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Effect of Nano-NPK and Nano-Chitosan Fertilizers on the Growth and Chemical Constituents of *Philodendron sellum* Plants

Emam Nofal[1], Fardous A. Menesy[1], Walid M. Abd El-Hady[2], Eman G. Shehab[2], Hassan El-Ramady[3] and **József Prokisch [4]**

(1) Horticulture Department, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Egypt
(2) Ornamental Plants and Landscape Gardening Research Department, Horticulture Research Institute, Agriculture Research Center, Egypt
(3) Soil and Water Department, Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, Egypt
(4) Institute of Animal Science, Biotechnology and Nature Conservation, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 138 Böszörményi Street, 4032 Debrecen, Hungary

NANOFERTILIZERS have great promise as a tool for environmentally friendly farming. Fertilizers of this type may have a high nutrient use efficiency and a slow-release nutrient profile, meaning they provide plants with the nutrients they need for an extended period of time, unlike mineral fertilizers. A pot study was conducted under plastic house condition at a private nursery in Mansoura City, Dakahlia Governorate, Egypt during two successive seasons of 2021 and 2022. The purpose of this study was to assess the effects of foliar application of nano-NPK and nano-chitosan at varying doses on the physiochemical characteristics and growth of *Phildedron* plant. Using the treatments of mineral NPK (3 g L^{-1}) as a control and nano-NPK at (1, 2 and 3 mg L^{-1}) as well as 2 mg L^{-1} nano-NPK combined with (1, 2, and 3 mg L^{-1}) nano-chitosan for each seedling. The obtained results showed that all nano fertilizer treatments increased all studied parameters especially with the treatmemt of 3 mg L^{-1} nano-NPK for vegetative growth parameters (plant height, fresh and dry weights of aerial parts/plant and leaf area) by 39.23, 70.84, 51.50 and 15.80%, respectively over the control and highest mean value for root growth (root length, root fresh and dry weights) and superiority chemical constituents (chlorophyll a, b and carotenoids, membrane stability index as well as mineral N, P and K (%), peroxidase and catalase activities) compared to the control treatment. The highest significant values of these traits and chemical constituents were observed for the treatments of either NPK nanofertilizer at 3 mg L^{-1}or nano-NPK at 2 mg L^{-1}plus nano chitosan at 3 mg L^{-1}.

Keywords: Nanofertilization, chitosan, antioxidants, carotenoid, *Phildedron*.

1. Introduction

The Araceae family includes the ornamental plant *Philodendron sellum*. Originating in South America, this plant is a tropical beauty. Because of its adaptability to indoor settings, appealing dark green foliage, big, chiny leaves with deeply lobed foliage, and widespread usage as a houseplant, this plant is quite valued (El-Shawa et al. 2022). Its primary utilized in grand patios, entryways, and palaces and villas.

Nano-fertilizers significantly improve plant nutrition, when applied to soil or sprayed over the vegetative system (Singh et al. 2024a; Singh et al. 2024b). According to El-Ramady et al. (2023), biological nanofertilizers in particular have great promise as a tool for environmentally friendly farming. Fertilizers of this type may have a high nutrient use efficiency and a slow-release nutrient profile, meaning they provide plants with the nutrients they need for an extended period of time, unlike mineral fertilizers (Haydar et al. 2024).

There are various types of nanofertilizers, including those based on macronutrients (N, K, P, etc.) (Chakraborty et al. 2023). In comparison to mineral fertilizers, nano-fertilizers produce a great deal more during the seedling growth stage, increasing plant height, number of leaves /plant, dry matter,

*Corresponding author e-mail: ramady2000@gmail.com
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leaf area, chlorophyll synthesis, and photosynthesis rate (Shalaby et al. 2022; Sundararajan et al. 2024; Haydar et al. 2024). Because of its wide surface area and capability, the N, P, and K micronutrients in nanocomposite fertilizer promote the absorption and use of nutrients by crops (Yang et al. 2023). NPK nanoparticles play a significant role in enhancing plant growth, since nitrogen has a stimulative influence on production of auxin, which promotes cell elongation and division during the vegetative growth stage of a plant. The amino acid tryptophan is a key building block for indole acetic acid, a key plant hormone, and it is an essential factor for its construction (Mahmoud and Swaefy 2020).

Natural polymer nano-chitosan is produced when chitin, which is found in fungi, insects, and crustaceans, is deacetylated. Al-Dhabaan et al. (2018) describe chitin as a naturally occurring polysaccharide that is composed of a copolymer of D-glucosamine and napethyl-D-glucosamine residues connected by b-1,4 glycosidic linkages. It can be found in the cell walls of some algae and fungus, the cuticles of insects, and the shells of crustaceans among other species. In addition to enhancing growth, chitosan nanoparticles (Ch-NPs) are powerful antimicrobials that can kill harmful bacteria and fungi (Yu et al. 2021). Román-Doval et al. (2023) found that chitosan, a bio-stimulant, boosts plant productivity and growth rate. Applying nano-chitosan to seedlings' leaves increased their photosynthetic pigments, chemical content, and macronutrients, as well as their vegetative development characteristics (Elshamy et al. 2019; Divya et al. 2022). Foliar application of nano-chitosan to *Kigelia africana* resulted in a marked improvement in growth and chemical components compared to the control group (Nofal et al. 2024). Nano-chitosan has been shown in numerous studies to have potential uses in biomedical attributes, energy storage, drug delivery, biosensing, and electronic fields, among others. These include agricultural applications (Shrestha et al. 2023), energy storage (Rostami and Khodaei 2023), biomedical attributes(Hassan et al. 2024), and biosensing.

Therefore, the objective of this study was to investigate the impact of nano-NPK and nano-chitosan as a foliar application at varying doses on the growth and chemical content of *Philodendron sellum* plants during the seedling growth stage By discussing its effect on the vegetative growth, chemical content of leaves, photosynthetic pigments, and antioxidant activity.

2. Materials and Methods

During the summers of 2021 and 2022, a number of pot experiments were carried out at a private nursery in Mansoura City, Dakahlia Governorate, Egypt (the site is located at 31.05º N latitude and 31.3833º E longitude). The study was conducted under plastic hous condition (27± 1ºC and 60-65% RH). Prior to cultivation, the soil used in each season was examined (Table 1) in accordance with (Sparks et al. 2020).

