

# Nano-Chitosan Loaded N Application for Improving Wheat Plants Yield: Impacts on Soil Nutrient Availability

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## Abstract

This work was held to study the effect of chitosan nanoparticles and loaded N on the wheat plants. A field study was conducted during the winter season 2021/2022 cultivated with wheat (*Triticum aestivum* L.) on sandy soil at the experimental unit of the Faculty of Agriculture farm-Suez Canal University-Ismailia-Egypt. Results may indicate that the application of foliar chitosan NPs.-loaded nitrogen in different concentrations has been employed to enhance plant growth and productivity, Nano-chitosan loaded with N (500 mg/L) yielded the most grains and was more effective than the control and nano-chitosan loaded N (250 mg/L, 750 mg/L).

## Keywords

Nano Fertilizer, NPK, Chitosan, Wheat, Sandy Soil

## 1. Introduction

World agricultural cropping systems intensively use large amounts of fertilizers, to achieve more production per unit area but using more doses than optimum of fertilizers leads to several problems like environmental pollution (soil, water, and air pollution), low input use efficiency, decreased quality of food material, less income from the production, soil degradation, deficiency of micronutrient in soil and toxicity to different beneficial living organism present above and below the soil surface [1]-[3]. Nanofertilizers have recently gained popularity in agriculture for increasing crop production, improving nutrient usage efficiency and lowering chemical fertilizer waste and cultivation costs. Furthermore, it facilitates direct nutrient

absorption utilization efficiency and a rapid response to crop development [4].

Nano-fertilizers enhance growth parameters (plant height, leaf area, number of leaves per plant) dry matter production, chlorophyll production, and rate of photosynthesis which results more production and translocation of photosynthesis to different parts of the plant compared with traditional fertilizers [5] [6]. Therefore, the aim of this study was to determine the effect of foliar feeding of nanoparticle loaded different N levels and combination of NPK fertilizer compared with control and traditional fertilizer on wheat yield and yield components.

Nitrogen (N) is widely recognized as a crucial primary nutrient required by plants. Consequently, the delivery of nitrogen enhances and optimizes the growth and productivity of different field crops [7] [8]. Significant efforts have been made to reduce nutrient losses and enhance agricultural yield by controlling release based on demand and improving plant uptake using porous nanomaterials like chitosan [9]. Conventional N fertilizers experienced losses of 50% - 70%, leading to decreased efficiency and higher production costs. This approach has significantly improved the yield of crops [10] [11].

Chitosan, a natural polymer derived from deacetylation of chitin, has been found to positively impact plant growth in roots, shoots, and leaves [12]. However, trials on chitosan in organic and conventional crops showed variable results. Also, [13] reported that the chitosan application increased yield by nearly 20% in tomato trials. Chitosan nanoparticles have the ability to promote development and effectively resist pathogenic fungus and bacteria as antimicrobial agents [14]. Alternatively, chitosan can also serve as nanocarriers for existing agrochemicals, resulting in the creation of chitosan-based agronanochemicals [15]. The nanocarrier system allows for the encapsulation of the agriculturally active chemical by ionic or covalent inter/intramolecular interactions, or by trapping it in a polymeric matrix of chitosan. This results in the development of an efficient nanodelivery system formulation [16].

According to [17] controlled-release chitosan microspheres loaded with nitrogen may be gradually released into the soil, thereby lowering the amount of nutrients that are lost and enhancing the overall utilization of fertilizer. This would allow plants to meet their nutrient requirements at various phases of development. The application of nano-formulated fertilizers has a substantial capacity to enhance crop yield [18]. [19] investigated the effectiveness of nano-chitosan-loaded N in preserving mineral N levels when applied in maize-based maize-soybean intercropping, while also improving land productivity. They found that the utilization of nano-chitosan-loaded nitrogen composite reduces the amount of applied nitrogen by roughly 25% of the acceptable rate, hence mitigating potential environmental damage. The aim of this study is to investigate the effect of nano-chitosan-loaded nitrogen with different concentrations on wheat growth and soil nutrient availability.

