Biogenic Synthesis of Potassium Nanoparticles from *Artocarpus hirsutus* Leaf Extract: A Novel Nanofertilizer for Enhanced Growth of *Vigna radiata*

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Abstract
The utilization of potassium nanoparticles as a novel nanofertilizer synthesized through biogenic means represents a significant advancement in agricultural technology. Potassium is a vital nutrient for plants, playing essential roles in growth, yield, metabolism, enzymatic activity regulation and overall physiological functions. In this study, potassium nanoparticles were synthesized using Artocarpus hirsutus plant leaf extract and their efficacy in promoting growth in Vigna radiata (green gram) plants was investigated. Characterization of the synthesized nanoparticles revealed their morphological and stability-related parameters. Transmission electron microscopy (TEM) measurements indicated a size range of 70 nm for the potassium nanoparticles, while Scanning electron microscopy (SEM) analysis reported a size of 400 nm. The elemental analysis using energy dispersive X-ray (EDX) confirmed the presence of potassium (K) in the synthesized nanomaterial, with approximately 40% potassium content.

In laboratory experiments, five different concentrations of nano potassium (ranging from 100 µg/mL to 1000 µg/mL) were tested alongside a blank control (with no external potassium supplement) for seed germination and plant growth activity. The results demonstrated that nano potassium-treated plants exhibited enhanced growth and yield compared to the control group. Additionally, plants sprayed with nano potassium showed efficient utilization of exchangeable potassium from the soil, leading to minimal potassium loss through leaching. The green synthesised KNPs show effective anti-oxidant activity. Overall, this study presents a promising potassium nano fertilizer that effectively promotes the growth and yield of Vigna radiata plants without causing any undesirable harmful effects on the environment.

Keywords: Nano fertilizer, potassium nanoparticles, *Artocarpus hirsutus*, seed germination, plant growth.

Introduction

Nanotechnology holds significant promise for advance research in plant science and other fields by offering new avenues for the development of tools incorporating nanoparticles. These nanoparticles boast high reactivity, tuneable properties and large surface area to volume ratio, making them versatile for various industrial applications[11]. Current studies underscore the vast potential of nanoparticles in agriculture, ranging from modifying plant genetics to enhancing crop growth and development, as well as in controlling the release of agrochemicals[7,17]. In agriculture, fertilizers play a crucial role in plant nutrition, yet a significant portion of applied fertilizers becomes unavailable to plants due to various factors like leaching and degradation. The advent of nanotechnology offers a solution through the development of nano-fertilizers which may exhibit properties like controlled release of nutrients, regulation of plant growth and enhanced target activity[6,12].

However, traditional methods for synthesizing nanoparticles pose several challenges including the use of potentially toxic chemicals, expensive equipment and environmental concerns[1,19]. These drawbacks have fuelled the exploration of green synthesis methods, utilizing biological sources such as plants, microorganisms and biopolymers[9]. Among these biological routes, nanoparticle synthesis employing plants is favoured due to their abundance, safety and the availability of a wide range of phytoconstituents acting as reducing agents.

Nano-fertilizers have emerged as smart alternatives to conventional fertilizers, with potassium being a particularly essential nutrient for crop growth and quality[8]. While metallic nanoparticles, such as copper, silver and gold, show promise for agricultural applications, their potential toxicity warrants consideration[2,13]. Studies indicate that potassium nanoparticles synthesized using extracts from *Sideroxylon capiri* possess antimicrobial properties which could be advantageous for agriculture[3,5]. This synthesis marks a significant step towards exploring the potential of green-synthesized nanoparticles in agriculture and warrants further investigation into their efficacy and environmental impact[16].

Material and Methods

Sampling and Preparation of Leaf Extracts: *Artocarpus hirsutus* leaves were obtained from rural area of Rajamundry, East Godavari district, Andhra Pradesh, India. The plant identification was carried and certified by Prof. Ch. Srinivasa Reddy, expert herbalist, Dept., of Botany, SRR and CVR Government Degree College, Vijayawada, with SRR-CVR/2024/PI/05 as voucher specimen number. Dried leaves of *Artocarpus hirsutus* leaves were washed with de-ionized water to remove foreign materials, air-dried for 5 days, grinded and sieved to obtain a fine particle mesh size.

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Exactly 50 g of mesh size of about 250-300 microns was weighed and mixed with 250 mL of de-ionized water in a 500 mL beaker. It was then set to boil at 60 °C for 15 min in a water bath. The extract was filtered using a Whatmann no. 1 filter paper. The filtered extract was then stored in a refrigerator below 20 ºC for further experiments.

Green Synthesis of Potassium Nanoparticles (KNPs): Potassium chloride analytical grade was purchased from chemical vendors in analytical reagent grade, Rankem Chemicals, Gujarat. Exactly 7.45 g potassium chloride was transferred into a 100 mL volumetric flask and dissolved to the mark to prepare 1.0 M KCl solution. Similar 0.1 and 0.01 M KCl solutions were prepared by dissolving potassium chloride into adequate volume of distilled water. To synthesize KNP, about 50 ml 1.0, 0.1 and 0.01 M of KCl solutions were transferred individually into a beaker containing 50 mL of the prepared *Artocarpus hirsutus* leaves extract. The mixture was heated to 80ºC and was continuously stirred using a mechanical stirrer for 20 minutes.

2 mL of 5% sodium hydroxide solution was added to the colloidal solution while stirring until the mixture became intense dark in colouration. The colour of the solution changed from light brown to dark brown with time which indicated the formation of KNP. It was then centrifuged at 3000 rpm for 30 minutes, Pellet was washed twice with distilled water and dried in an oven at 90ºC for 18 hours, then later transferred into an amber bottle for further analysis.

Characterization of Green Synthesized Potassium Nanoparticles (KNPs): A detailed characterization of KNPs using *Artocarpus hirsutus* leaves extract was subjected to UV, SEM, TEM, EDX and FT-IR analysis. The purified nanoparticle pellets were dissolved in distilled water and absorption spectrum was obtained within the wavelength range of 200–800 nm using UV-Visible spectrophotometer (Techcomp-2301) model with Hitachi software. The absorption spectra were also used to measure the solution concentration and to identify the organic compounds determining the maximum absorption of the nano solution. Functional group analysis was evaluated using the Agilent ATR-FTIR (Attenuated Total Reflectance Fourier Transform Infrared) spectrometer in the range of 4000 cm^{-1} to 650 cm^{-1} to analyse the functional groups present in both the *Artocarpus hirsutus* leaf extract and the synthesized potassium nanoparticles. This technique helps to identify chemical bonds and functional groups present in the samples.

