density is exhibited in bold for null values, dense lines for positive values, and dotted lines for negative values. Positive values of deformation density show charge accumulation, while negative values represent electron flow in the case of interacting atoms.

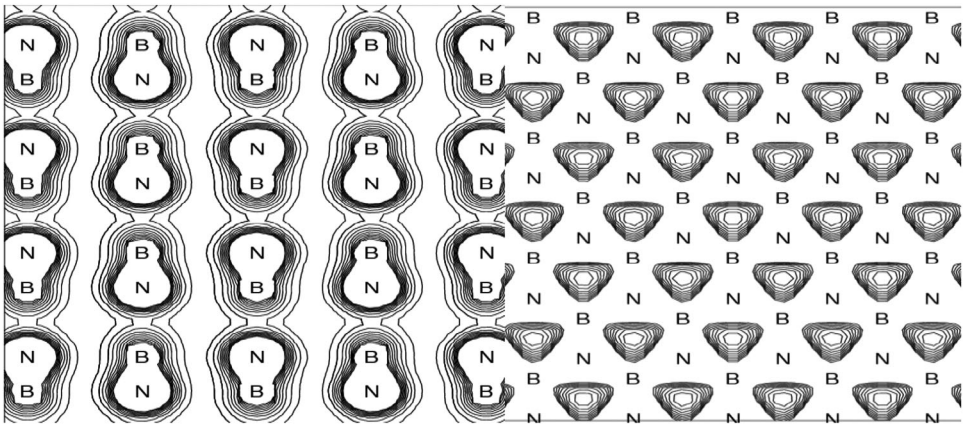


FIGURE 2 | Electron density (ρ) deformation density ($\Delta\rho$) maps of nano boron nitride.

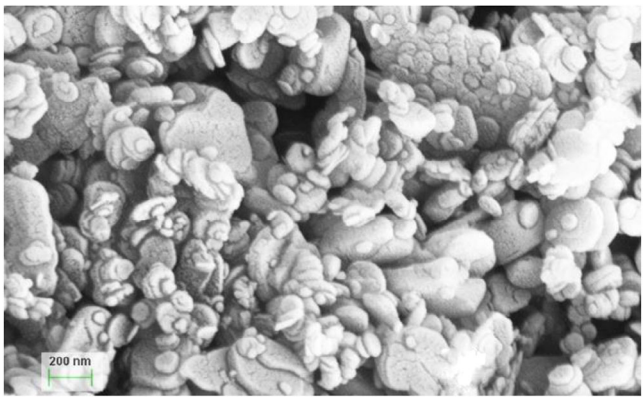


FIGURE 3 | SEM micrographs of boron nitride nanoparticles. SEM, scanning electron microscope.

3.1.3 | Scanning Electron Microscope

The principle of SEM is the magnification of the targeted object. Hence, these approaches provide the exact sizes of the particles synthesized using the green synthesis approach. The SEM images show that the green-synthesized nBN (Figure 3) samples were less than 100 nm in size and were homogenously dispersed. The larger particles were due to the aggregation of the smaller particles in the SEM measurements.

EDAX spectra results clearly indicate that boron nitride consists of B (35.37 wt%), N (46.98 wt%), C (14.06 wt%), and O (3.59 wt%), where carbon and oxygen were originated from biomolecule moieties of the synthesized phytochemicals, as shown in Figure 4.

3.1.4 | Transmission Electron Microscope

The TEM morphology of the green-synthesized nBN was thin, transparent nano sheets with an average lateral dimension of 69 nm, as shown in Figure 5. In case of boron nitride commercially available boron nitride consists of a thick layer of sheets so we can conclude that the morphology of the particles changed when they were converted into the nano-form. Thin layers are more efficient in penetrating plant tissue than thick sheets because of their excellent accessibility to active sites and inherent controlled diffusion properties; hence, green synthesized nanoparticles are more efficient than commercially available nanoparticles.