## 2. Materials and Methods

### 2.1. Preparation of Chitosan Loaded-N Nanoparticles

A modified ionic gelation method for producing chitosan nanoparticles was described

by [20]. To load different concentrations of nitrogen into chitosan nanoparticles, the appropriate amount of N was dissolved into 50 mL of chitosan nanoparticle solution under magnetic stirring for 8 hours at 25°C. This resulted in final concentrations of 250, 500 and 750 ppm of N.

## 2.2 Field Experiment

To study the effect of different levels of chitosan nanoparticles loaded N on wheat growth and productivity, a field study was conducted during the winter season 2021/2022 cultivated with wheat (*Triticum aestivum* L.) on sandy soil at the experimental unit of the Faculty of Agriculture farm-Suez Canal University-Ismailia-Egypt. Some physical and chemical properties of a sandy soil before planting were shown in (Table 3). The treatments were control (without any fertilizers), chitosan NPs., and chitosan NPs. loaded N (250 ppm), chitosan NPs. loaded N (500 ppm) and chitosan NPs. loaded N (750 ppm). The treatments were arranged in a randomized complete block design having four replicates using flood irrigation (Basin irrigation) system each plot was 2 m<sup>2</sup>. The treatments were foliar sprayed at wheat plants every two weeks after 15 days of the planting date.

## 3. Result and Discussion

### 3.1. Results

The results in (Table 1) show the effect of different levels of nano-chitosan-loaded N on wheat plant growth. The results showed that the root length of wheat plants ranged between 11.49 and 13.39 cm. The highest root length of wheat plants was observed at nano-chitosan-loaded N (500 mg/L). The data showed that there were no significant differences between the root length at the chitosan NPs. Treatment and the nano-chitosan loaded N (250 mg/L) treatment. The results showed that the nano-chitosan-loaded N (250 mg/L) treatment was highly significant in shoot length and plant height (85.62 cm and 98.36 cm, respectively). Also, the data showed that there were no significant differences between nano-chitosan-loaded N with different concentrations (250, 500, and 750 mg/L) of spike length. The number of spikelet and main spikes was 12.45 at chitosan NPs. Treatment, less than the number of spikelet and main spikes at nano-chitosan loaded N with different concentrations (250, 500, and 750 mg/L) treatments. The grain number on the main spike is higher in the nano-chitosan-loaded N treatments compared to the control and chitosan nanoparticles. Also, the results showed that treatment with chitosan nanoparticles (130.23 g) had the highest 1000 grains weight compared to other treatments. Nano-chitosan loaded with N (500 mg/L) yielded the most grains at 8728 kg·ha<sup>-1</sup>. The treatment was more effective than the control and nano-chitosan loaded N (250 mg/L). Chitosan NPs. increased the yield of grains to 7966 kg·ha<sup>-1</sup>. The Nano-chitosan loaded N (250 mg/L) treatment resulted in grain yield 8554 kg·ha<sup>-1</sup>, greater than the control Also, grain yield of 5428 kg·ha<sup>-1</sup> was achieved with nano-chitosan loaded N (750 mg/L), which was higher than the control but lower than the other treatments (Table 1). The nano chitosan

loaded N (500 mg/L) treatment showed a significant increase in grain production ( $\text{kg}\cdot\text{ha}^{-1}$ ) compared to the control, with a percentage increase of 104.83%. The results indicated that the grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) increased by 100.75% with nano-chitosan loaded N (250 mg/L), 27.38 with nano-chitosan loaded N (750 mg/L) and by 86.95% with chitosan NPs compared to the control.