Scanning Electron Microscopy (SEM) was performed with Carl Zeiss Supra 55 Gemin-German Technology Jena, Germany) model. SEM combined with EDX was used to capture images of the nanoparticles. SEM allows for high-resolution imaging of the surface morphology and structure of materials at the nanoscale. Energy Dispersive X-ray Spectroscopy (EDX) was utilized to identify the elements present in the nanoparticles and to estimate their concentrations. Additionally, it helps in determining the elemental distribution on the surface of the nanoparticles. This technique works by analysing the characteristic X-rays emitted by the elements when the sample is bombarded with electrons. To visualize the structural characteristics and topographical analysis, purified KNPs were examined under JEOL JEM-2100F) model Transmission electron microscopy (TEM) instrument.

The structural characteristics of the KNPs were investigated through X-ray Diffraction (XRD) analysis to discern their crystalline or amorphous nature. Utilizing a Rigaku Ultima III model XRD analyzer, XRD measurements were conducted over a 2θ range from 10° to 80°. Particle size distribution analysis was performed using Dynamic Light Scattering (DLS), a technique that monitors fluctuations in laser light intensity scattered by particles diffusing through a solvent. The Beckman Delsa Nano C series particle size analyzer was utilized for accurate size measurement and confirmation of nanoparticle size distribution. Furthermore, the Zeta potential (ZP) measurement of KNPs in water was conducted to determine the surface charge of the nanoparticles, providing valuable insights into their colloidal stability and interaction with the surrounding environment.

Seed germination study of KNPs on *Vigna radiata* seeds: The experiment investigated the influence of KNPs on the germination and growth of *Vigna radiata* seeds. KNPs stock solutions were prepared at concentrations of 1.0 M, 0.1 M and 0.01 M by dissolving 10 mg of potassium nanoparticles in 10 mL of distilled water. Five glass Petri plates, each covered with filter paper containing micro and macro nutrients, served as the growth substrate for the seeds. *Vigna radiata* seeds were inoculated onto the prepared glass plates. Over the course of five days, the seeds were treated twice daily with either water or potassium nanoparticles dissolved in water, with treatment volumes of 1.5 mL in the morning and 1.5 mL in the evening, drawn from the respective stock solutions. After the experimental period, the growth parameters including shoot length, root length, leaf length and leaf count were measured to assess the impact of the treatments on seed germination and growth.

Plant growth study of KNPs on *Vigna radiate*: In this experimental study, six nursery beds were prepared for the cultivation of sprouted seeds of *Vigna radiata* from the above seed germination experiment. A week after germination, the plants are inoculated into pots and for two weeks, synthesized potassium nanoparticles (from 1.0 M, 0.1 M and 0.01 M KNPs) were applied to the plants via foliar spray at a concentration of 100 mg/mL. A blank or control pot was maintained in order to observe the change in the effect of KNPs on the growth of plant. This application was repeated once every four days over a two-week period. Subsequently, a week after the final application, the plants were harvested for assessment.

Various growth parameters including plant total weight, plant height, leaf length, root length and stem diameter were measured. Plant height was determined by measuring the vertical distance from the base of the plant to the tip of the highest leaf while stem diameter was measured at the widest part perpendicular to its axis using a Caliper. Mature and healthy leaves were selected from different parts of the plant and their lengths were measured with a ruler. Care was taken during harvesting to prevent root damage and the plants were divided into leaves, stems and roots, with each part weighed using an analytical balance. The measurements were performed in triplicate to ensure accuracy and the average mean of each parameter was calculated for analysis. This experimental setup allows for a comprehensive investigation into the impact of potassium nanoparticles on the growth of *Vigna radiata* plants.

Study of anti-oxidant capacity: The experiment assessed the antioxidant properties of KNPs synthesized through eco-friendly methods and a plant extract using the DPPH free radical scavenging assay. Solutions of varying concentrations of KNPs, ascorbic acid and plant extract were mixed with methanolic DPPH solution and left to react. After 30 minutes, the absorbance of each solution was measured at 517 nm. The change in colour from violet to yellow indicated DPPH reduction, reflecting antioxidant activity. The data were analysed to calculate percentage inhibition, indicating the antioxidant effectiveness of KNPs and plant extract compared to ascorbic acid. This experiment provides valuable insights into the potential antioxidant properties of KNPs and plant extract with possible applications across multiple fields.

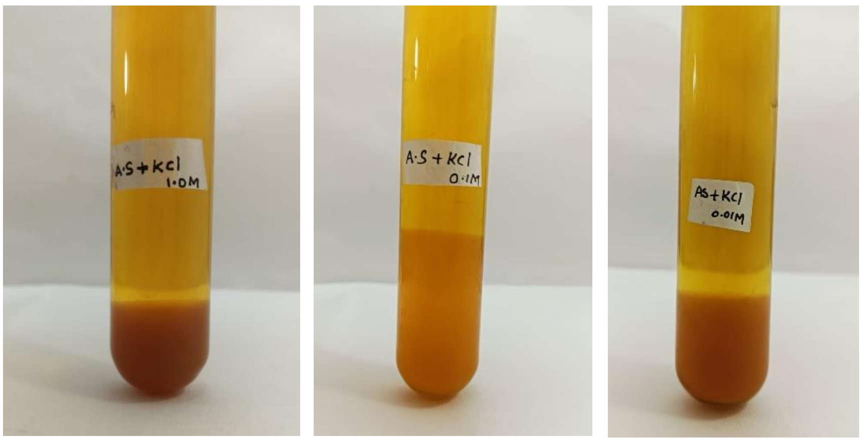
Results and Discussion

The absorption peak at 270 nm (Figure 2) indicates that the KNPs synthesized from *Artocarpus hirsutus* leaves extract fall within this wavelength range, unlike silver and copper nanoparticles. The concentration of the initial potassium chloride solution plays a vital role in both the formation and growth of KNPs. Figure 1 illustrates the effect of varying initial KCl concentrations (1.0 M, 0.1 M and 0.01 M) on the yield of synthesized nanoparticles. Generally, higher initial concentrations result in higher yields due to increased supersaturation. This can cause seed particles to either grow into stable nuclei or dissolve entirely. Conversely, lower concentrations may lead to reduced yields as there are fewer particles available to act as nucleation sites.

However, excessively high initial concentrations can lead to the formation of large, non-uniform particles. This is because a higher density of crystal nuclei per unit volume increases the likelihood of collisions, aggregation and subsequent growth into larger particles. Therefore, finding the optimal initial concentration is crucial for controlling both yield and particle size uniformity during the synthesis process. The distinct characteristic peaks observed in FT-IR spectra (Figure 3) for *Artocarpus hirsutus* KNPs were analyzed for their corresponding functional groups.