3.1.5 | Fourier Transformed Infrared Spectroscopy

The FTIR spectra of green-synthesized boron nitride, show two strong absorption bands located at 1385 and 810 cm^{-1} could be assigned to the in-plane B—N stretching vibration and out-of-plane B—N—B bending vibration, respectively. In addition, the peak centered at 3423 cm^{-1} can be attributed to the stretching mode of the —OH or H_2O groups (Figure 6a). The shapes and positions of the peaks recorded for the GsP were similar to those reported in the literature [5, 26].

3.1.6 | UV-Visible Spectroscopy

Each element has its own spectral peak of absorbance; hence, by recording a particular peak value, we can determine the presence of a particular element. The results indicate that the main absorbance peaks of boron nitride (Figure 6b) nanoparticles were observed in the range of 250–258 nm. The peak at 252 nm indicated the successful formation of boron nitride nanoparticles. Similar results have been reported in ref. [26]. The boron nitride shows Eg value of 2.4 eV.

3.1.7 | Raman Spectroscopy

The Raman band for the green-synthesized nBN was observed at 1381 cm^{-1} which was attributed to the Raman active mode E_{2g} due to the in-plane atomic displacement of boron and nitrogen atoms against each other, as shown in Figure 6c. Raman peaks are associated with the lattice vibration and hence are affected by the atomic bond and chemical structure of the material. Thus, stress is present in the affected Raman peak. The crystalline structure and ordering of the hexagonal boron nitride layers were evaluated by Raman shift and full width at half maximum (FWHM) of the E_{2g} vibrational band. It is well known fact that high-quality

Element	Weight %	Atomic %
B K	35.37	40.79
C K	14.06	14.60
N K	46.98	41.82
O K	3.59	2.80
Total	100.0	

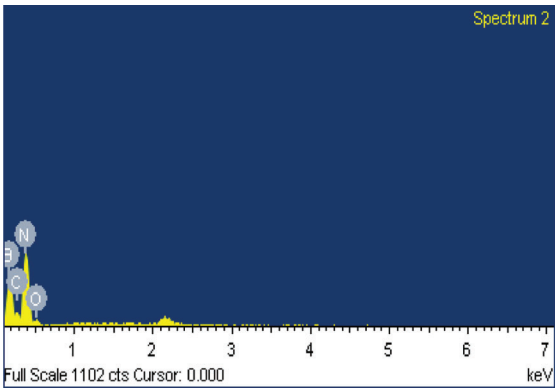


FIGURE 4 | EDX spectra of Boron nitride nanoparticle.

