



## Enhancing the Physiological Performance and Nutrient Utilization Efficiency in Two Faba Bean Cultivars via Nano, Mineral, and Chitosan Fertilization

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تحسين الأداء الفسيولوجي وكفاءة استخدام المغذيات في صنفين من الفول البلدي باستخدام الأسمدة النانوية والمعدنية والشيتوزان

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### Abstract:

A field experiment was conducted during the 2024/2025 harvest season in Sebha, Libya, to evaluate the physiological performance and nutrient use efficiency of two faba bean (*Vicia faba* L.) cultivars, under fertilization treatments: control, recommended mineral NPK, nano NPK, chitosan, 50% nano NPK + 50% mineral NPK, mineral NPK + chitosan, and nano NPK + chitosan. A randomized complete block design with three replications was used during current study. Water content, chlorophyll content, relative growth rate (RGR), the utilization efficiency of nitrogen, phosphorus, and potassium were evaluated. The combined application of nano NPK + chitosan resulted in the highest improvement in most of the studied parameters across treatments. The imported cultivar consistently outperformed the local cultivar in all evaluated traits, exhibiting greater leaf water content (88% vs. 80%), chlorophyll concentration (48% vs. 41%), relative growth rate (66 vs. 56 g/g/day), nitrogen use efficiency (57 vs. 46 kg/kg), phosphorus use efficiency (28 vs. 22 kg/kg), and potassium use efficiency (54 vs. 46 kg/kg). Nano-fertilizers and chitosan significantly enhanced water retention, photosynthetic efficiency, growth, and nutrient utilization, with the imported cultivar showing higher responsiveness. The findings suggest that the integration of nano-fertilizers and chitosan is an effective strategy to improve faba bean productivity in semi-arid regions of North Africa.

**Keywords:** Broad bean cultivars, Foliar application, NPKnps, NUE, Physiological traits.

### الملخص

تم إجراء تجربة ميدانية خلال الموسم الزراعي 2025/2024 في سبها، ليبيا، لتقييم الأداء الفسيولوجي وكفاءة استخدام المغذيات لصنفين من الفول (*Vicia faba* L.) تحت معاملات التسميد: الكونترول، التسميد المعدني الموصى به، التسميد النانوي، الشيتوزان، 50% تسميد معدني + 50% تسميد نانوي، تسميد معدني + شيتوزان، تسميد نانوي + شيتوزان، وتسميد نانوي + شيتوزان. وتم استخدام تصميم القطاعات العشوائية الكاملة مع ثلاث مكررات خلال التجربة، تم قياس محتوى الأوراق من الماء، محتوى الكلوروفيل، معدل النمو النسبي، كفاءة استخدام النيتروجين والفوسفور والبوتاسيوم، تشير النتائج إلى أن الصنف المستورد تفوق وبشكل مستمر على الصنف المحلي في معظم الصفات التي تم قياسها، حيث سجل أعلى محتوى من الماء في الأوراق بلغ

88% مقابل 80%)، ونسبة الكلوروفيل بلغت (48% مقابل 41%)، ومعدل النمو النسبي 66 مقابل 56 جم/جم/اليوم وكفاءة استخدام النيتروجين بلغ (57 مقابل 46 ملجم/كجم)، وكفاءة استخدام فوسفور بلغت (28 مقابل 22 ملجم/كجم)، استخدام الأسمدة النانوية مع الشيتوزان نتج عنه تحسن واضح في احتفاظ النبات بالماء وكفاءة التمثيل الضوئي، النمو، واستخدام المغذيات، مع وضوح الاستجابة الأكبر في الصنف المستورد، توضح النتائج ان دمج الأسمدة النانوية مع الشيتوزان يعتبر استراتيجية فعالة لتحسين محصول الفول في المناطق شبه الجافة في شمال افريقيا.

**الكلمات المفتاحية:** أصناف فول، الرش الورقي، اسمدة النيتروجين والفوسفور والبوتاسيوم النانوية، كفاءة استخدام النيتروجين، الصفات الفسيولوجية.

## Introduction

Faba bean (*Vicia faba* L.) is one of the most significant winter food materials in the world because it is a less expensive source of protein. Besides, it is a food with high calorific and nutritive values, especially in the culinary culture of low-income individuals, faba bean can be consumed by humans and can have effects as animal food and it is fresh or canned and is used as a vegetative, green, or dried ingredient. Faba bean is a good crop to plant in the cropping system because its costs of production are minimal, and it is the only crop that has the symbiotic property of fixation of atmospheric N<sub>2</sub> in both soil and atmosphere (El-Sheref *et al.*, 2025).

Today, nanotechnology fertilization is employed to deliver nutrients at a smaller scale, release nutrients at the correct time to meet plant, and increase nutrient use efficiency with decreased losses through leaching and volatilization. Nano fertilizer formulations have demonstrated enhanced uptake, enhanced yields with reduced doses, and enhanced resistance to stress as compared to conventional inputs, although the standardized field protocols and risk evaluation are a priority according to Easwaran *et al.* (2024).

Omer *et al.* (2025) reported that nano fertilizers are an efficient and eco-friendly technology for improving the productivity of beans, particularly in soils that are saline. The use of nano fertilizer to deliver micronutrients (Fe, Zn, and Mn) can greatly enhance beans' productivity in the presence of water conditions (Sheta *et al.*, 2025). The interaction between nano fertilizers of nitrogen and phosphorus produced the best seed yield (5466 kg/hectare) Alhasany *et al.* (2024) and Patra *et al.* (2024) also reported similar findings.