2.1 Plant materials

On March 25th, transplants uniform length of 19±1 cm was acquired from a private nursery located in Dakahlia Governorate, Egypt, and placed in a plastic house during the two-seasons. On April 11th, the plants were then planted in 30 cm diameter pots (10 kg) clayey loam soil. Every five days, the pots were manually irrigated with fresh tap water. A completely randomized block design was used with 7 treatments were evaluated and 3 replicates of each treatment were used, with each replicate holding six plants. Using mineral NPK (3 g L^{-1}) as a control and 1, 2 and 3 mg L^{-1} of nano-NPK at as well as 2 mg L^{-1} nano-NPK + 1, 2, and 3 mg L^{-1} nano-chitosan for each seedling, foliar spraying was applied on May 1st (Fig. 1). In both experimental seasons, foliar spraying was carried out in the mornings till runoff, with 15-day intervals. On the second day after applying 2 mg L^{-1} NPK, nano-chitosan was sprayed into the leaves.

2.2 The source of used treatments

Composed of 20% nitrogen, 20% phosphorus, and 20% potassium, the mineral NPK fertilizer (EGY FLEX, as commercial fertilizer 20:20:20) is manufactured by Egyptian Chem International for Agrochemicals. Nano-NPK was developed and manufactured by Biota EG Company. Its composition includes 4.0% nitrogen, 4.0% phosphorus, and 4.0% potassium. Biota EG Company manufactured a 2% solution of nano-chitosan (Ch-NPs). Fi. 2 (A and B) displays the results of nano-NPK and nano-chitosan Transmission Electron Microscopy (TEM). Thermo Fisher, Europe's Talos L120CG2 TEM model was used to measure these nanoparticles directly. For nano-NPK and nano- chitosan, the average sizes of the nanomaterials used was 274.2 and 302.6 nm, respectively. The studied concentrations were prepared by dissolving the required rate (mg) from every fertilizer in 1 L distilled water.

2.3 Vegetation parameters

At the end of experimental seasons during the first week of November in 2021 and 2022, the following data were recorded, including plant height (cm), fresh and dry weights, leaf area (cm^2) and leaf membrane stability index (MSI) as well as root growth traits as; root length (cm), fresh and dry weights (g).

2.4 Estimating chlorophyll

Chlorophyll content was measured using a gram of freshly chopped leaves was ground with 20 ml of

80% acetone. Then, it was centrifuged for 5 minutes at 5,000 rpm. Using 80% acetone, the volume was increased to l00 ml after transferring the liquid to a volumetric flask (100 ml). Using a spectrophotometer (Double beam UV/Visible spectrophotometer Libra S80PC, England), the solution's absorbance was red at 645 nm for chl a and 663 nm for chl b (mg/g. f.w.), which calculated using the following equation according to (Rajalakshmi and Banu 2015):

Chlorophyll a (mg/gm fw)=

[12.7(A663) – 2.69(A645)] V/1000W

Chlorophyll b (mg/gm fw)=

[22.9(A645) – 4.68(A663)] V/1000W

Where A = Absorbance of specific wavelength, V = Final volume of chlorophyll extract in 80% acetone and W = Fresh weight of tissue extract**.**

2.5 Estimating total carotenoids

Estimation of total carotenoids concentration was done using the same chlorophyll extract in a spectrophotometer (Double beam UV/Visible spectrophotometer Libra S80PC, England) reading at 470 nm (Sumanta et al. 2014), then using the following equation:

Total carotenoids (mg g-1 FW) =

(1000A470 - 1.82 Chl. a – 85.02Chl. b)/198

Where A = Absorbance at respective wave length, Chl. a= chlorophyll a and Chl. b= chlorophyll-b.

Table 1. Physio-chemical analysis of the used soil during 2021 and 2022 seasons.

Seasons	Coarse sand	Fine sand	Silt	Clay	Texture class	pH	EC, dS m^{-1}	SOM, %	Available nutrients (ppm)		
									N	P	K
2021	3.14	26.82	30.82	39.22	**Clayey loam**	7.97	1.74	1.34	43.18	9.48	312.51
2022	3.16	28.64	29.85	38.90		7.89	1.94	1.70	42.06	10.11	289.37

In both seasons, pH and soil electrical conductivity (EC) were determined in soil suspension (1:5) and saturated soil paste extract, respectively. SOM: soil organic matter