**Table 1.** Effect of nano-chitosan loaded N levels on plant growth parameters.

Treatments	Root length (cm)	Shoot length (cm)	Plant height (cm)	Spike length (cm)	Number of spikelet/main spike	Grain number/main spike	1000 grains weight (g)	Grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ )	Straw yield ( $\text{kg}\cdot\text{ha}^{-1}$ )	Biological yield ( $\text{kg}\cdot\text{ha}^{-1}$ )	Harvest index	Crop index
Control	11.49 <sup>b</sup>	73.27 <sup>c</sup>	84.77 <sup>c</sup>	5.94 <sup>b</sup>	10.87 <sup>c</sup>	18.03 <sup>c</sup>	92.64 <sup>ab</sup>	4261 <sup>c</sup>	3433 <sup>c</sup>	7695 <sup>c</sup>	1.23 <sup>ab</sup>	0.55 <sup>ab</sup>
Chitosan Nanoparticles	12.16 <sup>ab</sup>	76.92 <sup>bc</sup>	89.09 <sup>bc</sup>	6.83 <sup>b</sup>	12.45 <sup>b</sup>	26.18 <sup>b</sup>	130.23 <sup>a</sup>	7966 <sup>ab</sup>	4705 <sup>bc</sup>	12,672 <sup>ab</sup>	1.69 <sup>a</sup>	0.61 <sup>a</sup>
Nano-chitosan loaded N (250 mg/L)	12.73 <sup>ab</sup>	85.62 <sup>a</sup>	98.36 <sup>a</sup>	9.16 <sup>a</sup>	16.23 <sup>a</sup>	36.35 <sup>a</sup>	91.85 <sup>ab</sup>	8554 <sup>ab</sup>	6308 <sup>a</sup>	14,286 <sup>ab</sup>	1.26 <sup>ab</sup>	0.56 <sup>ab</sup>
Nano-chitosan loaded N (500 mg/L)	13.39 <sup>a</sup>	81.28 <sup>ab</sup>	94.67 <sup>ab</sup>	9.25 <sup>a</sup>	15.93 <sup>a</sup>	42.08 <sup>a</sup>	85.65 <sup>ab</sup>	8728 <sup>a</sup>	6772 <sup>a</sup>	1550 <sup>a</sup>	1.30 <sup>ab</sup>	0.56 <sup>ab</sup>
Nano-chitosan loaded N (750 mg/L)	13.34 <sup>a</sup>	80.92 <sup>ab</sup>	94.26 <sup>ab</sup>	8.73 <sup>a</sup>	15.00 <sup>a</sup>	36.95 <sup>a</sup>	66.23 <sup>b</sup>	5428 <sup>bc</sup>	5767 <sup>ab</sup>	11,195 <sup>bc</sup>	0.97 <sup>b</sup>	0.46 <sup>b</sup>

Different letter superscripts mean the degrees of significant differences. The same goes for all tables below.

The maximum straw yield was  $6772 \text{ kg}\cdot\text{ha}^{-1}$  with nano-chitosan loaded with N (500 mg/L). Chitosan NPs. and nano-chitosan loaded with N (250 mg/L) increased straw yield to  $6308 \text{ kg}\cdot\text{ha}^{-1}$  and  $4705 \text{ kg}\cdot\text{ha}^{-1}$  higher than the control. The straw yield of the nano-chitosan loaded N (750 mg/L) treatment was  $5767 \text{ kg}\cdot\text{ha}^{-1}$ , significantly higher than the control but lower than the other treatments (**Table 1**). The nano chitosan loaded N (500 mg/L) treatment showed an increase in straw yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) compared to the control, with a percentage increase of 97.26%. The results indicated that the grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) increased by 83.74% with nano-chitosan loaded N (250 mg/L), 67.98 with nano-chitosan loaded N (750 mg/L) and by 37.05% with chitosan NPs compared to the control.