Peaks at 3895.46 cm^{-1}, 3853.26 cm^{-1}, 3836.07 cm^{-1}, 3743.72 cm^{-1}, 3677.53 cm^{-1}, 3647.53 cm^{-1}, 3616.30 cm^{-1}, 3564.02 cm^{-1}, 3506.64 cm^{-1}, 3446.83 cm^{-1}, 3394.17 cm^{-1}, 3333.18 cm^{-1}, 3249.41 cm^{-1}, 3117.38 cm^{-1}, 3018.90 cm^{-1}, 2968.85 cm^{-1} and 2816.03 cm^{-1}were attributed to various stretching vibrations such as amine N-H stretching, alcohol and carboxylic acid O-H stretching and C-H stretching of terminal alkyne, vinyl, alkane and aldehydes. Additionally, peaks at 2358.95 cm^{-1}, 2163.29 cm^{-1}, 1917.36 cm^{-1}, 1867.99 cm^{-1}, 1835.41 cm^{-1}, 1741.30 cm^{-1}, 1648.37 cm^{-1}, 1544.26 cm^{-1}, 1518.27 cm^{-1}, 1457.23 cm^{-1} and 1422.35 cm^{-1}were associated with stretching vibrations of C=C, C=N, C=C=C, C≡C, C≡N, alkynes, alkenes, benzene and alines.

Furthermore, peaks at 1369.07 $cm^{-1}$and 11218.29 cm^{-1} were attributed to C-O stretching and $–CH_2$- bending vibrations while peaks at 1013.69 cm^{-1}, 797.67 cm^{-1}, 751.44 cm^{-1}, 669.16 cm^{-1} and 632.28 cm^{-1}were assigned to alkyl halides. In contrast, KNPs exhibited three main distinctive peaks: 1741.30 cm^{-1}, attributed to C=C stretching or terminal ≡C-H stretching, 1544.26 cm^{-1} for alkene C=C stretching and 1369.07 cm^{-1} for C-O stretch.



a b c

Figure 1 (a-c): Change in colour and yield observed with KNPs solution (1.0 M, 0.1 M and 0.01 M) using *Artocarpus hirsutus* leaves extract

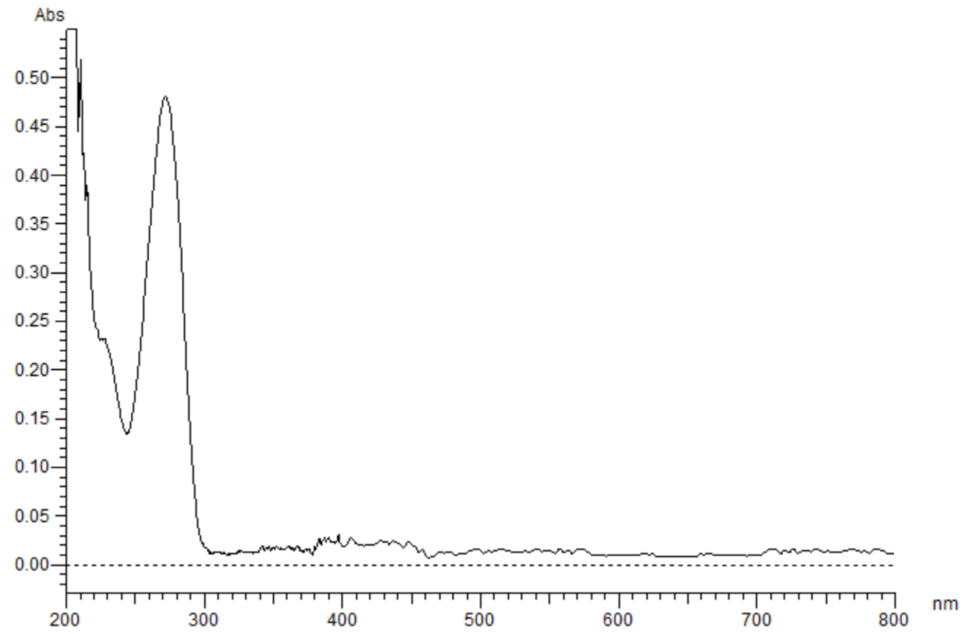


Figure 2: UV Spectra of synthesized KNPs solution using *Artocarpus hirsutus* leaves extract

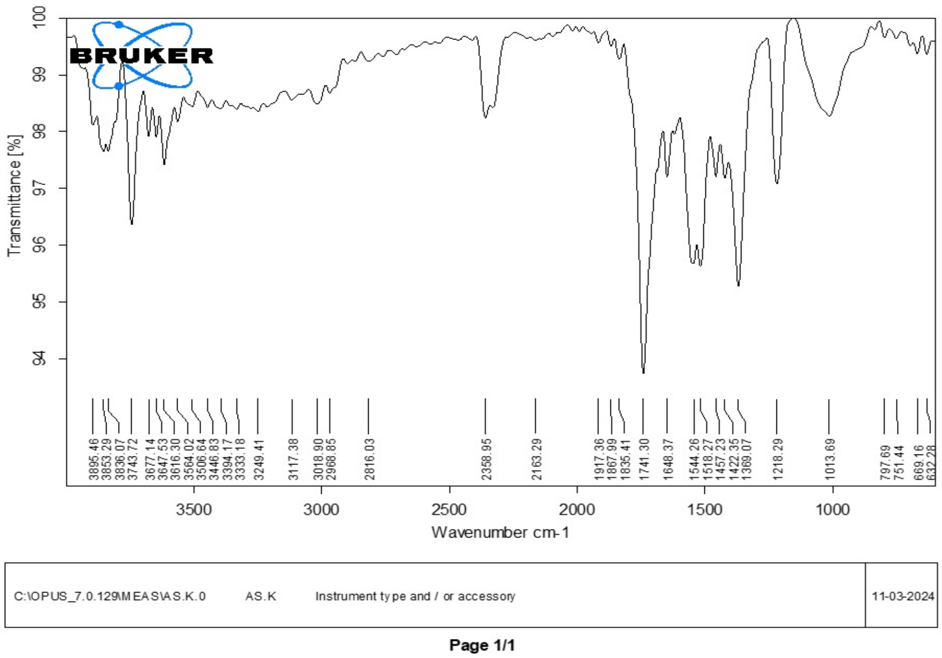


Figure 3: FT-IR spectra of KNPs synthesized using *Artocarpus hirsutus* leaves extract

The observed variations in wave numbers for these peaks in KNPs compared to other compounds may stem from conjugation, influenced by synthesis temperature. It is proposed that functional groups present in the *Artocarpus hirsutus* extract are likely to be responsible for reducing, capping and stabilizing the synthesized KNPs. This finding aligns with similar studies on plant-mediated synthesis of nanoparticles. Specifically, the synthesis of potassium nanoparticles by Judith et al[10] and magnetite nanoparticles by Shweta et al[15] corroborate this result.