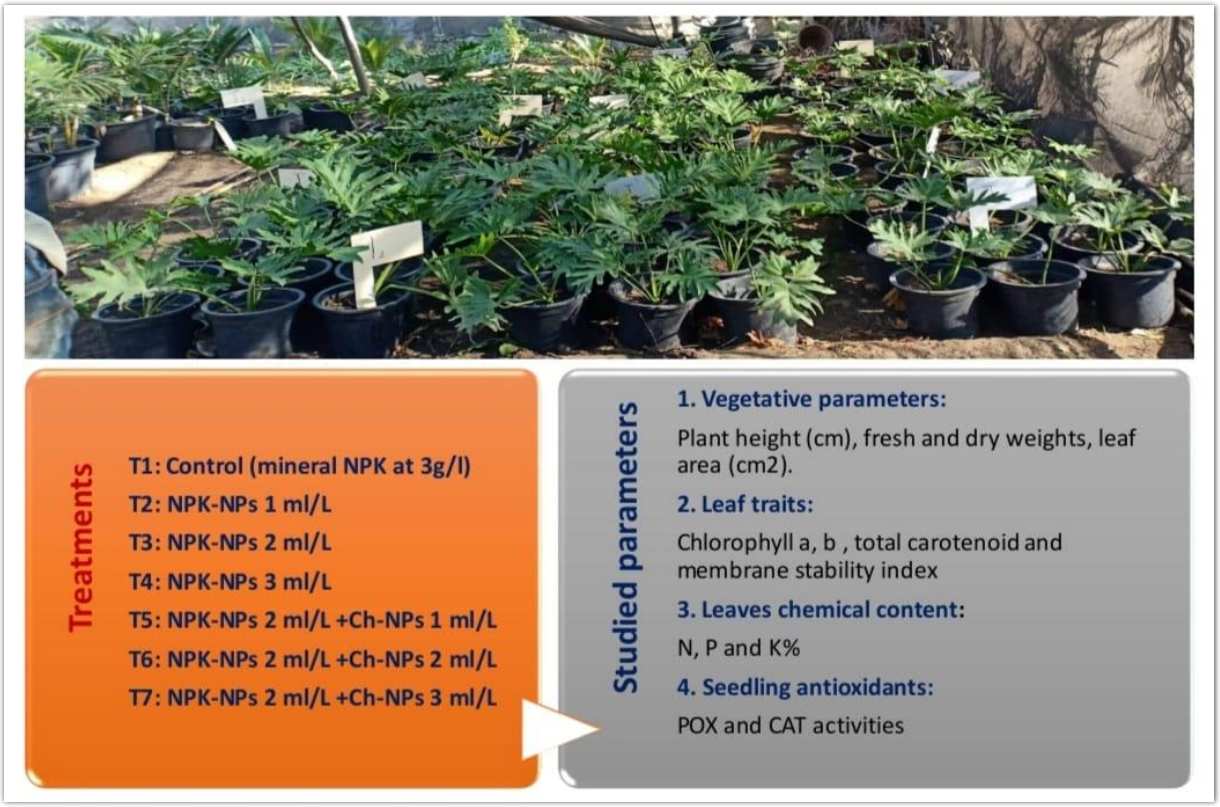

Fig. 1. A synopsis of the primary study treatments and studied traits.

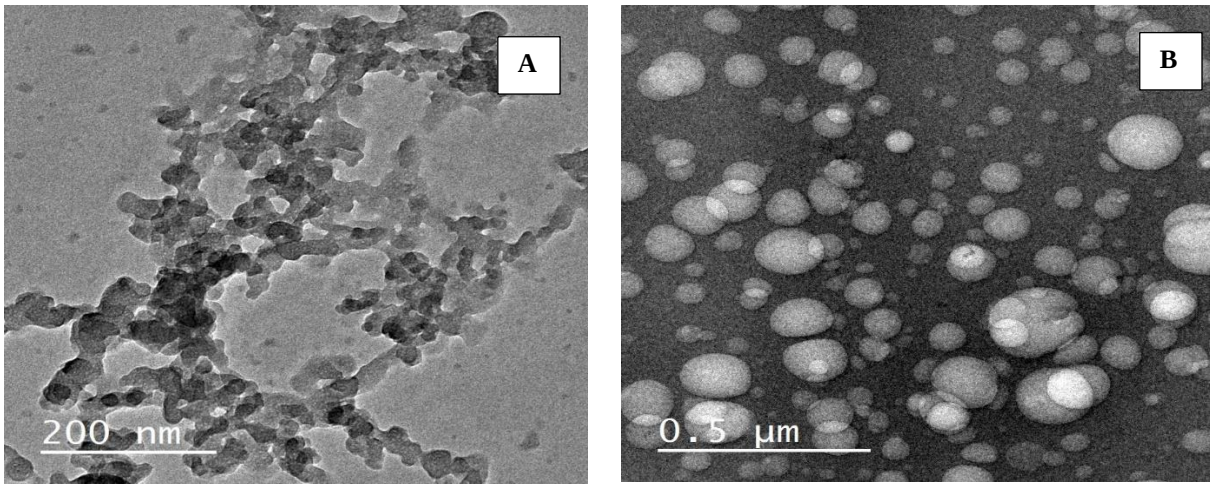

Fig. 2. TEM imaging of NPK-NPs (A) and chitosan-NPs (B) (274.2 and 302.6 nm, respectively).

2.5 Membrane stability index

Membrane stability index (MSI) was calculated in accordance with (Sairam et al. 1997). 200 mg of leaf disks were placed in two sets of test tubes with 10 ml of distilled water each. Electrical conductivity (C1) was measured after one set was maintained at 40°C in a water bath for 30 minutes. After 15 minutes of incubation at 100°C, the electrical conductivity (C2) of the second batch was measured. The following formula was used to calculate:

$$MSI\ (\%)=1(-C1/C2)\times 100$$

2.6 Chemical composition of leaf

Using 0.2 g of the digested solution, the Kjeldahl device, a spectrophotometer (Jenway 6405), and a flame photometer (Jenway PFP7, Staffordshire, UK) were used to estimate the N, P, and K content in the dried leaves, respectively.

2.7 Enzyme activity measurement

To determine the Catalase (CAT) and peroxidase (POX) activity, 0.3g of leaves were soaked in liquid nitrogen, 2 ml of homogenization solution was added, and then the mixture was centrifuged for 15 minutes at 12,000 × g and 4°C. The homogenized media as: 0.1 M potassium phosphate buffer (pH 6.8), 1 mM PMSF, 0.1 mM EDTA, and 1% PVPP (weight/volume) (Peixoto et al. 1999). To test the CAT (EC1.11.1.6) activity, 2.9 ml of an enzymatic extract was combined with a reaction solution comprising 50 mM potassium phosphate buffer (pH 7.0 and 12.5 mM H_20_2) according to (Havir and McHale 1987). At a temperature of 25°C, the absorbance began to drop at 240 nm after one minute of reaction. (Anderson et al. 1995) used 36 mol/L/cm of molar extinction coefficient to compute the enzymatic activity, which is represented as µmol of H_2O_2 min/mg of protein. Using the purpurogallin generation rate at 420 nm and 2.47 mmol/cm of molar extinction coefficient, the method proposed by (Nakano and Asada 1981) was used to determine the POX activity (EC 1.11.1.7). The enzyme activity was measured in µmol purpurogallin min/g FW. A spectrophotometer (Jenway 405, Japan) was used to assess CAT and POX.

2.8 Statistical analyses

The statistical differences between treatments were calculated using the means±SE. Data was analyzed, mean comparisons were made using Duncan's test (Duncan 1955) at $p < 0.05$ (Gomez and Gomez 1984), and ANOVA was performed using Costate (version 6.303, Cohort, USA, 1998-2004).