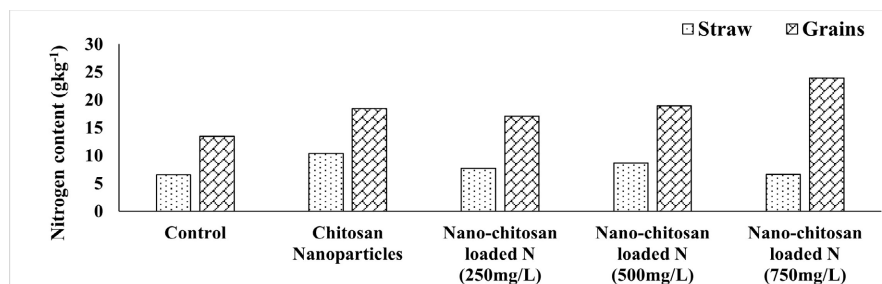
For the biological yield, nano-chitosan loaded with N (500 mg/L) yielded  $15,500 \text{ kg}\cdot\text{ha}^{-1}$ , the highest of any treatment. The treatment outperformed the control group and Nano-chitosan loaded N (250 mg/L). Nano-chitosan loaded with N (250 mg/L) increased biological yield to  $13,361 \text{ kg}\cdot\text{ha}^{-1}$ . Chitosan Nanoparticles increased biological yield to  $12,671 \text{ kg}\cdot\text{ha}^{-1}$ , much higher than the control. The Nano-chitosan loaded N (750 mg/L) treatment produced  $10,805 \text{ kg}\cdot\text{ha}^{-1}$ , more than the control but less than the other treatments (**Table 1**). The study indicates that Nano-chitosan loaded with N significantly enhances biological yield, particularly at a 500 mg/L concentration, and at a 250 mg/L concentration. The nano chitosan loaded N (500 mg/L) treatment showed an increase in biological yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) compared to the control, with a percentage increase of 101.45%. The results indicated that the grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) increased by 93.16% with nano-

chitosan loaded N (250 mg/L), 45.50% with nano-chitosan loaded N (750 mg/L) and by 64.68% with chitosan NPs compared to the control.

The harvest index is higher in the nano-chitosan treatment compared to other treatments. These results may indicate that the application of foliar chitosan NPs.-loaded nitrogen in different concentrations has been employed to enhance plant growth and productivity. According to [21], chitosan nanoparticles exhibit a high degree of absorption by leaves, enabling their penetration into plants via stomata. Subsequently, these nanoparticles are transported through the phloem and deliver nutrients to various plant tissues. The study conducted by [22] focused on the biophysical properties of chitosan NPs. and their impact on the growth of Robusta coffee in a greenhouse environment. The application of chitosan NPs. resulted in a significant enhancement in the absorption of nitrogen, phosphorous, and potassium, with increases ranging from 9.8% to 27.4%, 17.3% to 30.4%, and 30% to 45%, respectively. Furthermore, the utilization of chitosan NPs. exhibited a discernible influence on the growth of coffee seedlings. In a study conducted by [23], the efficacy of chitosan NPs.-NPK fertilizer applied through foliar application was demonstrated in enhancing wheat production. The experiment was conducted on two different soil types. The application of foliar treatment resulted in an increase in wheat plant yield, while concurrently decreasing the crop life cycle duration.