SEM Micrographs and EDX Analysis of Synthesized KNPs: Figure 4 presents SEM micrographs showcasing the synthesized KNPs, revealing near-spherical particles with an average size of 68 nm. However, non-uniform distribution and agglomeration of nanoparticles were observed, potentially attributed to the concentration of the precursor used as well as biomolecules and secondary metabolites present in *Artocarpus hirsutus* leaves extract. This extract contains numerous naturally derived secondary metabolites with notable reducing capacities. The abundance of antioxidants and secondary metabolites in *Artocarpus hirsutus* leaves renders it an excellent choice for the biosynthesis of KNPs.

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This finding resonates with similar outcomes demonstrated by Judith et al[10] in their synthesis of potassium nanoparticles from *Sideroxylon Capiri* and by Sheoran et al[14] in the biogenic synthesis of potassium nanoparticles. Moreover, parallels can be drawn from the biosynthesis of magnetite nanoparticles from *Polyalthia longifolia* leaves as documented by Shweta et al[15]. These similarities may stem from various factors such as the choice of precursor or the specific reaction conditions employed during synthesis.

EDX analysis: The elemental composition of the synthesized nanoparticles was determined through EDX analysis. Spectral data of KNPs revealed predominantly pure potassium (75.17%), followed by peaks of oxygen (19.63%) and sodium (2.61%) as shown in figure 5. Notably, a significant percentage of magnesium and sodium atoms was observed on the surface of the potassium nanoparticles. This observation could be attributed to the plant leaf extract used or impurities from the precursor including the 5% sodium hydroxide utilized in the synthesis process. The EDX results also indicated a strong signal at 3.3 keV, confirming the presence of potassium and organic components from plant biomaterials on the surface of the synthesized nanoparticles. This finding aligns with similar results reported by Judith et al[10] and Sheoran et al[14]. However, it is worth noting that Sheoran et al[14] reported higher results compared to Judith et al[10] and the current study, which could be attributed to differences in the potassium precursor utilized.

TEM analysis of KNPs: The TEM analysis of the dried KNPs powder revealed important insights into their morphology and size distribution. The TEM micrograph in figure 6 illustrates the nearly spherical formation of KNPs, with an average diameter of 68 nm. The observed distribution indicates that the majority of nanoparticles synthesized fall within the diameter range of 55-85 nm, suggesting uniformity in size. However, it is noteworthy that agglomeration of nanoparticles is observed, likely due to high surface energy and magnetic interactions between them. Despite this agglomeration, the nanoparticles maintain their nano-size characteristics.

Furthermore, the TEM results confirm that the dried black powder consists entirely of nano-sized particles, with cubic shapes observed. This confirmation underscores the nano-size characteristics of the synthesized particles, aligning with their intended application as nano fertilizers. Overall, the TEM analysis provides valuable insights into the morphology, size and distribution of the synthesized KNPs, supporting their potential efficacy as nano fertilizers for agricultural applications.

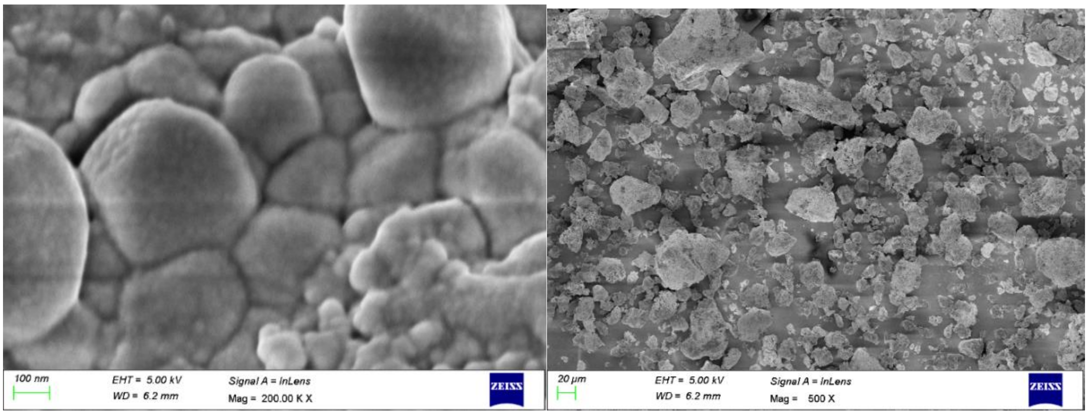

Figure 4: SEM micrographs of KNPs synthesized using *Artocarpus hirsutus* leaves extract

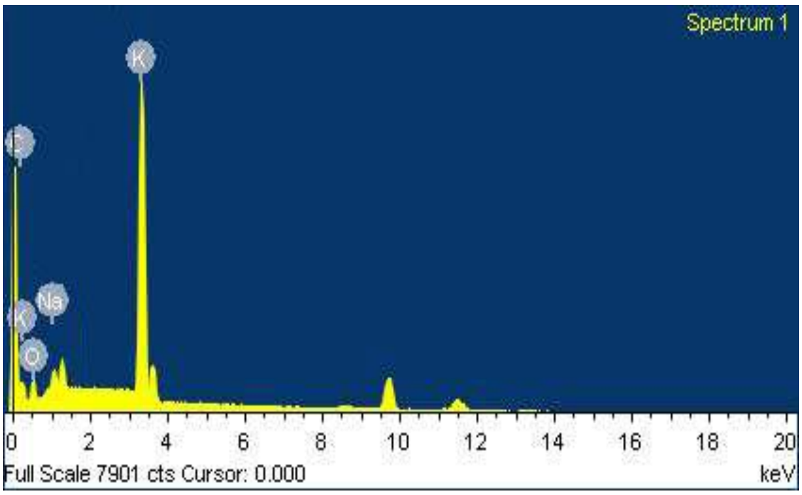

Figure 5: EDX spectra and quantitative elemental results of KNPs synthesized using *Artocarpus hirsutus* leaves extract

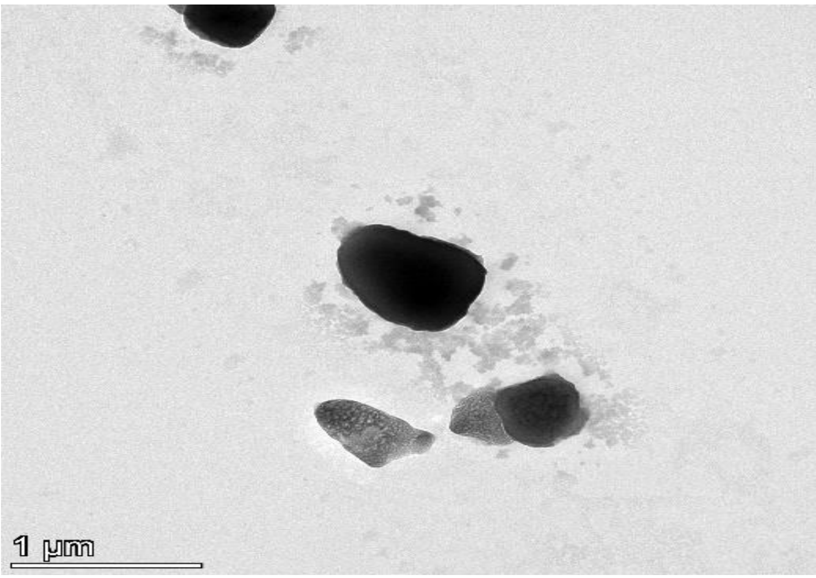

Figure 6: TEM images of KNPs synthesized using *Artocarpus hirsutus* leaves extract