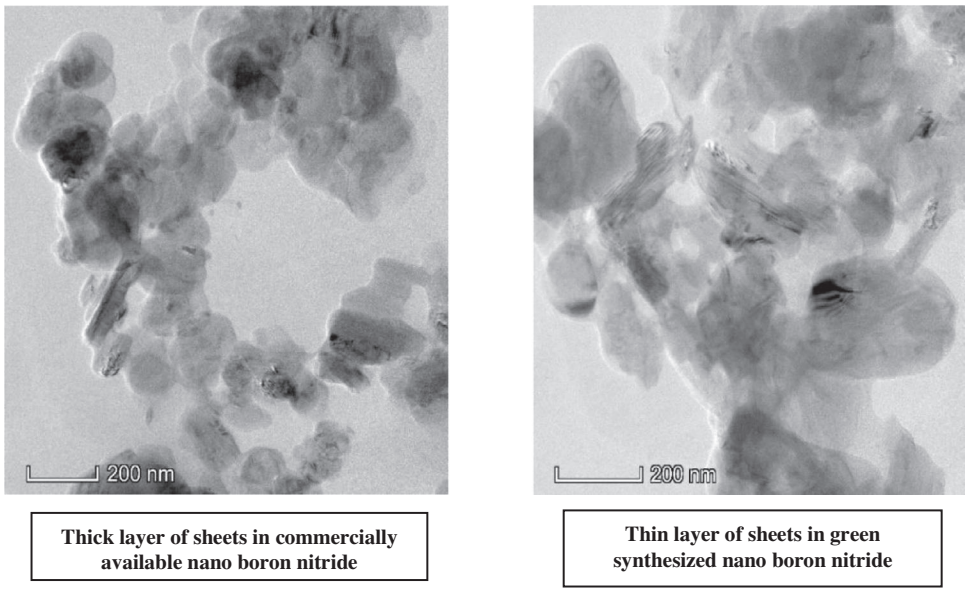


FIGURE 5 | TEM images of commercial and green synthesized nano boron nitride. TEM, transmission electron microscope.

single crystals (h-BN) exhibit an intrinsic E_{2g} vibration peak at 1367 cm^{-1}.

E_{2g} shifts to higher frequencies in polycrystalline materials. Domain size is also related to the FWHM of this peak, and fwhm increases with a decrease in size. In the present case, the blue-shifted E_{2g} vibration mode (1381 cm^{-1}) is due to the weaker interaction between the interlayer of boron nitride. The broadening of E_{2g} peak may be attributed to the shrinking size of the ordered boron nitride layers.

3.1.8 | Particle Size Analysis

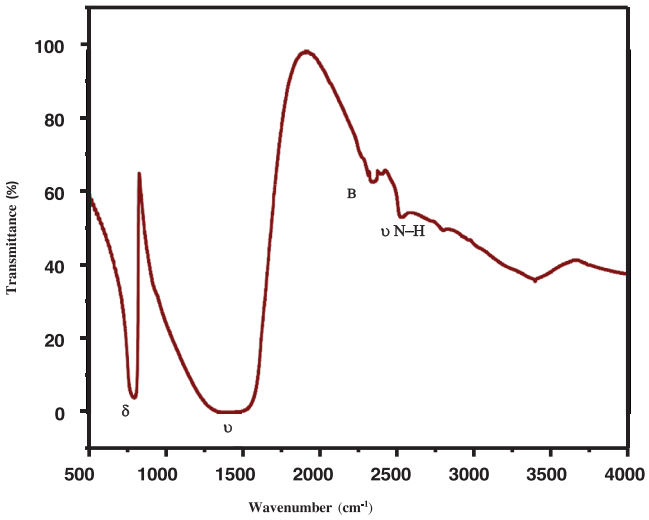
The sizes of the green-synthesized nBN was analyzed using a particle-size analyzer. The size distribution of boron nitride analysis showed that 95% of the particles were 82.74 nm in diameter (standard deviation 36.2 nm) and 5.3% of the particles were 16.66 nm in diameter (standard deviation of 4.3 nm). The average size of the nano particle was 69.4 nm. The data clearly indicate that the particles are distributed homogeneously, as shown in Figure 7.

3.2 | Laboratory Studies: Two Sets of Experiments Were Carried out to Optimize the Nano Nutrient Concentration for Sunflower

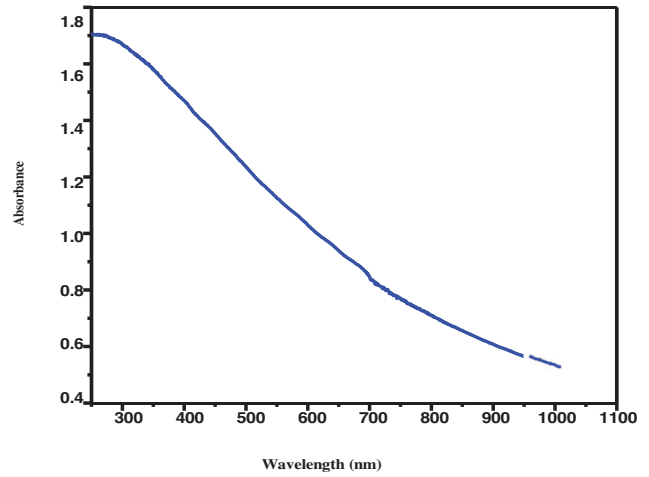
3.2.1 | Experiment I—Impact of Nano Boron Nitride on Sunflower Germination