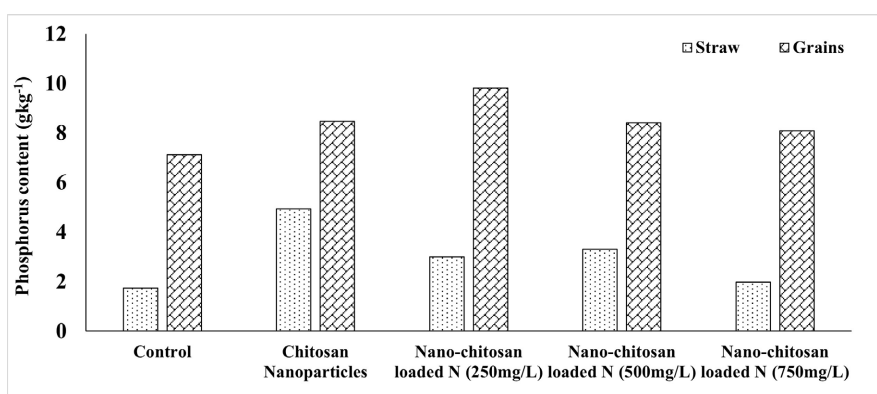
### 3.2. Nutrients Content and Uptake

Nano-chitosan loaded N was sprayed with different concentrations on the wheat plants to evaluate its effect on nutrients uptake at straw and grains of wheat are shown in **Figure 1**. Results showed that nano-chitosan loaded N (250 mg/L and 500 mg/L) and chitosan nanoparticles enhanced nitrogen at straw compared to control. Also, Nitrogen content in the grains increased from 18.45 g/kg to 23.9 g/kg at all treatments compared to control. The results represented that the increase in the nano-chitosan loaded N concentration improved the uptake of nitrogen in wheat straw and grains. This result is in agreement with [24] who found that the application of different doses of NPK nano fertilizers on the leaves of coffee seedling increased the nitrogen uptake by 17.04% compared to control. Also, [25] found that nano fertilizer treatment improved growth parameters and yields of onion, with the recommended normal nitrogen dosage being the most effective. The higher dosage of nano 15% N with chitosan (1.5 g/L) showed the highest performance.

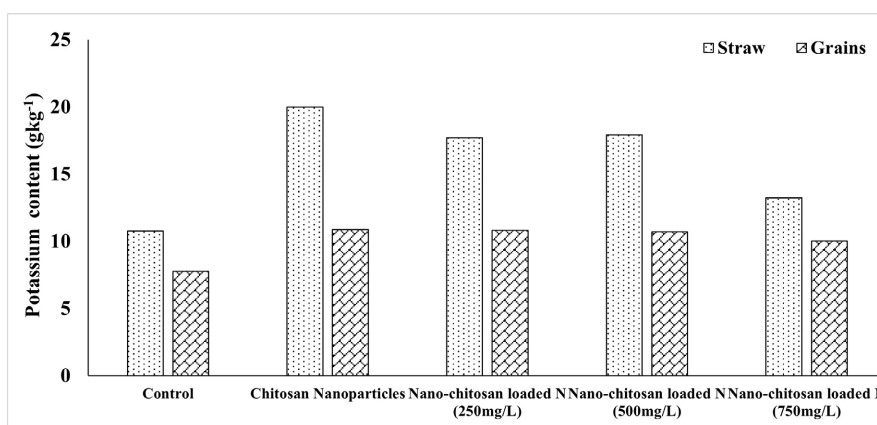


**Figure 1.** Effect of Nano-chitosan loaded N levels on nitrogen content in straw and grains of wheat plants.

With respect to phosphorus content in different parts of wheat plants (**Figure 2**), there was an increase in phosphorus content in wheat straw and grains. The results showed that the most significant value of phosphorus in straw was 4.94 g/kg recorded at chitosan nanoparticles treatment. Additionally, the phosphorus content in grains was the highest 9.81 g/kg at nano-chitosan loaded N (250 mg/L). At general, the content of phosphorus at wheat straw and grains increased with the different concentrations of the nano-chitosan loaded N compared to control. [21] found that in comparison to control, grains harvested from wheat plants treated with conventional or nanofertilizers and planted on clay, clay-sandy, or sandy soils showed varying increases in phosphorus. Conversely, [24] found that the phosphorus uptake was not affected by foliar application of NPK nanofertilizer. The results in **Figure 3** showed that potassium content in wheat straw increased from 10.77 g/kg in the control to 19.97 g/kg at chitosan nanoparticles treatment. This may be due to the fact that chitosan has been shown to directly impact gene expression, metabolism, and induce a variety of biological responses in plants. These effects could increase nutrient uptake in plant leaves either directly or indirectly [26] [27]. Furthermore, [28] reported that chitosan nanoparticles and methacrylic acid-based N nanofertilizers increased lettuce nitrogen use



**Figure 2.** Effect of Nano-chitosan loaded N levels on phosphorus content in straw and grains of wheat plants.



**Figure 3.** Effect of Nano-chitosan loaded N levels on potassium content in straw and grains of wheat plants.

efficiency compared to free urea. The study suggests that chitosan nanoparticles and N, P, and K nutrients can enhance nutrient uptake. The use of nano-engineered composites, specifically N, in grain crops enhances nutrient uptake and utilization, synchronizing fertilizer release with crop uptake, preventing nutrient losses to soil, water, and air [29] [30].