Reducing foliar treatment using water-soluble NPK fertilizer two times resulted in significant increases in seed yield in lentils. The two-thirds application of the recommended dose of Nano NPK demonstrated the highest yield of grain (838.47 kg/hectare), and the use of two-thirds of the recommended dose of Nano NPK resulted in the best yield (838.47 kg/hectare). The application of 75% of conventional fertilizers and the use of Nano DAP foliar spray showed the best results as an alternative.

Pandao *et al.* (2024), reported that the emulsion bio fertilizer resulted in a high yield and its elements in chickpeas, as demonstrated by Abisankar *et al.* (2024), the use of 25% of the Nano NPK dose gave the highest values of growth and yield as compared to higher doses or conventional fertilizer in faba bean according to Abou-Youssef *et al.* (2022)

Chitosan is a biodegradable bio stimulant and defense elicitor, which enhances germination, root growth, chlorophyll, and photosynthesis, enhancing nutrient uptake and nutrient use efficiency to enhance yields in a variety of crops. It also stimulates plant immunity response and antioxidant system, making it less severe in disease and drought and salinity stress in case of application as seed coating, foliar spray, or soil amendment. (Rojas *et al.*, 2024).

Abdel Kader (2025) manifested that chitosan in combination with humic acid enhanced vegetative growth and seed quality characteristics in the two seasons of faba bean, The seed/foliar applications of chitosan improved germination, seedling activity, and yield attributes in groundnut (*Arachis hypogaea*) in the field (Malarkodi *et al.*, 2024). Chitosan showed enhanced stress tolerance, photosynthesis, and antioxidant activity in legumes (Rojas *et al.*, 2024).

Nandini *et al.* (2025) showed that Chitosan/Ch NP controlled release carrier systems increased nutrient uptake and nutrient esterification of legumes; nano formulations were considered sustainable inputs. The fungicidal/elicitor effect of chitosan/nano chitosan was comparably good to that of the traditional protectants on field beans and reduced disease pressure (El-Blasy *et al.*, 2024). Foliar chitosan (~750 ppm) during deficit irrigation enhanced growth and yield and was suggested as an anti-transparent strategy in faba bean. Chitosan and chitosan NP sprays reduced the severity of chocolate spot (*Botrytis fabae*), Fouda *et al.* (2022).

Thamarsha *et al.* (2022) highlighted that priming/spraying and chitosan films/coatings were investigated as increasing legume protein systems; they could be applied in seed coats and legume products. The increased phenolic and antioxidant enzyme activity raised the weight per plant of the seed (Giza 40) affording to (Galal *et al.*, (2021)

Therefore, the aims of the present research were to gain a clear understanding of whether nano-formulated nutrients and chitosan, singly or in combination with sources of minerals, could boost physiological performance and nutrient use efficiency of faba bean genotypes chosen to grow in semi-arid, salty-prone, and moisture-limited

environments of Sebha and to gain a clear understanding of the most effective fertilization packages to be used in the North African desert margin environments.

### Material and methods

The effect of mineral, nano, and chitosan fertilization on physiological performance and nutrient use efficiency of two faba bean (*Vicia faba* L.) cultivars, local and imported, and soil chemical properties were tested using a field experiment during the 2024–2025 growing season at Sebha, Libya. The study was arranged as a two-factor factorial experiment.

Randomized complete block design (RCBD) consisting of three repetitions. The first factor was the consideration of the seven fertilization treatments, and the second factor was the consideration of the two-faba bean cultivars. The treatments included:

- Control
- Mineral NPK (NPK) that is recommended.
- Recommended Nano NPK (NPK NPs)
- Chitosan
- 50 NPK Nps (Nano) + 50 mineral NPK (NPK)
- Mineral NPK (NPK) + Chitosan and
- Nano NPK (NPK NPs) + Chitosan.

The method of fertilization adopted was the use of urea, diammonium phosphate (DAP), and potassium sulfate, all at the suggested rates per hectare. The DAP was included in the soil as a basal application when the land was being successfully prepared and at the time of sowing so that there would be a sufficient supply of phosphorus to induce the growth of roots and nodules. A small starting dose of urea was applied to the plants around 2–3 weeks after seedling germination to improve initial vegetative growth. Potassium sulfate was divided into two applications. The first application was made on the land during land preparation, and the second application was made during the flowering stage to aid in pod development and the filling of seeds.

The recommended dosage of the Nano fertilizers (NPK) was sprayed on the field at the ages of 25, 40, and 55 days. The use of chitosan was done 10 days after the nano fertilizer application by spraying it on the plants and in the required dosage. With suggested interspacing, normal agronomic practices were implemented in growing faba beans, which included soil preparation, irrigation, and weed management. The field soil was medium fertile and semi-dry, and it was reflective of the Sabha environment.

The measured characteristics were:

- Leaf water content.
- Percentage of chlorophylls in leaves.
- Relative growth rate ( $\text{g g}^{-1} \text{d}^{-1}$ ).
- Efficiency of nitrogen use (kg/kg).
- Efficiency of phosphorus use (kg/kg).
- Potassium utilization rate (kg/kg)
- Leaf water Content.