In this research study, sunflower (*H. annuus*) seeds were subjected to a series of treatments involving varying concentrations (250, 500, 750, 1000, 2000, and 3000 ppm) of chemically synthesized and green synthesized nBN. The primary objective was to assess the effects of these treatments on germination percentage and other germination-related parameters

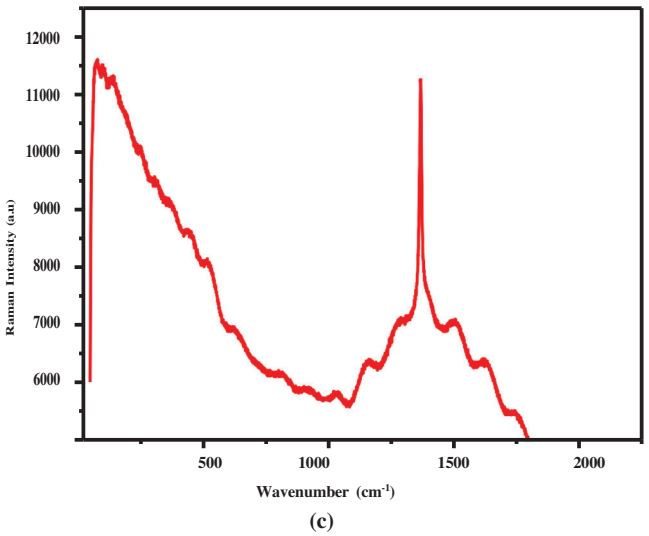
The results of the experiment revealed noteworthy findings. Notably, the treatment with 1000 and 2000 ppm of green synthesized nBN led to significantly elevated germination percentages, However, in the case of chemically synthesized nBN, it was the 2000 ppm concentration that yielded the most favorable outcomes. Control treatment recorded lesser germination (75.5%), MDG (12.2), CVG (13.7) and higher mean days of germination (4.86).



(a)



(b)



(c)

FIGURE 6 | (a) FTIR spectra; (b) UV-Visible absorbance; (c) Raman spectroscopy. FTIR, Fourier transformed infrared spectroscopy.

Given these intriguing results, a subsequent series of experiments was undertaken. The purpose of this additional investigation was to refine the concentration ranges, further compare the performance of green synthesized and chemically synthesized nanoparticles, and ascertain their respective efficiencies. By conducting this comprehensive research, we aim to contribute to a deeper understanding of the potential benefits and variations in outcomes when utilizing different concentrations of chemically and green synthesized nBN. This research sheds light on the complex interplay between these treatments and sunflower seedling development, ultimately paving the way for more informed and targeted agricultural practices (Figures 8 and 9).

3.2.2 | Experiment II—Impact of Nanoparticles on Sunflower Germination Parameters

The objective of this investigation was to refine the concentration levels employed in the experimental treatments. In this experiment, both commercially available and green synthesized nanoparticles of boron nitride (1000, 1250, 1500, 1750, 2000, and 2250 ppm) concentrations were tested along with the control (water treated).

3.2.2.1 | Germination Per Cent, Mean Days of germination (Days), CVG and MDG. Nanoparticles significantly affected germination related parameters, with the highest germination rate (98.2%) observed in the 1500 ppm nBN treatment (GsP). In various nBN concentrations (CP), the most substantial germination rate (93.8%) occurred at 2000 ppm. When seeds were treated with nano particles observed the thinnest seed coat. The treatments also influenced the mean number of days of germination, indicating that lower values correspond to faster seed germination. The control treatment exhibited a significantly greater mean day of germination (4.98 days) compared to others, while the lowest mean number of days of germination (2.19 days) was obtained in the 1500 ppm nBN (GsP) concentration. In the various concentrations of nBN (CP), the 2000 ppm concentration showed the lowest mean number of days of germination (2.98 days).