The results in **Table 2** illustrate the impact of nano-chitosan loaded N levels on nutrients uptake in straw, grains and total nutrients uptake of wheat plants. Chitosan nanoparticles and nano-chitosan loaded N (250 ppm) treatments increased straw nitrogen uptake to 48.9 and 48.7 kg·ha<sup>-1</sup> compared to the control. The straw absorbed 58.6 kg·ha<sup>-1</sup> of nitrogen from nano-chitosan containing 500 ppm nitrogen, higher than the control, chitosan NPs. and the 250 ppm nitrogen treatments. The straw absorbed 38.1 kg·ha<sup>-1</sup> of nitrogen from the nano-chitosan loaded N (750 ppm) treatment, which was lower than the chitosan nanoparticles and 250 ppm treatments. Application of chitosan NPs. on wheat plants increased straw phosphorus uptake to 23.2 kg·ha<sup>-1</sup>, higher than the control. The straw absorbed 19.1 kg·ha<sup>-1</sup> of phosphorus from Nano-chitosan loaded N (250 ppm), which was lower than chitosan nanoparticles treatment. Nano-chitosan with 500 ppm N absorbed 22.4 kg·ha<sup>-1</sup> of phosphorus in straw, somewhat more than 250 ppm (**Table 2**). Nano-chitosan loaded N (750 ppm) uptake 10.5 kg·ha<sup>-1</sup> of phosphorus in straw, less than other treatments.

The application of chitosan nanoparticles and nano-chitosan loaded with N (250 mg/L) resulted in a considerable increase in potassium uptake in straw (**Table 2**) and. The uptake values were determined at 91.9 and 111.4 kg·ha<sup>-1</sup> for chitosan NPs. and nano-chitosan loaded with N (250 mg/L), respectively, which were significantly greater than the control. The straw assimilated 121.1 kg·ha<sup>-1</sup> of potassium from nano-chitosan containing 500 ppm nitrogen (N), which was marginally higher compared to the straw treated with 250 mg/L. The straw uptake 77.8 kg·ha<sup>-1</sup> of potassium from nano-chitosan loaded N (750 mg/L), which was comparatively lower than the other treatments.