Oven-Dry Weight Procedure. This includes weighing fresh leaves and drying the leaves in an oven until they attain the same weight, after which water content is determined by weighing again. (**Ji et al., 2025**)

The chlorophyll content of the leaves was determined an SPAD-502 chlorophyll meter, which approximates chlorophyll concentration in the leaf of the plant by the light absorbance value at two wavelengths and which was transformed into  $\mu\text{g cm}^{-2}$  using the equation  $Y = -2.79 + 0.88 X$ , where  $X = \text{SPAD units}$ . Relative Growth Rate is determined based on two time points of measurements. The equation is  $\text{RGR} = (\ln(S2) - \ln(S1)) / (t2 - t1)$ , where  $\ln$  is the natural logarithm,  $t1$  and  $t2$  are the times of the first and second measurements, and  $S1$  and  $S2$  are the sizes at times  $t1$  and  $t2$ . (**Hoffmann et al., 2002**)

### Nitrogen use efficiency (NUE):

The Difference Method.  $\text{PFR} = (\text{NF} - \text{NC})/\text{R}$ , where  $\text{NF}$  is total N uptake in fertilized plots,  $\text{NC}$  is total N uptake in unfertilized plots, and  $\text{R}$  is the fertilizer N application rate. **EU Nitrogen Expert Panel. (2016).**

### Phosphorus Use Efficiency (PUE):

Procedure: Recovery by crops of fertilizer P applied can be computed using the different method that is considered as the traditional one. University of Adelaide. (n.d.). The productivity of phosphorus fertilizer in soils.

### Potassium Use Efficiency (KUE):

Procedure Agronomic K use efficiency (KUE) is the yield of a crop divided by unit K made available. (Murrell *et al.*, 2021).

These indices represent agronomic nutrient use efficiency indicators derived from nutrient uptake and/or yield response to applied fertilizers. Therefore, the reported values reflect efficiency indices rather than internal plant nutrient concentrations.

The collected data were analyzed by using ANOVA to conduct a two-factor factorial experiment in a Randomized Complete Block Design (RCBD). The first factor was the fertilization treatments, and the second factor was cultivars. Means of the significant treatments were compared using the least significant difference (LSD) test with a probability level of 0.05.

**Table 1. Soil properties of the experimental site at Sebha, Libya (2024/2025 seasons)**

Mechanical analysis											
Clay (%)			Silt (%)		Sand (%)		Organic matter (%)		Texture class		
20.5			18.3		61.2		0.65		Sandy clay loam		
Chemical analysis											
pH	EC (dS/m)	HC O <sub>3</sub> - (%)	CaCO <sub>3</sub> (%)	N (mg/k g)	P (mg/k g)	K (mg/k g)	Fe (mg/kg)	B (mg/k g)	Zn (mg/kg)	Cu (mg/k g)	Mn (mg/k g)
8.2	1.7	11.5	23.5	26.0	6.8	180.0	4.5	0.9	1.0	2.0	5.0

## Results

### Leaf Water Content:

Results in **Figure 1** showed that Nano fertilizer + Chitosan sample had the best average value of the leaf water content, with 80 % at the local cultivar and 88 % at the imported cultivar. The results due to the combination of certain nanotechnology and chitosan significantly increase the plant's ability to absorb and retain water. The 50% Nano+ 50% Mineral treatment showed a 77% and 86% of leaf water content of local and imported, respectively, in the second level. Although this represents a significant improvement over the control, the water content remains low compared to the Nano fertilizer + Chitosan treatment due to the absence of a synergistic effect from chitosan, which enhances water uptake efficiency. The control treatment registered the lowest leaf water content, where the average values of local and imported were 61% and 66%, respectively. This treatment lacks sufficient moisture content, probably because the proper availability of nutrients is insufficient, which hinders the physiological functions of the plant as far as water retention is concerned.

### Chlorophyll Percentage:

As indicated in **Figure 2**, Nano fertilizer + Chitosan treatment recorded the highest mean percentage of chlorophyll, 41% and 48 %, respectively, on the local cultivar and the imported cultivar. This increase in the effectiveness of the combination of certain nanotechnology and chitosan, which markedly increased nutrient uptake and leaf hydration. The 50 % Nano fertilizer + 50 % Mineral treatment subsequently resulted in a chlorophyll percentage of 38 % and 46% for both the Local and Imported cultivars. This is good, but still lower than Nano fertilizer + Chitosan, which implies that adding chitosan helps achieve the maximum potential of photosynthesis. The lowest chlorophyll values were measured under the control treatment (27% and 35% of local and imported cultivars respectively). The low number signifies that insufficient nutrient availability directly affects chlorophyll production, resulting in diminished photosynthetic efficiency.

### Relative Growth Rate:

The Nano fertilizer + Chitosan treatment exhibited superior performance in relative growth rate, with average values of 56 g g<sup>-1</sup> d<sup>-1</sup> for local and 66 g g<sup>-1</sup> d<sup>-1</sup> for imported specimens. This growth indicates an enhanced metabolic process and growth mechanism, facilitated by improved nutrient and water absorption. The relative growth rate of the 50% Nano fertilizer + 50% Mineral treatment was 50 g g<sup>-1</sup> d<sup>-1</sup> in the local one and 57 g g<sup>-1</sup> d<sup>-1</sup> in the imported. While this represents a notable enhancement, it does not match the growth rate of Nano fertilizer + Chitosan, likely due to the diminished efficacy of nutrient interactions in the absence of chitosan, as illustrated in **(Figure 3)**. Conversely, the control treatment had the lowest average relative growth rate of 34 g g<sup>-1</sup> d<sup>-1</sup> in the

local and 39 g g<sup>-1</sup> d<sup>-1</sup> in imported. This treatment lacked nutrient optimization and exhibited inadequate water retention, likely inhibiting growth activities.