3. Results

3.1 Vegetative growth traits

Results showed that all rates of NPK-NPs or NPK-NPs + Ch–NPs considerably enhanced the growth traits compared to the control treatment (traditional NPK fertilizer), as shown in Table (2), which displays data of *Philodendron sellum* growth aspects such as plant height, fresh and dry weights, and leaf area. The control treatment scored the lowest value for these features, while plants treated with 3 mg L^{-1} NPK-NPs, 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch–NPs, and 3 mg L^{-1} chitosan produced the highest values. There was a marked decrease in values for the other treatments. After treatment with 3 mg L^{-1} NPK-NPS, the rate of increase was 37.50% for plant height, 70.84% for fresh weight /plant, 51.50% for dry weight and leaf area increased by 15.79%.

Table 2. Some vegetative growth parameters of *Phyllodendron sellum* plants as affected by foliar applied of nano-NPK and nano chitosan (average of two growing seasons).

Treatments	Plant height, cm	Fresh weight of aerial parts / plant (g)	Dry weight of aerial parts / plant (g)	Leaf area, cm^2
T1: Control (mineral NPK at 3 g L^{-1})	39.37f±3.57	55.87e±1.58	12.99f±0.10	258.73g±1.30
T2: NPK-NPs 1 mg L^{-1}	43.23e±2.53	72.29d±2.09	16.04d±0.08	278.40e±2.20
T3: NPK-NPs 2 mg L^{-1}	48.12bc±0.92	84.33c±2.43	18.16c±0.17	289.08c±2.58
T4: NPK-NPs 3 mg L^{-1}	54.03a±1.19	95.45a±2.19	19.68a±0.16	299.60a±1.64
T5: NPK-NPs 2 mg L^{-1}+Ch-NPs 1 mg L^{-1}	45.31de±2.89	69.43d±1.78	15.43e±0.13	275.98f±2.15
T6: NPK-NPs 2 mg L^{-1} +Ch-NPs 2 mg L^{-1}	45.90cd±0.91	80.84c±1.97	15.47e±0.07	285.43d±1.39
T7: NPK-NPs 2 mg L^{-1} +Ch-NPs 3 mg L^{-1}	48.69b±1.32	91.59b±2.34	19.00b±0.15	296.10b±2.30
F- test	**	**	**	**

Mean±SE in the same column with the same letter do not differ significantly by Duncan's test at 5% level

3.2 Root growth traits

Table 3 shows that as compared to a control treated with mineral NPK, treatments with NPK-NPs or NPK-NPs + Ch–NPs considerably enhanced root length, fresh weight, and dry weight. Treatment with 3 mg L^{-1} of NPK-NPs resulted in the greatest values for root length, fresh weight, and dry weight of roots, followed by treatment with 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch–NPs. In contrast, the control treatment yielded the lowest values for the root parameters. There was a marked decrease in values for the other treatments. Root parameters were found to increase with foliar application of 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch–NPs. The root metrics showed the greatest growth at the highest rate of nano NPK, with a 94.54% rise in root length, a 57.44% increase in fresh weight, and a 108.17% increase in dry weight.

Table 3. Root parameters of *Phyllodendron sellum* plants as affected by foliar applied of nano-NPK and nano chitosan (average of 2021 and 2022 seasons).

Treatments	Root length cm	Root fresh weight (g)	Root dry weight (g)
T1: Control (mineral NPK at 3 g L^{-1})	35.77f±1.09	82.59g±0.09	13.94g±0.02
T2: NPK-NPs 1 mg L^{-1}	48.67de±1.12	105.22e±1.48	22.21e±0.30
T3: NPK-NPs 2 mg L^{-1}	55.31c±1.31	118.07c±1.63	25.56c±0.36
T4: NPK-NPs 3 mg L^{-1}	69.59a±1.69	130.03a±1.86	29.02a±0.41
T5: NPK-NPs 2 mg L^{-1}+Ch-NPs 1 mg L^{-1}	46.92e±1.20	102.58f±0.09	21.24f±0.03
T6: NPK-NPs 2 mg L^{-1} +Ch-NPs 2 mg L^{-1}	51.50d±1.18	113.55d±1.60	24.75d±0.32
T7: NPK-NPs 2 mg L^{-1} +Ch-NPs 3 mg L^{-1}	65.26b±2.91	127.12b±1.75	27.89b±0.04
F- test	**	**	**

Mean±SE in the same column with the same letter do not differ significantly by Duncan's test at 5% level

3.3 Photosynthetic pigments

The results shown in Figure 4 (A, B, and C) that compared to the control treatment, all of the NPK-NPs and NPK-NPs + Ch–NPs treatments considerably raised the chlorophyll a, b, and total carotenoids levels. Treatments with 3 mg L^{-1} NPK-NPs (T4) followed by 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch–NPs (T7) produced the greatest values for these features, while most other treatments had much lower values.

3.4 Membrane stability index (MSI)

Figure 4 (D) further shows that the membrane stability index was considerably higher after all

treatments than the control treatment. Results indicated that the foliar application with 2 mg L^{-1} NPK-NPs (T4) treatment produced the greatest values, followed by the 2 mg L^{-1} NPK-NPs + 2 mg L^{-1} Ch–NPs (T7) treatment. Significantly lower values were produced by the other treatments.