**Table 2.** Effect of nano-chitosan loaded N levels on nutrients uptake in straw and grains of wheat plants.

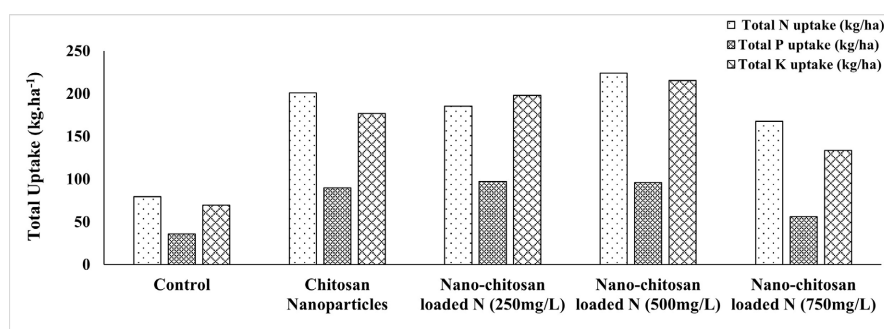
Treatments	Straw			Grains			Total uptake		
	N	P	K	N	P	K	N	P	K
	kg·ha <sup>-1</sup>								
Control	22.7 <sup>c</sup>	5.8 <sup>c</sup>	36.3 <sup>b</sup>	56.6 <sup>b</sup>	30.1 <sup>c</sup>	33.1 <sup>c</sup>	79.35 <sup>b</sup>	35.90 <sup>b</sup>	69.52 <sup>c</sup>
Chitosan Nanoparticles	48.9 <sup>ab</sup>	23.2 <sup>a</sup>	91.9 <sup>a</sup>	151.6 <sup>a</sup>	66.6 <sup>ab</sup>	84.7 <sup>ab</sup>	200.65 <sup>a</sup>	89.86 <sup>a</sup>	176.77 <sup>ab</sup>
Nano-chitosan loaded N (250 ppm)	48.7 <sup>b</sup>	19.1 <sup>ab</sup>	111.4 <sup>a</sup>	136.8 <sup>a</sup>	78.3 <sup>a</sup>	86.3 <sup>ab</sup>	185.53 <sup>a</sup>	97.42 <sup>a</sup>	197.81 <sup>a</sup>
Nano-chitosan loaded N (500 ppm)	58.6 <sup>a</sup>	22.4 <sup>a</sup>	121.1 <sup>a</sup>	165.3 <sup>a</sup>	73.7 <sup>ab</sup>	94.4 <sup>a</sup>	223.99 <sup>a</sup>	96.15 <sup>a</sup>	215.51 <sup>a</sup>
Nano-chitosan loaded N (750 ppm)	38.1 <sup>b</sup>	10.5 <sup>bc</sup>	77.8 <sup>ab</sup>	129.7 <sup>ab</sup>	45.4 <sup>bc</sup>	55.6 <sup>bc</sup>	167.79 <sup>a</sup>	56.06 <sup>b</sup>	133.41 <sup>b</sup>

The results presented in **Table 2** and illustrated in **Figure 4** showed that the application of chitosan NPs. increased grain nitrogen uptake to 151.6 kg·ha<sup>-1</sup>

compared to the control. Nano-chitosan loaded N (250 mg/L) treatment increased grain nitrogen absorption to 136.8 kg·ha<sup>-1</sup>, less than chitosan nanoparticles but more than the control group. The grains absorbed the maximum nitrogen (165.3 kg·ha<sup>-1</sup>) from nano-chitosan containing 500 mg/L N. The results demonstrate that 500 mg/L nano-chitosan loaded with nitrogen increased nitrogen absorption and accumulation in grains most significantly. The grains absorbed 129.7 kg·ha<sup>-1</sup> of nitrogen from nano-chitosan (750 mg/L), which was less than the chitosan nanoparticles and 500 mg/L treatments. Compared to the control, chitosan nanoparticles increased grain phosphorus absorption to 66.6 kg·ha<sup>-1</sup>. The Nano-chitosan loaded N (250 mg/L) treatment increased grain phosphorus absorption to 78.3 kg·ha<sup>-1</sup>, surpassing the control and chitosan nanoparticle treatments. The grains absorbed 73.7 kg·ha<sup>-1</sup> of phosphorus from nano-chitosan with 500 kg·ha<sup>-1</sup> N, slightly less than with 250 mg/L N. Nano-chitosan loaded N (750 mg/L) resulted in 45.4 kg·ha<sup>-1</sup> phosphorus absorption in grains, which was lower than chitosan nanoparticles and 250 mg/L.

The results showed that the utilization of chitosan nanoparticles increased grain potassium uptake to 84.7 kg·ha<sup>-1</sup>, compared to the control. The Nano-chitosan loaded N (250 mg/L) treatment increased grain uptake of potassium to 86.3 kg·ha<sup>-1</sup>, more than the control and chitosan nanoparticle treatments. In grains treated with 500ppm nitrogen nano-chitosan, potassium absorption was 94.4 kg·ha<sup>-1</sup>, substantially higher than with 250 mg/L nitrogen. Nano-chitosan loaded N (750 mg/L) caused grains to absorb 55.6 kg·ha<sup>-1</sup> less potassium than chitosan nanoparticles and 250 mg/L. Based on the results, it is evident that the use of chitosan nanoparticles, as well as nano-chitosan loaded with different concentrations of nitrogen (N), led to enhanced absorption of nutrients in the grains (nitrogen, phosphorus, and potassium) compared to the control group. The treatment with nano-chitosan loaded N at 500 mg/L showed the highest nutrient uptake values, indicating that it effectively increased the accumulation of nutrients in the grains of wheat plants.