#### **Nitrogen Use Efficiency (NUE):**

**Figure 4** indicates that the Nano fertilizer + Chitosan treatment achieved the highest nitrogen use efficiency, averaging 46 kg/kg for local samples and 57 kg/kg for imported samples. This enhancement is attributed to the treatment's ability to improve nitrogen absorption and utilization, benefiting the plants overall. The mean nitrogen use efficiency (NUE) of the 50% Nano fertilizer + 50% mineral treatment was 42 kg/kg and 47 kg/kg at the two cultivars. This is superior to the control, however less effective than Nano fertilizer + Chitosan, which has synergistic actions that enhance nitrogen absorption. The control exhibited the lowest average NUE value, 32 kg/kg and 39 kg/kg. This treatment exhibits a distinct shortfall in the improper availability of nutrients and their effective absorption, which restricts the plants' capacity to utilize nitrogen.

#### **Phosphorus Use Efficiency (PUE):**

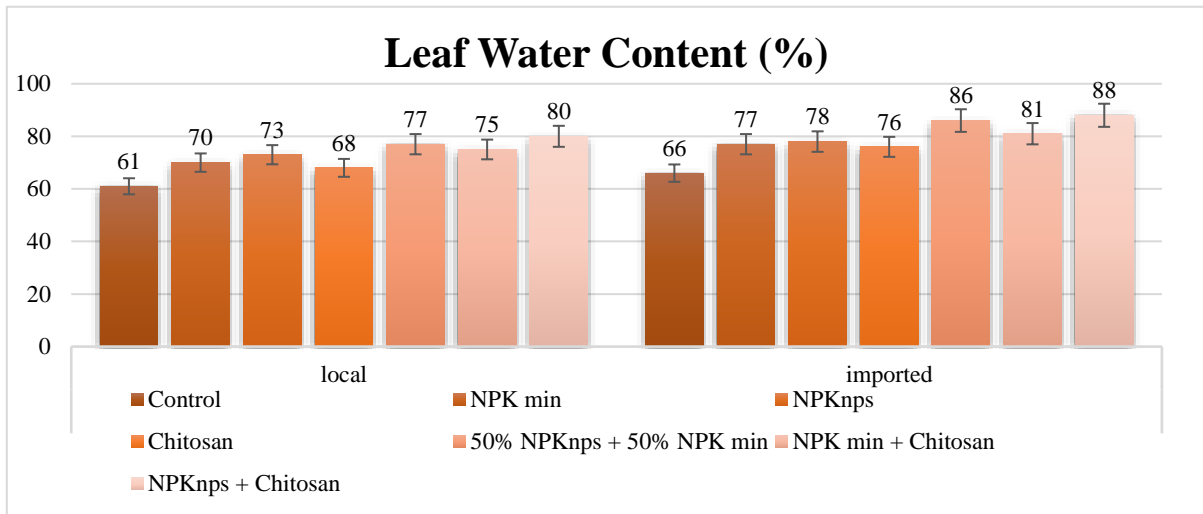
The Nano fertilizer + Chitosan treatment exhibited the highest phosphorus use efficiency, averaging 22 kg/kg for local and 28 kg/kg for imported variants. The high efficiency may be associated with improved nutrient absorption facilitated by nanotechnology and chitosan. The local and imported treatments, each comprising 50% Nano fertilizer + 50% mineral components, yielded average PUE values of 19 kg/kg and 26 kg/kg, respectively. These figures are inferior to those of Nano fertilizer + Chitosan; yet, this is beneficial, indicating that phosphorus uptake is consistently lower than with chitosan. According to **Figure 5**. The control exhibited the lowest PUE, with an average value of 12 kg/kg across both cultivars. The inadequacy of this therapy may be ascribed to an insufficient supply of phosphorus and suboptimal root development.