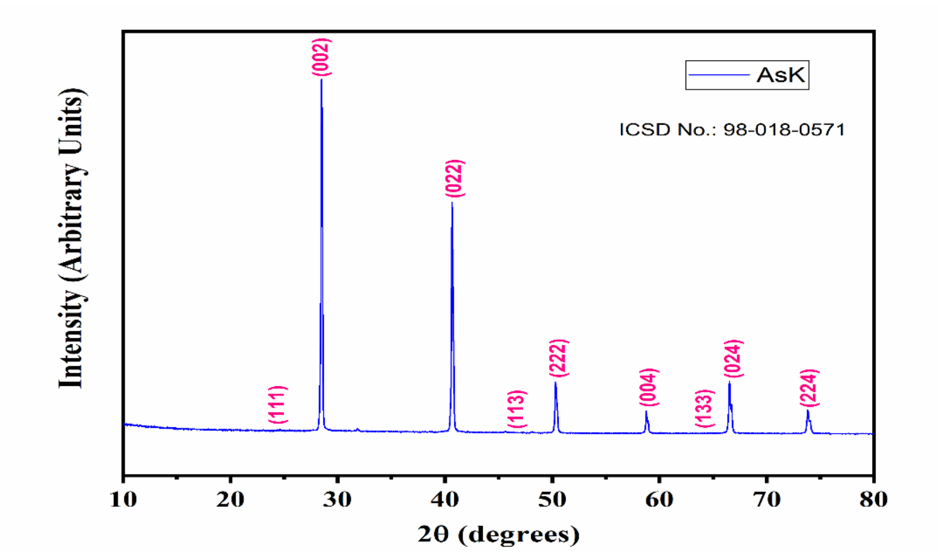

Figure 7: XRD spectra of KNPs synthesized using *Artocarpus hirsutus* leaves extract

XRD analysis: The XRD analysis was employed to examine the crystalline nature and crystallographic structure of the KNPs. As shown, there are 8 prominent peaks at 2θ° of 24.254°, 28.55, 40.126, 47.440°, 50.689°, 58.04°, 63.83°, 67.909° and 74.134° represented by the crystallographic planes (111), (002), (022), (113), (222), (004), (133), (024) and (224) respectively (Figure 7). These peaks are associated with distinct KNPs crystallographic planes according to the Yamanaka et al[18] and Blackman et al[4]. This reveals that crystalline KNPs were successfully fabricated due to the formation of NPs with a well-defined and ordered crystal structure, as evidenced by the presence of intense and sharp peaks. The presence of extra peaks in XRD could be attributed to the capping agent from the fungal extract, which was confirmed by EDX analysis.

DLS analysis and Zeta potential analysis: The smaller size of NPs is particularly significant for their integration across various applications. Smaller NPs exhibit higher stability in suspension and reduced aggregation or settling over time. Additionally, smaller sizes boast higher surface area-to-volume ratios, thereby potentially enhancing catalytic activity, as noted by Ruiz-Romero et al[13]. In the case of green-synthesized KNPs, the measured potential of -23.5 mV suggests the stability of NPs within the colloidal system.

Application of KNPs in seed germination of *Vigna radiata*: The integration of nanotechnology into agriculture holds significant promise for enhancing plant nutrient absorption and overall crop productivity. In our study, the application of prepared KNPs as a promoter for seed germination demonstrates the potential benefits of nanomaterials in agriculture. The observed increase in seed germination and growth after the application of KNPs compared to a blank sample highlights the effectiveness of these nanoparticles as growth promoters. The enhanced germination and growth can be attributed to several factors including the ability of nanoparticles to improve nutrient uptake by plants, to facilitate water absorption and to promote root development. Among all concentrations soil with KNPs concentrations, 500 µg/mL have shown predominant growth improvement in all considered parameters. The growth percentage of inoculated *Vigna radiata* sprouts was measured and soil with 500 µg/mL and 1000 µg/mL was found with 95% high growth percentage among all studied concentrations. Soil with 250 µg/mL concentration have shown less (65%) growth percentage than the blank (80%) soil. Impact of KNPs concentration on germination of *Vigna radiata* seeds at different time intervals is presented in figure 9. The results of growth percentage are presented and compared in table 1 and figure 10.

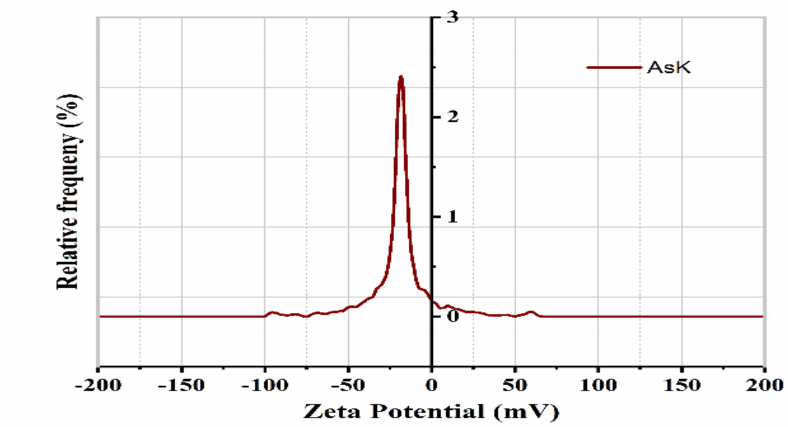

Figure 8: The Zeta potential value which shows the surface charge of –23.5 mV.