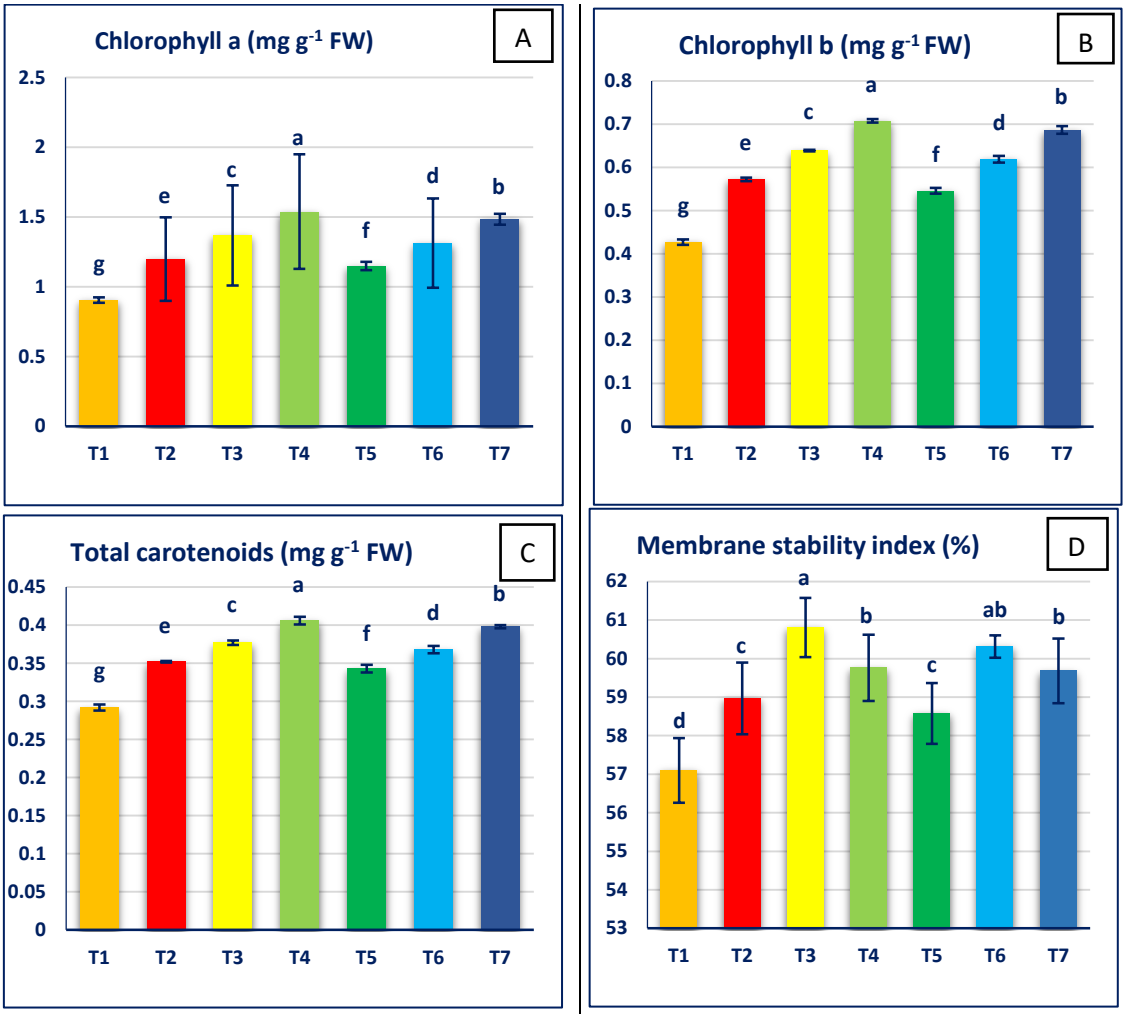

Fig. 4. Pigment contents in mg/g. f.w (chl a (a), chl b (b), carotenoid (c) and MSI (d) as affected by foliar applied of nano-NPK and nano chitosan (average of 2021 and 2022 seasons) represented the standard error ±SE.

T1: Control; T2: NPK-NPs 1 mg L^{-1} ; T3: NPK-NPs 2 mg L^{-1} ; T4: NPK-NPs 3 mg L^{-1} ; T5: NPK-NPs 2 mg L^{-1} +Ch-NPs 1 mg L^{-1} ; T6: NPK-NPs 2 mg L^{-1} + Ch-NPs 2 mg L^{-1} and T7: NPK-NPs 2 mg L^{-1} +Ch-NPs 3 mg L^{-1}

3.5 Leaves chemical composition

The results shown in Figure 5 (A, B, and C) realize that the N, P, and K content in the leaves were increased with increasing doses of all treatments, including NPK-NPs alone or in combination with Ch-NPs. The treatment with 3 mg L^{-1} NPK-NPs (T4) resulted the highest values of N, P, and K content in the plant leaves, with 3.92, 0.526, and 2.73%, respectively. The next treatment with 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch-NPs (T7) produced 3.86, 0.522, and 2.70% for N, P, and K content, while the control treatment yielded the lowest values at 3.24, 0.462, and 2.15%, respectively.

3.6 Antioxidant activity

All NPK-NPs and NPK-NPs + Ch-NPs treatments improved the up-regulation of enzyme activity in the Philodendron leaves for peroxidase and catalase, according to findings shown in Fig. 6 (A and B). The significantly highest activity resulted from the treatment of 3 mg L^{-1} NPK-NPs (T4) followed by the treatment of 2 mg L^{-1} NPK-NPs + 3 mg L^{-1} Ch-NPs (T7). The other treatments gave significantly less activity. The highest increase rate in POX and CAT activities were resulted from the treatment of 3 mg L^{-1} NPK-NPs as gave 106.01 and 92.32% respectively.