#### **Potassium Use Efficiency (KUE):**

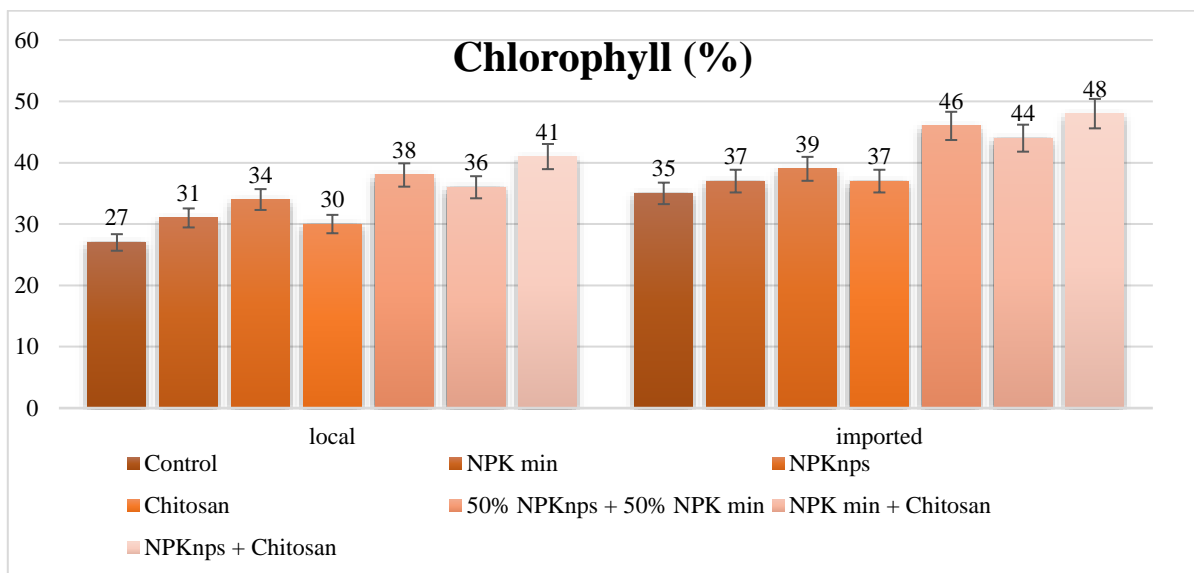
Ultimately, the Nano fertilizer + Chitosan treatment had the highest average potassium utilization efficiency, measuring 46 kg/kg for local sources and 54 kg/kg for imported sources. This figure is enhanced by the treatment's ability to augment nutrient absorption and utilization in the plants. The local and imported samples each had 50% Nano fertilizer + 50% mineral treatment, with average KUE values of 42 kg/kg and 48 kg/kg, respectively. This is a significant enhancement; yet it cannot rival Nano fertilizer + Chitosan, presumably due to the absence of Chitosan. KUE exhibited the lowest average value in the control group, with an average of 28 kg/kg for local and 37 kg/kg for imported. This ineffectiveness can be ascribed to insufficient potassium availability and a diminished capacity for nutrition intake. As seen in **Figure 6**. The combination of Nano fertilizer + Chitosan treatment demonstrated the highest efficacy across all assessed metrics, significantly enhancing growth and nutrient utilization efficiency in both native and imported fava bean plants. The subsequent treatment consisted of 50% Nano and 50% Mineral, which demonstrated significant benefits, albeit with an inadequate utilization of chitosan. The control treatment was the least successful, underscoring the necessity for optimal nutrient management to attain sustainable farming practices.

Data in **Table (2)** demonstrated that Nano fertilizer + Chitosan treatments significantly enhanced soil organic matter levels and nutrient availability compared to the control. Notably, the highest organic matter level was observed in the Nano fertilizer + Chitosan treatment (0.88% versus 0.60% in the control). The pH exhibited a slight reduction (8.0 compared to 8.18 in the control), while micronutrient levels were as follows Zn = 1.3 mg/kg and Mn = 5.4 mg/kg versus 0.8 mg/kg and 5.0 mg/kg, respectively. Nitrogen, phosphorus, and potassium became more accessible with all fertilization treatments compared to the baseline and control; nitrogen increased to ≈ 55-50 mg/kg in NPK treatments (mineral/nano/mixed) and 12 mg/kg in the control, phosphorus reached 13.2 mg/kg in Nano fertilizer + Chitosan, and potassium was 248mg/kg in nano treatments versus 150 mg/kg in the control. Chitosan was seen to increase organic matter (0.85 vs. 1.0% in control) and improve micronutrient levels (B = 1.2, Zn = 1.1 mg/kg vs. 1.60 in the control, 1.70 at baseline) but did not influence electrical conductivity (1.75–1.82 ds/m across most Nano fertilizer +chitosan treatments vs. 1.60 in the control). The combined treatments (50%

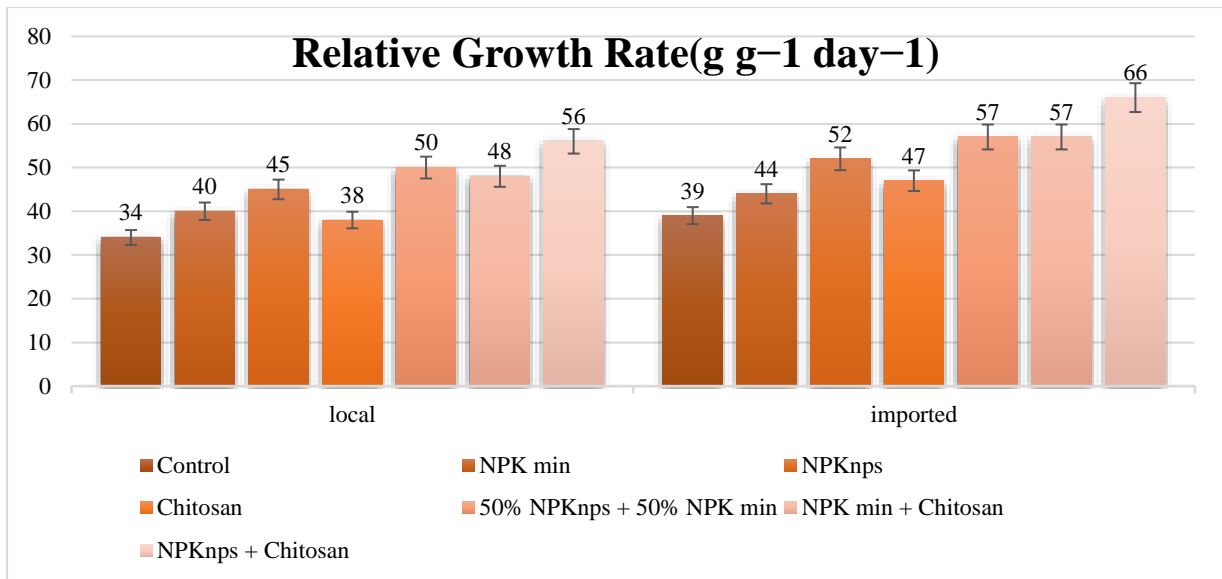
Nano fertilizer + 50% mineral and NPKmin + Chitosan) produced a balanced effect: they reduced pH to 8.0510 and elevated P to 12.0128 mg/kg, K to 235–245 mg/kg, and OM to 0.75–0.80 % compared to the control.