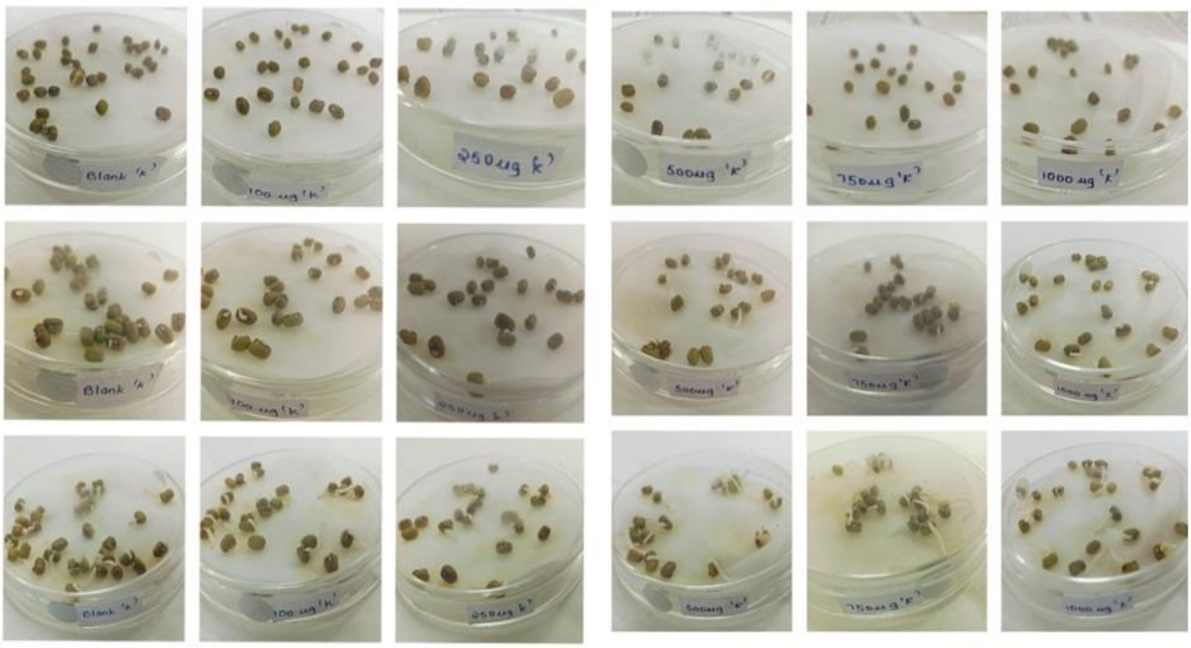

Figure 9: Impact of KNPs concentration on germination of *Vigna radiata* seeds at 0 hour (1st row), 24 hours (2nd row) and 48 hours (3rd row) respectively.

Table 1
Results of growth percentage of KNPs on of *Vigna radiata* seeds

KNPs concentration In µg/mL	No of plants grown	Growth percentage
Blank	16	80 %
100	17	85%
250	13	65%
500	19	95%
750	16	80%
1000	19	95%

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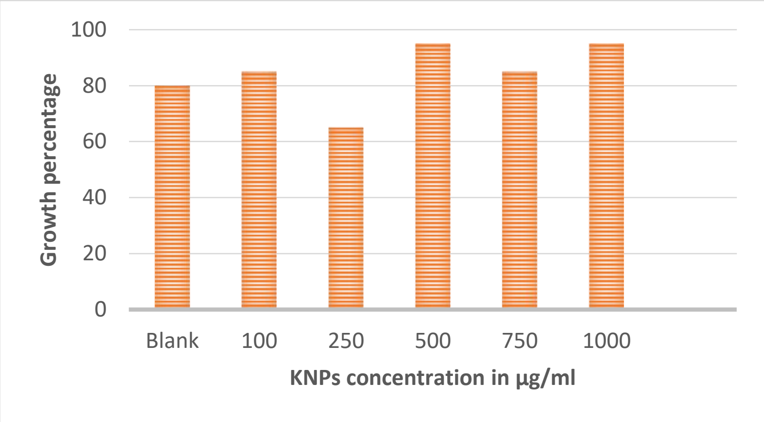

Figure 10: Comparison of seed germination percentage on of *Vigna radiata* seeds at different concentrations

Development Plants parts of *Vigna radiata* plant: The green synthesized KNPs were applied to *Vigna radiata* plant in different concentrations in order to evaluate the impact of KNPs concentrations. The growth characters such as number of plants grown, growth percentage, average height of plant, root length, leaf width were measured after 10 days of observation growth period. After completion of growth period, plants with high concentrations of KNPs were seen to have an intense green colouration signifying a higher chlorophyll pigment when compared with the controlled. This is because potassium is crucial in photosynthesis as it is involved in the synthesis of chlorophyll, contributing to healthy and vibrant foliage. A confident structural integrity of the foliar spray plant was also observed due to the contribution of potassium towards the strength and rigidity of plant cell wall, including those in the stem preventing them from becoming weak and brittle.

Similar results were shown by titanium oxide nanoparticles TiO_2 NPs, zinc oxide nanoparticles ZnO NPs.

The KNPs fertilized *Vigna radiata* plants showed an increase in number of plants grown, growth percentage, average height of plant, root length and leaf width as observed in all plants added with KNPs in soil compared with blank soil. The average height of the plants grew in different concentrations of KNPs measured and it was found that *Vigna radiata* plants have high growth at 1000 µg/mL (15.5 cm) soils compared with blank (15 cm), 500 µg/mL (15 cm), 250 µg/mL (11cm) and 750 µg/mL (14 cm) respectively. High growth was found at 1000 µg/mL concentrated soil where as low average growth was observed at 250 µg/mL. Length of the root from the radicle was measured and compared.

The average length of the root found that *Vigna radiata* plant root grew high at 500 µg/mL (8.1 cm) compared with blank (2.8 cm), 100 µg/mL (3.2 cm), 250 µg/mL (2.2 cm), 750 µg/mL (4.1 cm) and 1000 µg/mL (3.8 cm) respectively. The average leaf width of all the grown plant at 10th day was measured compared at different concentrations KNPs in soil. The average leaf width found that *Vigna radiata* plant root grew high at 500 µg/mL (1.9 cm) compared with blank (1.2 cm), 100 µg/mL (1.0 cm), 250 µg/mL (0.8 cm), 750 µg/mL (40.9 cm) and 1000 µg/mL (1.1 cm) respectively. The results concluded that KNPs concentration from 250 µg/mL and above have resulted in high growth activity in *Vigna radiata* plant.

The comparative plant growth characters were presented in the table 2 and growth plant on soils were presented in figure 6. It was observed that not all plants part showed direct and significant increase upon KNPs application in *Vigna radiate*. The most noticeable parameters with great difference were both the Leave length and the root width, root length and average plant length thus favouring the edible part of the plant. The growth characters of root and other parts are found very dominant in the 500 µg/mL from seed germination levels. Hence it is found that 500 µg/mL concentration of KNPs in soil was found optimum to induce the high growth of *Vigna radiata* plant. A graphic representation of impact of different concentrations of KNPs on *Vigna radiata* plant parts is presented in figure 11. Growth comparison of average plants with different concentrations of KNPs on *Vigna radiata* (green gram) plant is presented in figures 12 and 13.

The succulent nature of a plant's stem indeed plays a crucial role in providing balance and strength to support the plant's growth and the weight of its branches and fruits. As the plant grows taller, the stem's strength becomes increasingly important to withstand external forces like wind and to support the additional branches that will form, bearing more fruit. Furthermore, the length of the roots significantly impacts a plant's ability to survive drought conditions by allowing it to access water and nutrients from deeper soil layers.