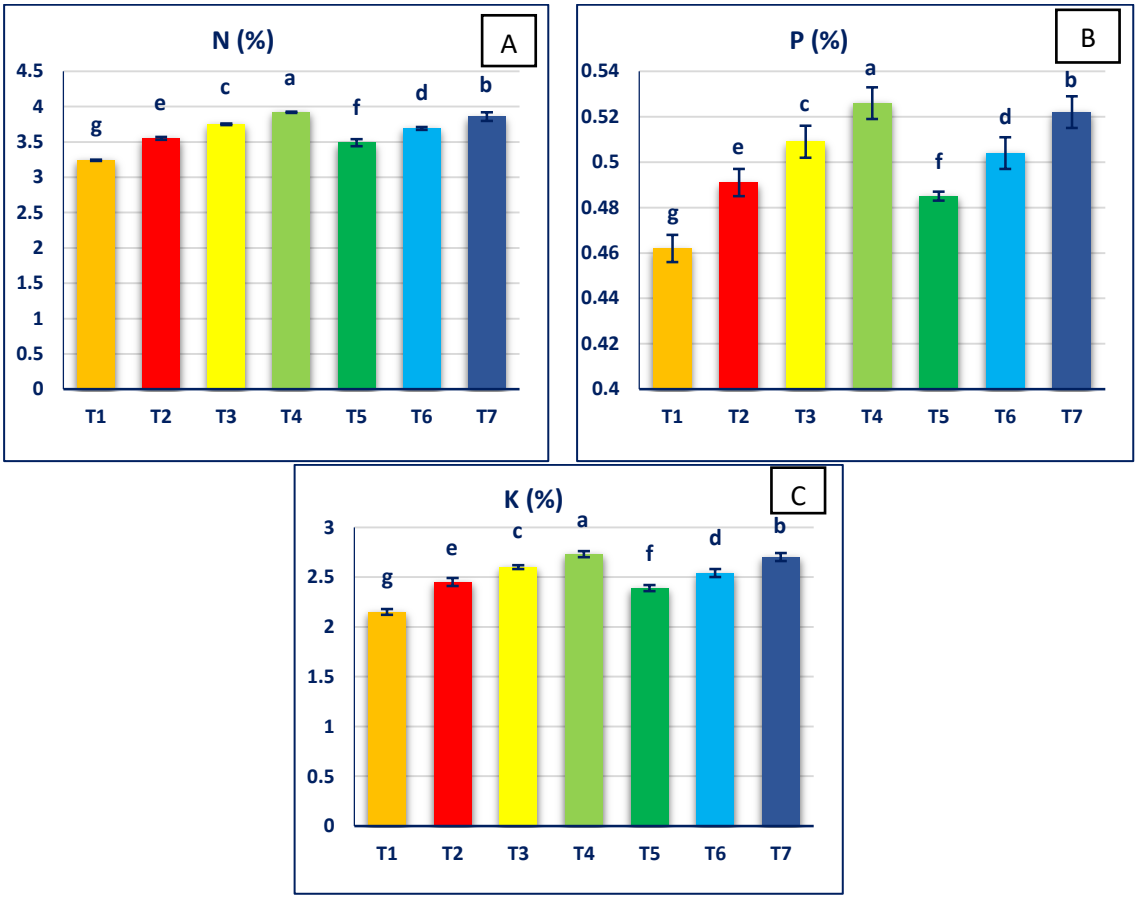

Fig. 5. N, P and K% of *Phyllodendron sellum* plants as affected by foliar applied of nano-NPK and nano chitosan (average of 2021 and 2022 seasons) represented the standard error ±SE.

T1: Control; T2: NPK-NPs 1 mg L^{-1} ; T3: NPK-NPs 2 mg L^{-1} ; T4: NPK-NPs 3 mg L^{-1} ; T5: NPK-NPs 2 mg L^{-1} +Ch-NPs 1 mg L^{-1} ; T6: NPK-NPs 2 mg L^{-1} + Ch-NPs 2 mg L^{-1} and T7: NPK-NPs 2 mg L^{-1} +Ch-NPs 3 mg L^{-1}

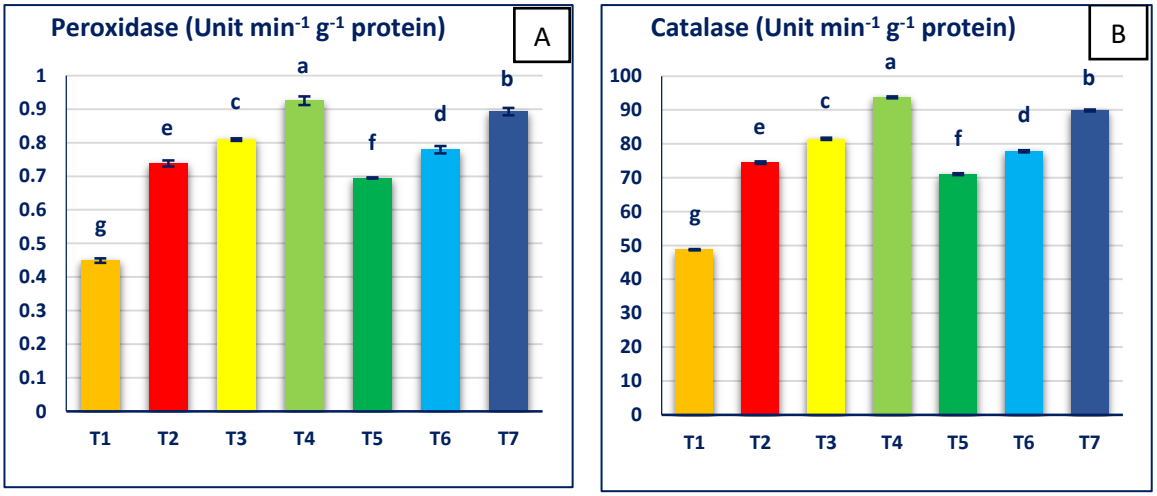

Fig. 6. Effect of nano-NPK and nano chitosan foliar fertilizer on enzyme activity (POX and CAT) of *Phyllodendron sellum* plants represented the standard error ±SE. (average of 2021 and 2022 seasons)

T1: Control; T2: NPK-NPs 1 mg L^{-1} ; T3: NPK-NPs 2 mg L^{-1} ; T4: NPK-NPs 3 mg L^{-1} ; T5: NPK-NPs 2 mg L^{-1} +Ch-NPs 1 mg L^{-1} ; T6: NPK-NPs 2 mg L^{-1} + Ch-NPs 2 mg L^{-1} and T7: NPK-NPs 2 mg L^{-1} +Ch-NPs 3 mg L^{-1}

4. Discussion

Producing enough high-quality plants to meet the demands of a growing global population while limiting negative effects on the environment has become the top priority of modern agriculture. This prompted researchers to consider applying nanotechnology to farming (Ingle et al. 2022). There are a number of potentials agriculturally useful complexes formed by the amine group of chitosan and the negatively charged polymers (Orzali et al. 2017).