The findings revealed significant variation in the coefficient of velocity of germination (CVG), with the 1500 ppm (GsP) treatment exhibiting a significantly greater CVG value (32.9). Among the various concentrations of nBN (CP), the highest CVG value (27.1) was observed at the 2000 ppm concentration, surpassing the control treatment (13.9). Additionally, the 2000 ppm concentration of nBN (CP) had the highest mean days of germination (MDG) value (18.1), which was notably higher compared to the control (12.4) (Figure 10).

4 | Discussion

4.1 | Effect of Nanoparticles on Germination, Mean Days of Germination (Days), CVG, MDG of Sunflower Seedlings

Compared to the control, seed treatments with nBN had higher coefficients of velocity of germination, mean daily germination, and reduced mean days of germination. Higher CVG, MDG,

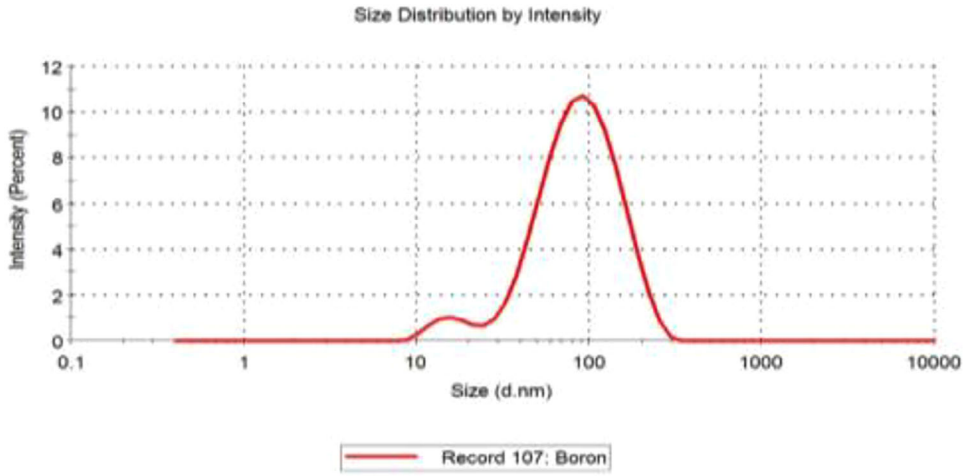


FIGURE 7 | Particle size distribution of nano boron nitride.

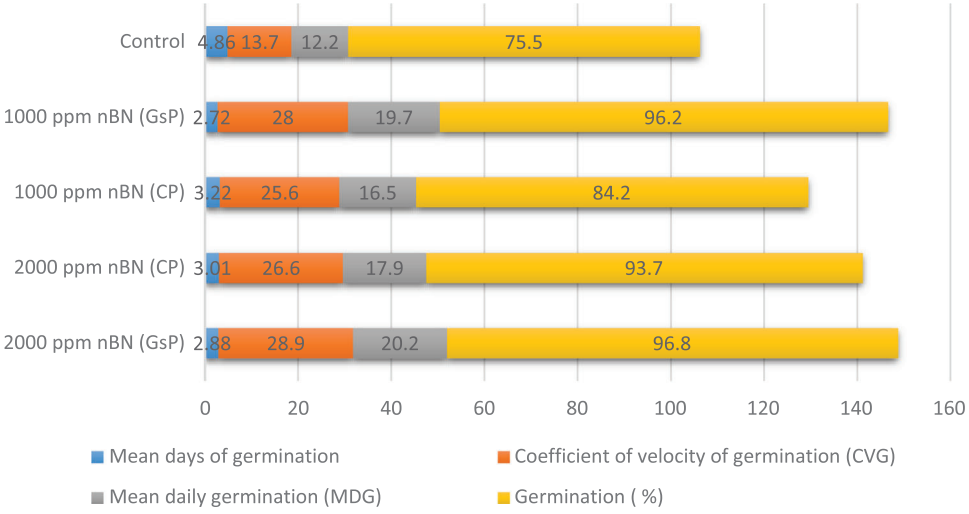


FIGURE 8 | Impact of nanoparticles on sunflower germination parameters.