Study of antioxidant capacity: The antioxidant activity of KNPs synthesized from *Artocarpus hirsutus* was evaluated using the DPPH assay, with DPPH serving as the negative control and ascorbic acid as the standard. Various concentrations of standard ascorbic acid, *Artocarpus hirsutus* plant extract and KNPs were prepared individually. The DPPH assay relies on spectrophotometric measurement of DPPH concentration changes resulting from its reaction with antioxidants. When DPPH accepts an electron donated by an antioxidant on the surface of the KNPs solution, it becomes decolorized, allowing quantitative measurement through absorbance changes.

Table 2
Results and comparison of growth parameter of KNPs on *Vigna radiata* plant

KNPs concentration In µg/ml	Average height of plant in cm*	Height of the plant			Root length in cm*	Leaf width in cm*
		Height	Moderate	low		
Blank	15	17	15	6	2.8	1.2
100	15	20	15	7	3.2	1.0
250	11	14.8	11	5.4	2.2	0,8
500	15	22	15	6	8.1	1.9
750	14	15.8	14	6	4.1	0.9
1000	15.5	20.5	15.5	7	3.8	1.1

*cm= centimetre

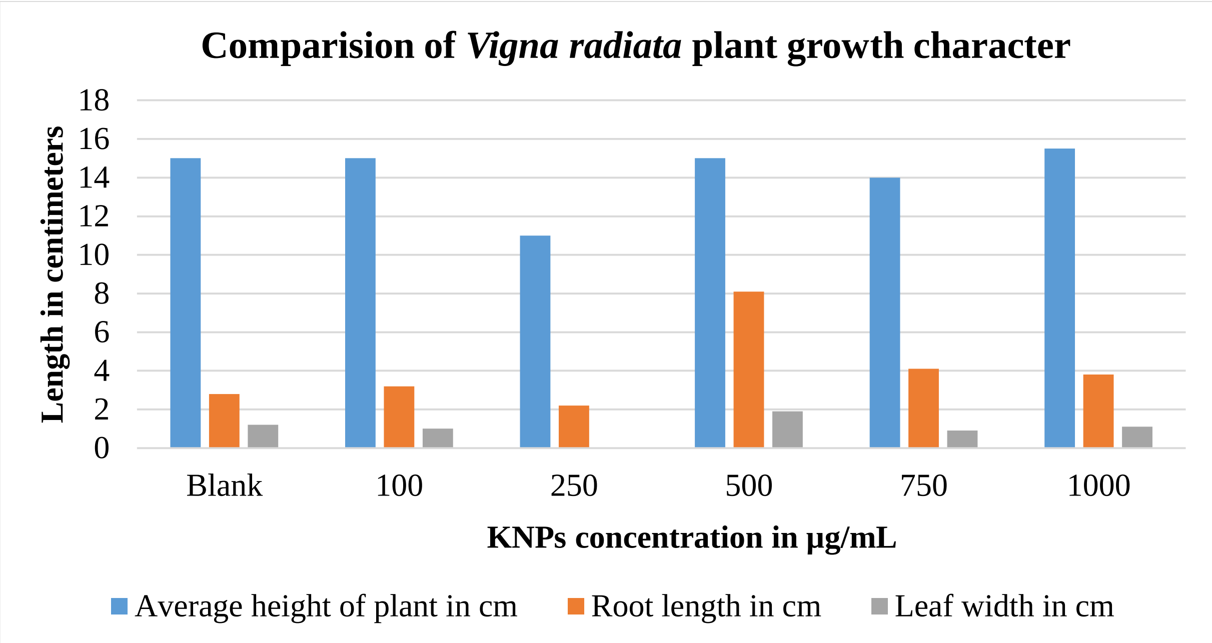

Figure 11: Comparison of growth parameter of KNPs on *Vigna radiata* plant

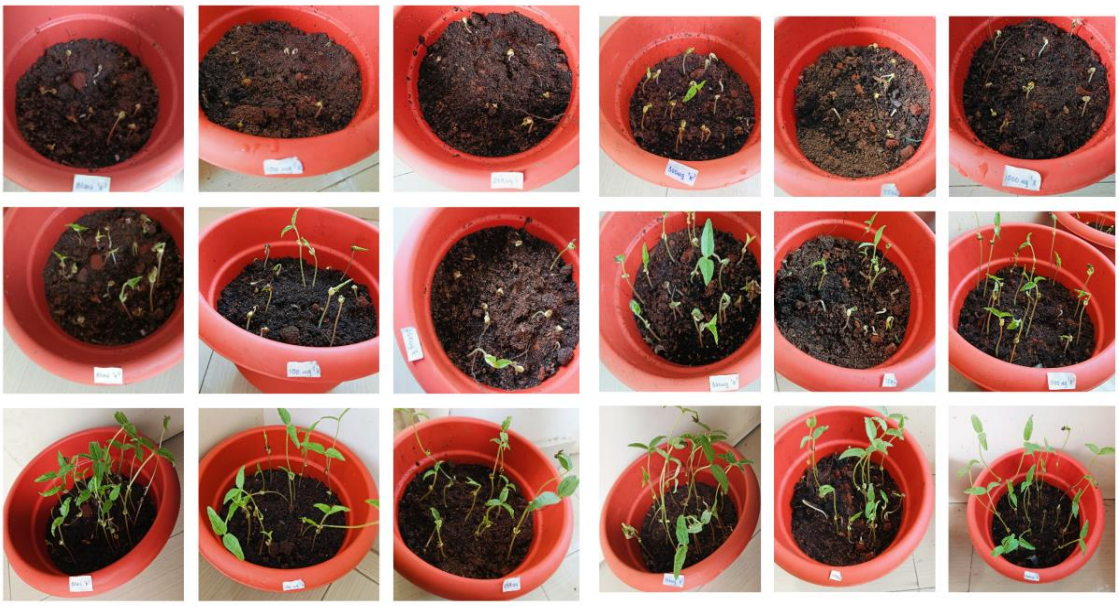

Figure 12: Impact of KNPs concentration on germination of *Vigna radiata* seeds at 1 day (1st row), 4 day (2nd row) and 10 days (3rd row) respectively.