Nanoparticles (NPs) can be used to increase plant growth and stress tolerance (Seleiman et al. 2020). Because of their tiny size and high surface area, NPs exhibit characteristics that are different from bulk materials; this includes a higher surface reactivity (Seleiman et al. 2020; Wang et al. 2021; Mohamed et al. 2022). In this study, Ch-NPs improved metabolic processes, increased photosynthetic efficiency, and boosted resistance to antioxidant enzymes, among other vegetative and biochemical characteristics. According to (Sathiyabama and Manikandan 2021; Faizan et al. 2021), once CH-NPs penetrate leaf tissue, they can be carried to the core of plant cells, where they can enhance the plant's resistance. The processes that underlie this reaction appear to entail the activation of both non-enzymatic antioxidants (phenolic chemicals) and antioxidant enzymes. In order to promote plant growth, various types of chitosan are used in the field. When applied to plants, chitosan increases their photosynthetic rate, closes their stomata, and enhances antioxidant enzymes by way of signaling pathways including nitric oxide and hydrogen peroxide. A key component of pathways for energy metabolism and stress tolerance, it also promotes the manufacture of metabolites such as organic acids, sugars, and amino acids (Behboudi et al. 2018).

As a plant growth stimulant, ChNPs have been reported in many studies (Mohamed et al. 2022). In this study, Ch-NPs improved metabolic processes, increased photosynthetic efficiency, and boosted resistance to antioxidant enzymes, among other vegetative and biochemical characteristics. These findings are consistent with what has been reported in other research on various crops, including wheat (Hajihashemi and Kazemi 2022), grapes (Aazami et al. 2023), *Catharanthus roseus* (L.) G. Don. (Hassan et al. 2021) and *Kigelia africana* (Nofal et al. 2024). One possible explanation is that the nano fertilizers' reduced diameter makes them more able to pass past the plant cell wall and into the plasma membrane, where they can exert their effects.

When compared to traditional NPK, Nano-NPK has approximately 10,000 times greater surface area due to its nanoscale particles (Kumar et al. 2023). As a result, according to (Upadhyay et al. 2023), the nano-NPK particles exhibit a high surface area to volume ratio, special magnetic characteristics, electronic states, and catalytic processes. The very high reactivity of nano-fertilizers as compared to traditional fertilizers is a manifestation of their unique features (Grillo et al. 2021; Mohamed et al. 2022). The capacity of the nanoparticles to connect with carrier proteins via ion channels and aquaporin tends to promote various metabolic processes in plant systems, leading to an increase in photosynthate production (Kumar et al. 2023). Additionally, according to (Upadhyay et al. 2023), nanofertilizers facilitate nutrient absorption in accordance with plant nutrient demands. The role of nano-fertilizer and its ready-to-absorb form of nutrients (N, P, and K) is also attributed to the reason of nano-fertilizer is important in boosting meristematic activity and generating carbon-forming enzymes and plant hormones, which in turn positively reflected in an increase in plant height, stem diameter, number of side branches, number of leaves, leaf area, and chlorophyll production, ultimately increasing the efficiency of the building process. Al-Tamimi et al. (2023) state that photosynthesis, the buildup of nutrients and carbohydrates, improving the root's capacity to absorb water and nutrients and store them inside plant cells, and photosynthesis all contribute to the plant's increased absorption of mineral elements. It is most likely because of the function of the mineral NPK nanoparticles, where nitrogen participates in the synthesis of DNA and RNA, some plant hormones, including IAA, different enzymes, and vitamins, as well as works to promote cell division and elongation and increase meristematic activity (Upadhyay et al. 2023). It might be because of the function of phosphorous, which in plant tissues works to generate the organophosphate chemicals required for the synthesis of phospholipids and

nucleic acids (El-Azizy and Habib 2021). Regarding the role of potassium, the most significant cation in plant physiology, for its physiological, chemical, and essential processes, including promoting the growth of meristem tissue and dividing cells (Haydar et al. 2024). Could be the result of nanoparticles working together to boost vegetative development, mineral element absorption, and metabolic processes, all of which increase the chemical composition of leaves (Abd et al. 2020). Our results are in agreement with those of Hasaneen et al. (2016) on French bean (Elshamy et al. 2019), Ha et al. (2019), (Ashraf et al. 2022) and (AL-Malikshah and Abdulrasool 2024) on potato, (Nofal et al. 2024) on *Kigelia africana* plant are a few of the recent publications that highlight the increased productivity of various crops when nano-chitosan combined with nano-NPK. This combination shows promise as a nano-based fertilizer that can be administered in both normal and stressful situations, which is in line with the results of earlier investigations.

The proposed mechanisms of applied nano-chitosan could be summed up in **Figure 7**. Due to its unique qualities, such as biocompatibility, biodegradability, non-toxicity, and extraordinary adaptability, chitosan nanoparticles have become a viable instrument in agricultural improvements (Riseh et al. 2024). Agricultural production, nutrient absorption, and pest management can all be improved with the help of Ch-NPs due to their intrinsic qualities as well as their antibacterial, antioxidant, and eliciting capabilities.Therefore, the current research anticipates the synergistic effect of nano-NPK and nano-chitosan on plant growth.