FIGURE 9 | Germination test with different forms and levels of nBN (Experiment-I). nBN, nano boron nitride.

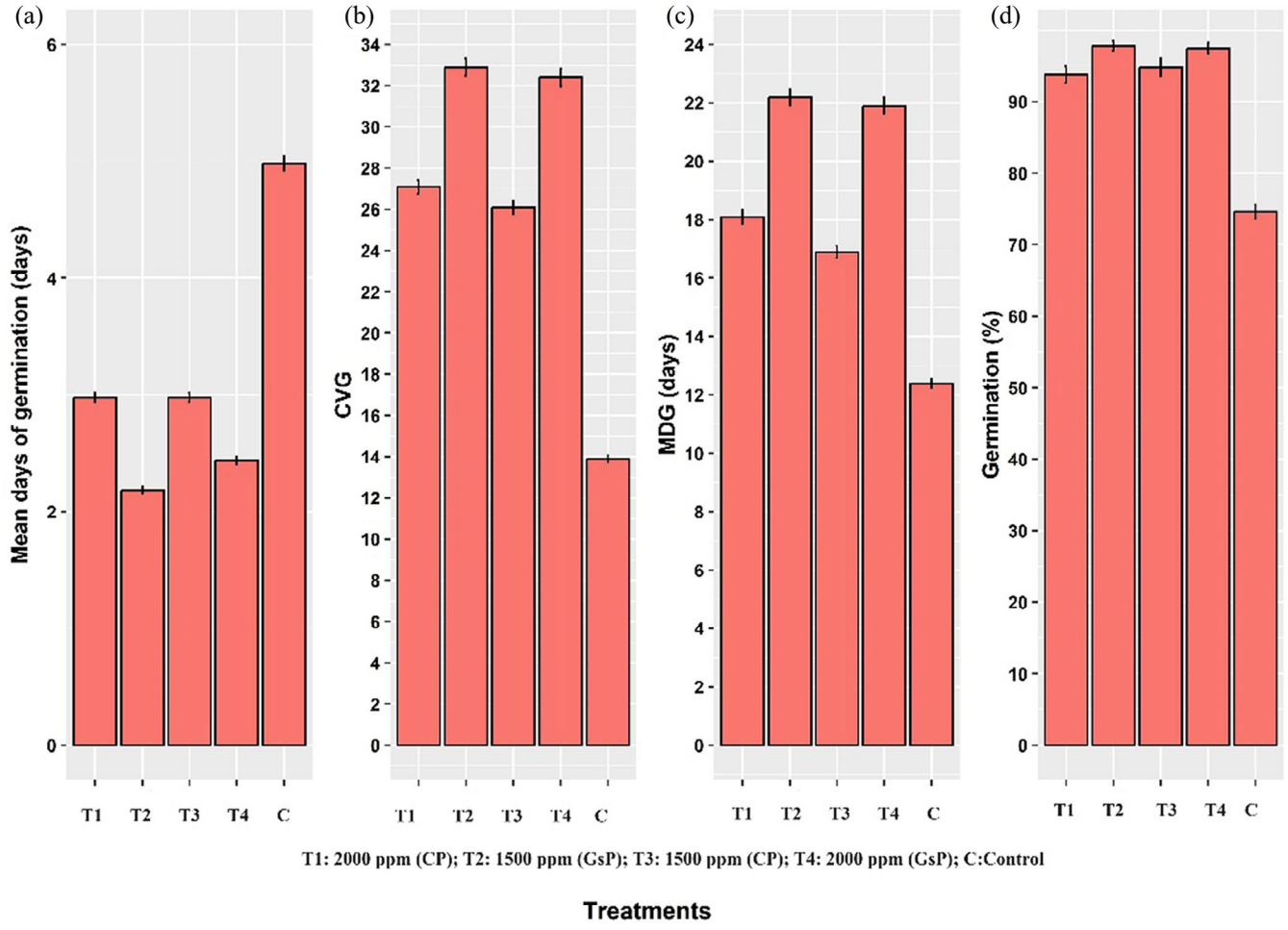


FIGURE 10 | Germination parameters of sunflower seedlings as influenced by different forms and levels of nBN (error bars indicate standard error of mean). (a) Mean days of germination; (b) Coefficient of velocity of germination; (c) Mean daily germination; (d) Germination.

and lower mean days of germination indicated that the seeds germinated well. The mean number of days required for cotton germination was reduced by 50% in plots treated with nBN and lesser germination parameters were recorded in untreated (control) treatment [21, 29]. Boron nitride-coated cotton seeds demonstrated quicker germination of radicles and plumules, attributed to enhanced activity of proteases and lipases, which solubilize larger molecules essential for the advancement of the embryo [22]. When nanoparticles are seeded, they enter the cell via plasma membrane invagination via vesicles that can migrate to different compartments of the cell leads to higher velocity of germination and mean daily germination [22, 31, 32]. Using x-ray computed nanotomography and hyperspectral imaging microscopy [31], discovered that *Arabidopsis thaliana* seedlings treated with nanoparticles exude mucilage, which enhances germination by a factor of 10 and recorded higher CVG and MDG [30] investigated the effect of four metal oxide nanoparticles on watermelon crop peak value and germination value. Using transmission electron microscopy, they discovered that tiny nanoparticles could pierce and enter the epicotyl area, leads to lower mean days of germination in watermelon seeds [15, 33, 34] evaluated the germination value of cucumber seeds treated with CeO_2 nanoparticles and discovered an increased CVG in nano CeO_2 seed treatment compared with regular CeO_2 seed treatment. According to [32], nanoparticles boost amylase activity in oilseed crops