The treatments utilizing Nano-chitosan with different levels of nitrogen (250 mg/L, 500 mg/L, and 750 mg/L) reveal a higher total uptake of nutrients in comparison to the control (Figure 4). Increasing the concentration of Nano-chitosan



**Figure 4.** Effect of Nano-chitosan loaded N levels on total nutrients uptake (N, P and K) in wheat plants.

loaded N leads to a proportional increase in the total uptake values for N, P, and K. These findings suggest that the use of nano-chitosan, particularly when combined with nitrogen, can improve the absorption of nutrients in wheat plants. Also, the results showed that the nano-chitosan loaded N (500 mg/L) has the highest values of the total uptake of N, P and K with values 223.99, 96.15 and 215.51, respectively

### 3.3. Effect of Nano-Chitosan Loaded N Levels on Soil Nutrients Availability

The results in **Table 3** showed the effect of nano-chitosan loaded N levels on Soil nutrients availability. The results revealed that the mean values of A.N, A.P and A.K contents in soil were increased with applied nano-chitosan loaded N (750 mg/L) treatment followed by nano-chitosan loaded N (500 ppm). The results showed variations among the levels of nano-chitosan Loaded N of 250 mg/L, 500 mg/L, and 750 mg/L suggesting the presence of a potential dose-response relationship. This observation indicates that there is a positive correlation between the concentration of nano-chitosan loaded with N and the corresponding values of the measured variables (A.N, A.P, and A.K), implying that an increase in the concentration of nano-chitosan loaded with N leads to an increase in the measured variables compared to control. According to [24] who found that the slow release of nitrogen in NPK fertilizer is attributed to the ionic bond force between positive and negative chitosan nanoparticles. Also, [31] found that the nutrient release pattern from conventional and nanofertilizer exhibited a significant decline with time, with the nano-fertilizer demonstrating a larger release of nitrogen compared to the conventional fertilizer. [32] reported that nitrogen in nano-form has slow-release characteristics and improves nitrogen use efficiency (NUE) when given via drip irrigation and foliar application.

**Table 3.** Effect of Nano-chitosan loaded N levels on Soil nutrients availability.

Treatments	Available Nitrogen	Available phosphorus	Available potassium
		mg/kg	
Control	9.70 <sup>b</sup>	27.22 <sup>c</sup>	214.38 <sup>b</sup>
Chitosan Nanoparticles	10.79 <sup>b</sup>	43.60 <sup>ab</sup>	261.78 <sup>ab</sup>
Nano-chitosan loaded N (250 ppm)	10.75 <sup>b</sup>	39.00 <sup>b</sup>	249.77 <sup>ab</sup>
Nano-chitosan loaded N (500 ppm)	11.70 <sup>b</sup>	45.72 <sup>ab</sup>	277.57 <sup>a</sup>
Nano-chitosan loaded N (750 ppm)	15.55 <sup>a</sup>	51.62 <sup>a</sup>	291.12 <sup>a</sup>

## 4. Conclusion

The study indicates that Nano-chitosan loaded with N significantly enhances biological yield, particularly at a 500 mg/L concentration, and at a 250 mg/L concentration. The nano chitosan loaded N (500 mg/L) treatment showed an increase in biological yield (kg·ha<sup>-1</sup>) compared to the control.

The results indicated that the grain yield ( $\text{kg}\cdot\text{ha}^{-1}$ ) increased by 100.75% with nano-chitosan loaded N (250 mg/L), 27.38 with nano-chitosan loaded N (750 mg/L) and by 86.95% with chitosan NPs compared to the control.

One of the most important recommendations for using nano fertilizers is that: using nano fertilizers gives an early crop of 15 - 20 days, and this is a very important result because early cropping leads to saving fertilizers and water and obtaining a good price.

## Conflicts of Interest

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

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