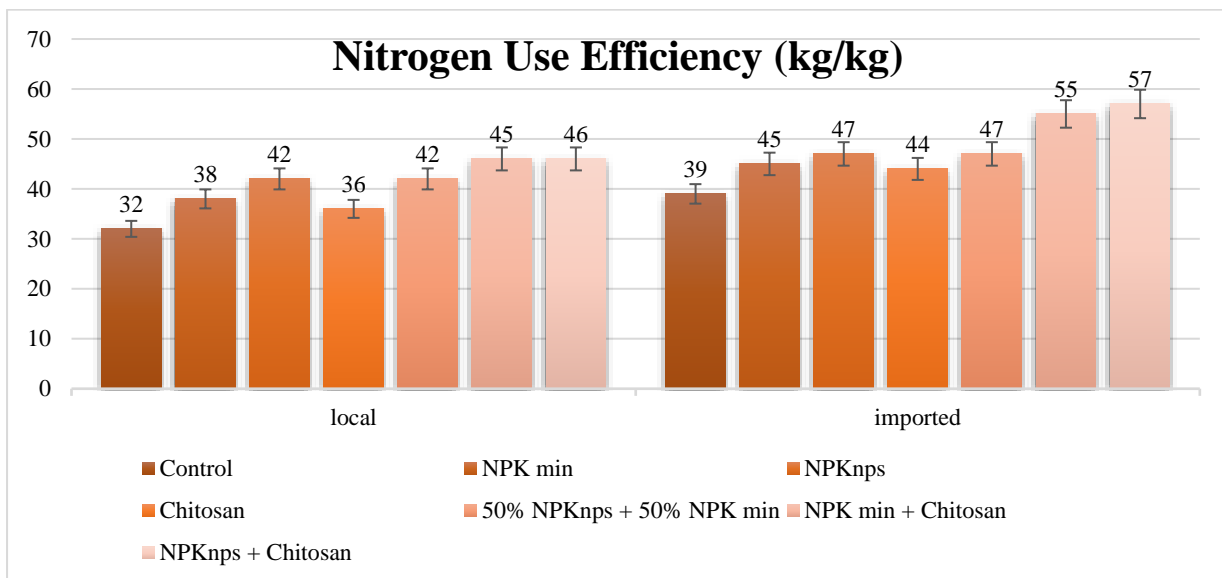
**Figure 1:** Average value of leaf water content (%) for local and imported Faba Bean cultivars



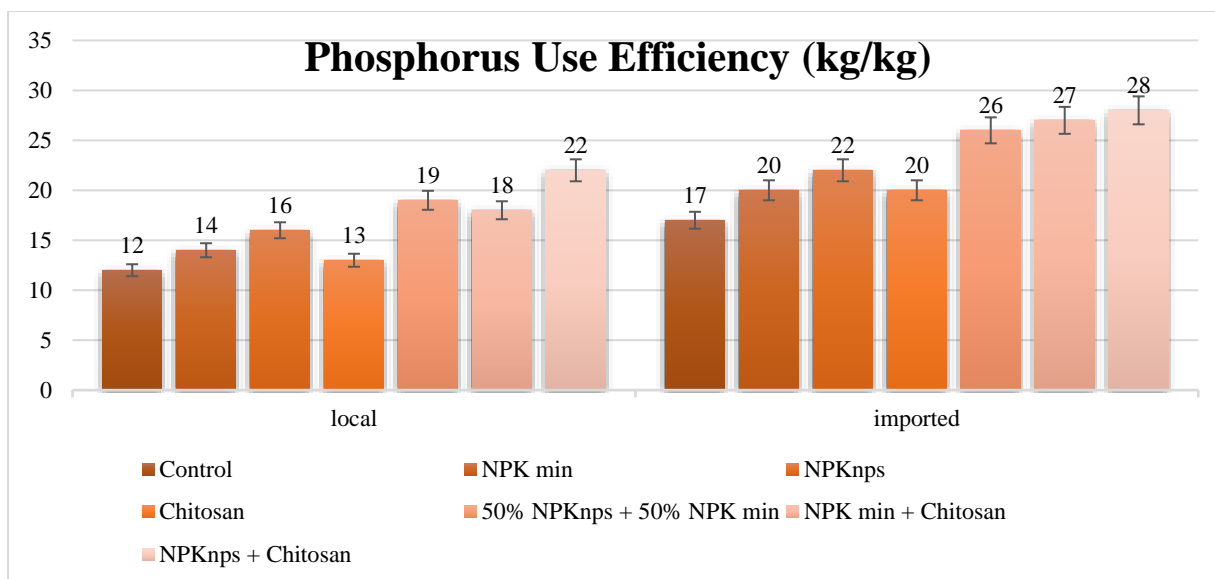
**Figure 2:** Average value of chlorophyll (%) for local and imported Faba Bean cultivars