and promote germination under stressful conditions. nBN nitride-treated tomato seeds exhibited higher germination percentages and took 22 h less for germination than untreated seeds [34]. Nano zinc-treated maize seeds had a greater peak value and germination value, and the higher the peak value, the faster the seeds germinated under stressful conditions [35]. Sunflowers exhibit leaf-adaptive mechanisms to overcome nutrient and water-stressed conditions for effective germination [36]. The research findings showcased the intricate regulation of certain low molecular weight (LMW) heat shock proteins (HSPs) within the plant's cytoplasm, indicating their potential role in sunflower growth by enhancing water and nutrient stress tolerance [27].

5 | Conclusions

nBN prepared via an eco-friendly green synthesis method utilizing *C. fistula* leaf extractant is economical for the synthesis of nanoparticles. Once the green-synthesized nBN is obtained, comprehensive characterization will be conducted using various instruments. PXRD will continue to be utilized for determining sample purity. The UV-Vis spectrophotometer will be used to

identify the main absorbance peaks of the nanoparticle, while TEM will reveal that commercially available nBN contains thick layers of sheets, whereas green-synthesized nBN contains thin, transparent nanosheets.

In future agricultural practices, green synthesized nBN fertilizer will need to be optimized for seed treatment and foliar application for other oilseed crops. Green-synthesized nanoparticles will be more effective than conventional fertilizers in promoting seed germination and crop growth, contrasting with commercially available nano fertilizers, which will be less effective. This method will find utility in dry lands, addressing nutrient and water scarcity, and offering the potential for larger economic returns.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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