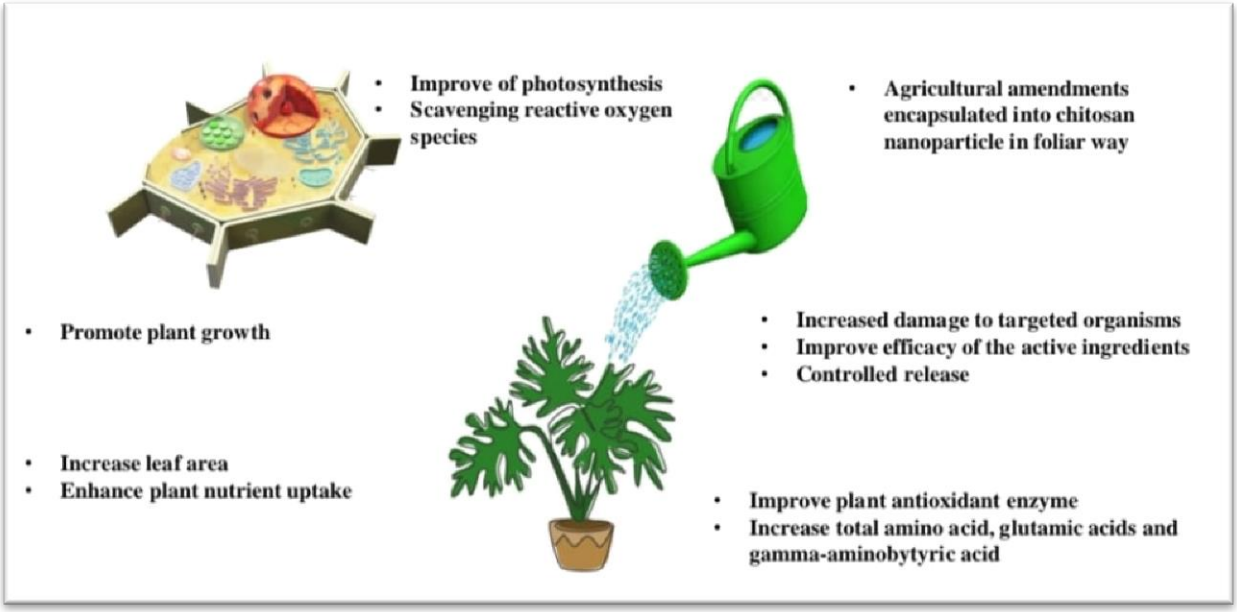

Fig. 7. The proposed mechanisms by using of nano-chitosan.

Nanofertilizers and growth of seedlings

Seedlings of different horticultural plants recorded distinguished response to applied nano-fertilizers. Depending on the kind of nanofertilizers, the response of seedlings can be positive under low applied dose and the right time, but negative under higher applied doses (**Table 4**). Applied nano-NPK fertilizers were investigated on different ornamental seedlings under different stresses like soil salinity or normal (non-stressful) conditions. The main factors are controlling this impact can be presented in **Table 4**. Salinity stress can reduce many physiological parameters, but applied nano-NPK can promote this effect. It could notice from Table 4 that improving studied parameters by increasing applied dose of nano-NPK fertilizer under both stressful and nno-stressfull conditions.

Table 4. Impacts of applied different kinds of nanofertilizers on plant species under different conditions.

Seedling species	Nanofertilizer (dose and size)	Experimental conditions	Main findings	Ref.
Kigelia africana (Lam.) Benth	2 mg L^{-1} nano-NPK (308 nm) + 2 mg L^{-1} nano-chitosan (302.6 nm)	Saline soil (4.5 dS m^{-1})	Improved seedlings tolerance stress via vegetative growth, photosynthetic pigments and antioxidants (CAT, POX)	[1]
Coffee seedlings	Chitosan-NPs loaded in KNO_3 at dose from 10 - 50 mg L^{-1} (500 nm)	Under green-house using Ferrasols	As nanofertilizer enhanced growth coffee seedlings via high uptake of nutrients and photosynthesis	[2]
Tomato seedlings	Bacteria-based MnO-NPs (2.5-5.0 mg ml^{-1}; 22 nm)	Polluted soil with Pb (50 mg L^{-1})	Seed nano-priming mitigated toxic lead by improving carotenoid and chlorophyll contents, proline and sugar accumulation	[3]
Tomato and chilli seedlings	Green ZnO-NPs from 10 to 500 mg L^{-1} (40-50 nm)	Sand culture growth for 28 days	Lower doses (10 mg L^{-1}) improved seed germination and seedling growth, and metabolism of plants, higher are toxic	[4]
Cowpea (*Vigna unguiculata* L. Walp.)	Green CuO-NPs from 25 to 100 mg L^{-1} (122 nm)	Pots using soil and foliar applications	Optimum dose was 50 and 40 mg L^{-1} for soil and foliar application increased plant growth compared to control	[5]
Brassica oleracea var. italica seedlings	Green Fe_3O_4-NPs at 15 and mg L^{-1} (30–80 nm)	Sand culture growth with Cd (50 mg L^{-1})	Nanofertilizer alleviated the deleterious effect of Cd-toxicity on plants by inducing the anti-oxidative stress	[6]
Without plants	Chitosan nano-fertilizer (259.4 nm)	Incubation of sandy loam for 60 days	Zn-chitosan nano-composite is plausible to enhance crop growth through addition economical for soil application	[7]
Rice (*Oryza sativa* L.) seedlings	Fe_3O_4-NPs (20–30 nm), nanohydroxy-apatite (60-80 nm)	Hydroponics polluted Cd, Pb for 14 d	Applied nano (up 1000 mg L^{-1}) increased accumulation of Cd in rice roots and decreased the Pb and Cd in the cell wall	[8]
Rice (*japonica rice*) variety Gangyu 6	Nanoclinoptilolite based-urea fertilizer (100 nm)	Field exper. silty loam soil, pH 6.76	Applied nano reduced ammonia volatilization and runoff loss along with romoted N-balance in rice field	[9]
Philodendron sellum L.	Nano-NPK (2 mg L^{-1}) + nano-micro-nutrients (2 mg L^{-1})	Pots exper., non-saline soil	Nanofertilizers improved the chlorophyll a, b and carotenoids, as well as mineral N, P and K (%), peroxidase and catalase activities) compared to control treatment	[10]

Refs. [1] Nofal et al. (2024a), [2] Ha et al. (2019), [3] Anar et al. (2024), [4] Singh et al. (2024), [5] Mustafa et al. (2024), [6] Singh et al. (2023), [7] Cyriac et al. (2023), [8] Wu et al. (2023), [9] Sun et al. (2024), [10] current study

5. Conclusion and Future Prospective

The use of regular or foliar application of nanofertilizer (nano-NPK and nano-chitosan) on *Philodendron sellum* plants at varying concentrations has been shown to result in notable and significant increases in all growth metrics. Foliar treatment of either 3 mg $L^{-1}$of nano-NPK or 2 mg $L^{-1}$of nano-NPK combined with 3 mg $L^{-1}$of nano chitosan every 15 days demonstrates the optimal use of nanofertilizers and improves the development, productivity, and chemical composition of *Philodendron sellum* plants. Overuse of fertilizer to increase crop yields does not always result in improved growth; instead, it endangers public health and has detrimental effects on the environment. However, more field research

is required to determine the impact of various agrochemical inputs on the growth and metabolism of various plant species as well as to guarantee the safety of plants treated with nanotechnology for use by humans and animals. Further research is also needed on the mechanisms underlying the uptake and production of nanoparticles in plants. Additional research on this crop is required, with a particular emphasis on its molecular characteristics. When conducting an inquiry into fertilizers based on nanotechnology, it is crucial to take into account the ecological and economic elements of the matter.

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