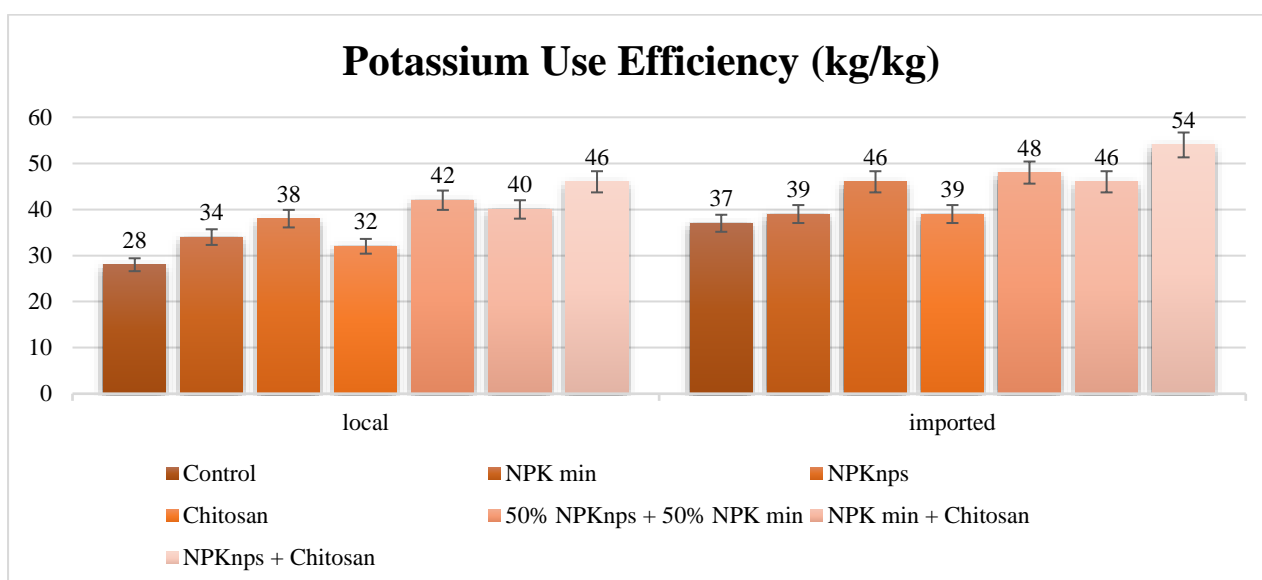
**Figure 3:** Average value of Relative Growth Rate (g/g/day) for local and imported Faba Bean cultivars



**Figure 4:** Average value of Nitrogen Use Efficiency (kg/kg) for local and imported Faba Bean cultivars



**Figure 5:** Average value of Phosphorus Use Efficiency (kg/kg) for local and imported Faba Bean cultivars



**Figure 6:** Average value of Potassium Use Efficiency (kg/kg) for local and imported Faba Bean cultivars

**Table 2.** Some soil properties of the experimental site at Sebha, Libya (after planting, season 2024/2025)

Treatment	pH	EC (ds/m)	OM (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)	Fe (mg/kg)	B (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Mn (mg/kg)
Control	8.18	1.60	0.60	12	4.5	150	4.0	0.7	0.8	1.8	4.5
NPK min	8.1	1.9	0.7	55	12.5	240	4.6	0.9	1.1	2.1	5.2
NPK NPs	8.0	1.8	0.72	50	13.0	250	4.8	1.1	1.2	2.2	5.3
Chitosan	8.15	1.75	0.85	40	10.0	210	4.7	1.2	1.1	2.0	5.1
50% NPKNPs + 50% NPK min	8.05	1.85	0.75	53	12.8	245	4.7	1.0	1.2	2.2	5.3
NPK min + Chitosan	8.1	1.8	0.8	52	12.0	235	4.8	1.1	1.2	2.1	5.2
NPKNPs + Chitosan	8.0	1.82	0.88	51	13.2	248	4.9	1.3	1.3	2.3	5.4

## Discussion

The research underscores the ineffectiveness of conventional mineral fertilizers in non-semi-arid settings in Sebha. The findings indicated that nano-fertilizers and chitosan, whether used independently or in conjunction with mineral fertilizers, markedly enhanced physiological performance and nutrient utilization efficiency in faba bean, hence facilitating the formulation of optimized fertilization strategies for North African ecosystems. The presence of a rise in leaf water content in the Nano fertilizer + Chitosan treatment was in line with **Omer *et al.* (2025)** and **Abou-Youseff *et al.* (2022)**, who mentioned that nano-fertilizer (NPK) improved the nutrient uptake and kept a higher leaf water content than the controls. **Alencar *et al.* (2025)**, **Alshammari *et al.* (2024)** informed that chitosan lessened the reduction of leaf relative water content that was caused by the drought, consequently improving the plant's drought tolerance during the drought conditions. This increase is a sign of an increase in the efficacy of root water uptake and increased resistance to water stress, which helps physiological activities like photosynthesis and nutrient metabolism to be more efficient. Such improvements can contribute to enhanced overall development and increased biomass production.

The increased chlorophyll content under the Nano fertilizer + Chitosan treatment corresponds with the findings of **Fadalah *et al.* (2023)**, **Hussain *et al.* (2021)**, which noted a significant rise in leaf chlorophyll levels associated with nano-fertilizers, particularly with nano-NPK. The findings of **Alencar *et al.* (2025)**, **Hussain *et al.* (2021)** support this. Chitosan kept more chlorophyll in the leaves of plants that were stressed by water, and 75 mg/L of chitosan made the chlorophyll content of stressed plants even higher. The concentration of photosynthetic pigments, which makes it easier for plants to absorb light and convert energy. Plants that get this advanced treatment probably have a higher photosynthetic capacity, which helps them grow faster and stay healthy, and it may even help them produce more fruit.