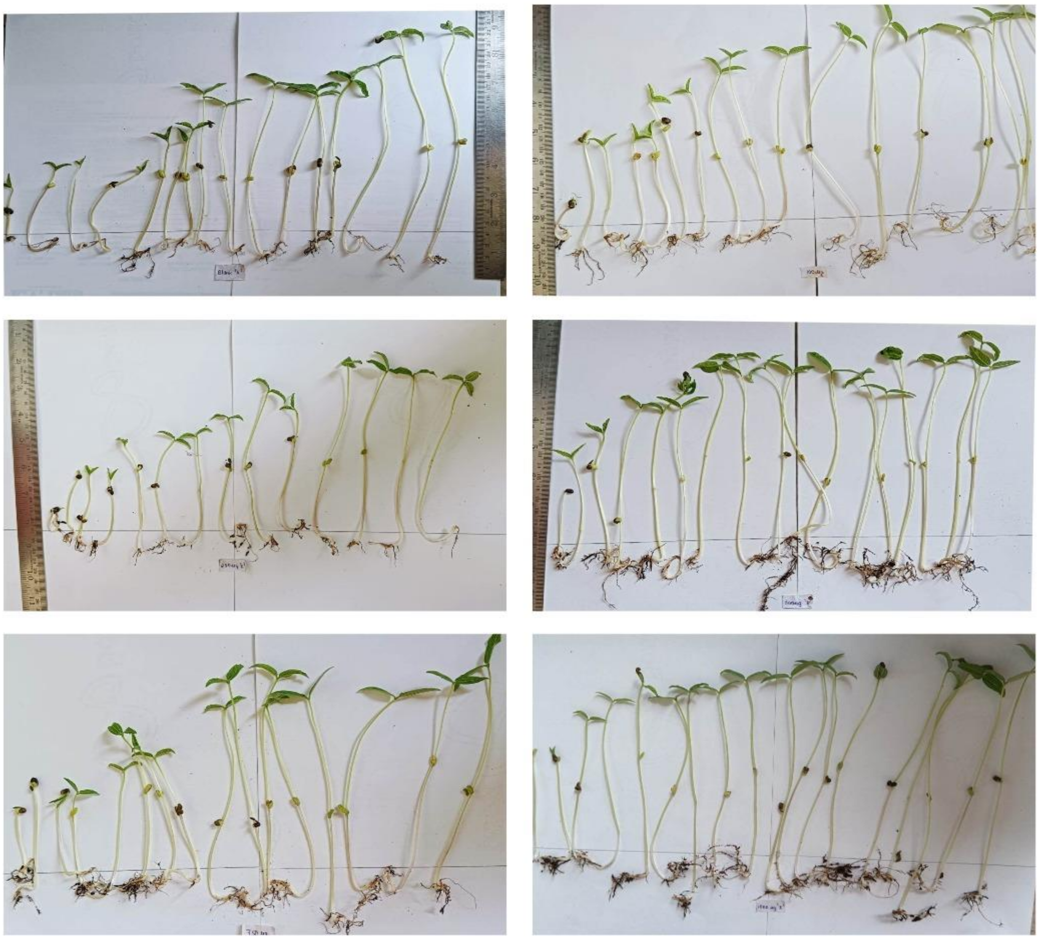

Figure 13: Growth comparison of average plants with different concentrations of KNPs on *Vigna radiata* plant

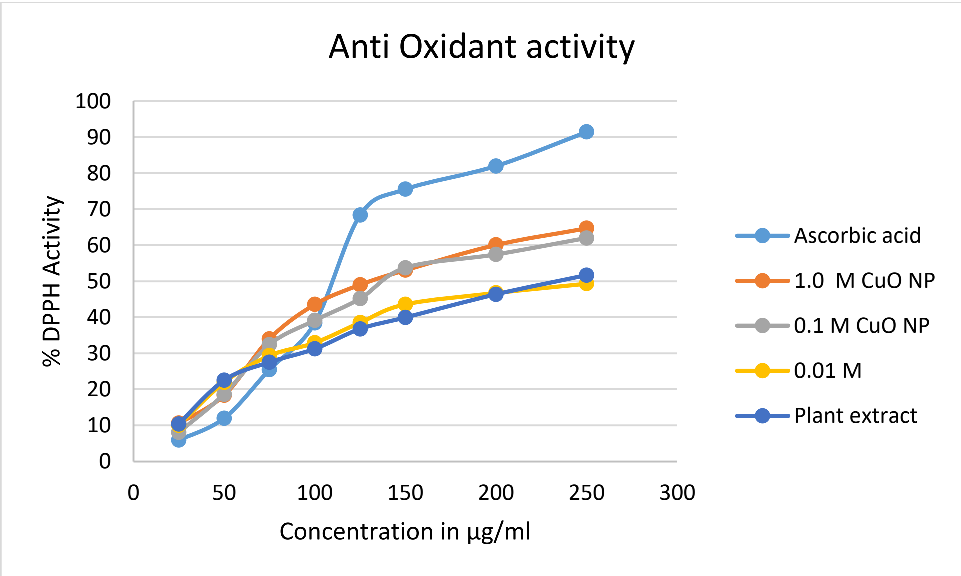

Figure 14: Comparative anti-oxidant activity of KNPs at different concentration (1.0 M, 0.1 M and 0.01 M) and aqueous extract of *Artocarpus hirsutus* plants

The antioxidant activity of KNPs, plant extract and standard ascorbic acid was compared graphically and is presented in figure 14. Antioxidant activity was expressed as the percentage of DPPH inhibition, indicating the ability of antioxidants to reduce DPPH free radicals. The IC50 value, representing the concentration at which 50% of DPPH radicals are inhibited, was used to quantify antioxidant strength. Ascorbic acid exhibited the lowest IC50 value of 91.5 µg/mL followed by 127.5 µg/mL for green-synthesized KNPs (127.5 for 1.0 M, 138.5 for 0.1M and 162.3 for 0.01

M) and 170.1 µg/mL for *Artocarpus hirsutus* plant extract. Hence it is confirmed that the synthesized KNPs indicated that nanoparticles synthesised with 1.0 and 0.1 M potassium solution have a strong antioxidant property as compared to the control.

Conclusion

These KNPs biosynthesized using the extract of *Artocarpus hirsutus* leaves for foliar application on the *Vigna radiata* plant are an innovative approach toward better nutritional and growth improvements of plants. Round in shape and ~68 nm in size, as revealed by SEM, it shows uniformity and suitability for foliar application, efficient to be absorbed by plant tissues. It also confirms from FTIR that functional groups are responsible for the capping and stabilization of nanoparticles to ensure their stability and to measure their activity during application. This could mean that the potassium ions will be released for a longer period to make nutrients available continuously to the plants. Also, from the EDX spectra, elemental composition analysis shows potassium at 75.17%, followed by peaks of oxygen at 19.63% and sodium at 2.61% for the requirements of a very effective nano fertilizer.

The remarkable growth across different concentrations of seeds treated with KNPs underlines the positive impact that nanotechnology has on seed germination and early plant development. The synthesized KNPs have been reported to show effective anti-oxidant activity with nanoparticles synthesized from 1.0 M and 0.1 M potassium solutions. The present study shows seed germination enhancement and improvement in early plant growth upon application of KNPs. These findings add to the small but growing body of research in exploring applications of nanomaterials to revolutionize agricultural practices toward challenging global food security.

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