The relative growth rate in the Nano fertilizer + Chitosan treatment indicates enhanced biomass accumulation during the growth period, as proved by **Abisankar *et al.* (2024)** and **Abou-youseff *et al.* (2022)**. Who has mentioned that nano fertilization increased dry matter and, specifically at the 25% nano NPK dose, elevated the relative growth rate (RGR); the chitosan increased the total dry biomass of vegetative parts and raised the relative growth rate (RGR) Based on the findings of **Alencar *et al.* (2025)**. This result means that physiological activity improved, such as photosynthesis, nutrient transport, and protein synthesis. These kinds of responses show how advanced fertilization can help plants grow and suggest that it could lead to a higher final seed yield.

Enhanced NUE signifies an augmented ability of plants to absorb and utilize nitrogen efficiently for protein and enzyme synthesis, as well as for photosynthetic processes, aligning with the findings of **Pandao *et al.* (2024)**, **Abou-youseff *et al.* (2022)** and **Liu *et al.* (2022)**, who demonstrated that Nano-NPK elevated nitrogen uptake, indicating increased nitrogen use efficiency (NUE) in beans; the co-application with organic fertilizers further improved NUE. **Riseh *et al.* (2023)** and **Raut *et al.* (2022)** Showed that chitosan-improved nitrogen use efficiency by providing bioavailable N and increasing the activity of N metabolism enzymes, which helped plants take in and use nitrogen better. The highest NUE seen with the Nano fertilizer + Chitosan treatment shows that plants can grow and produce more with the same amount of nitrogen, which means they are using nutrients more efficiently and supporting overall plant performance.

A higher Use of phosphorus efficiently (PUE) shows that the plant is better at taking up and moving phosphorus to tissues that are growing quickly. The Nano fertilizer + Chitosan treatment resulted in the highest PUE, in keeping with **Pandao *et al.*, (2024)**, **Abou-youseff *et al.* (2022)** and **Hussain *et al.*, (2021)** have also reported similar results, **Ali *et al.* (2025)**, **Riseh *et al.* (2023)** and **Costales -Menéndez *et al.* (2020)** found that nano phosphorus inputs (nano-NPK) increased phosphorus uptake and raised phosphorus use efficiency (PUE) in beans. They also found that chitosan enhanced phosphorus uptake and increased leaf P content, which means that P was acquired more effectively at low doses. This suggests better energy metabolism (ATP synthesis) and enzyme activation, which are important for both vegetative growth and reproductive development. These physiological advantages probably lead to higher yields of seeds and biomass.

The enhanced potassium use efficiency (KUE) observed with the Nano fertilizer + Chitosan treatment arrange in line with findings from **Rani *et al.* (2025)**, **Alhasany *et al.* (2024)** and **Abou-Youseff *et al.* (2022)**, hich stated that a nano NPK regime yielded the highest results. Additionally, low-dose nano-K (including foliar nano-KNO<sub>3</sub>) facilitated increased potassium uptake and improved growth, indicating superior potassium use efficiency with nano inputs. **Ali *et al.* (2025)**, **Rojas *et al.* (2024)** and **Riseh *et al.* (2023)**. It has been established that chitosan enhances root function and functions as an efficient fertilizer carrier, thereby boosting K delivery to plants and reducing losses. This improvement makes potassium use more efficiently. This reflects improved stomatal regulation, enhanced water transport, and more efficient translocation of photosynthates and ions, contributing to improved physiological performance. This advancement increases the tolerance of plants to the environment.

Speeds up metabolism, and encourages the body to use nutrients more effectively. Therefore, higher KUE leads to better growth and yield potential.

The increase in available N, P, and K observed with nano treatments, especially NPKnps and NPKnps + chitosan, indicates that these formulations facilitate a slow and controlled nutrient release, ensuring more efficient transport of nutrients to the root zone. This enhances nutrient availability and increases the likelihood of plant uptake compared with conventional mineral fertilization. **Elshayb et al. (2024)** and **Hameed et al. (2024)** reported that chitosan-based nano-carriers for NPK enable gradual nutrient release, improving N, P, and K uptake and yield performance relative to traditional fertilization.

This improved nutrient uptake efficiency, combined with controlled-release behavior, may also contribute to improved nutrient cycling in the soil–plant system by reducing nutrient losses and enhancing rhizosphere interactions. Consequently, such polymeric delivery systems synchronize nutrient supply with plant demand, leading to improved nutrient use efficiencies (NUE, PUE, and KUE).

The significant increase in organic matter (OM) with chitosan (from 0.60 to 0.85–0.88%) substantiates its function as a bio stimulant and carrier that enhances soil structure and the retention of moisture and nutrients, while also improving micronutrients—especially zinc (Zn) and manganese (Mn)—which leads to increased enzyme activity and improved metabolic efficiency. Findings were consistent with those of **Riseh et al. (2023)** and **Faqir et al. (2021)**, who showed that chitosan, as a carrier/coating, enhances soil structure and water retention while facilitating slow, targeted nutrient release, thus improving nutrient availability and micronutrient uptake within the soil–plant system; as a bio stimulant, it increases soil fertility and promotes enzymatic activity and plant growth by enhancing moisture retention and the availability of macro- and micronutrients.

The superiority of the nano–chitosan combination (NPKnps + Chitosan) over other treatments in P, K, micronutrients, and soil organic matter indicates a synergistic effect between nano slow-release and chitosan-mediated root-zone delivery and loss reduction, supporting more efficient fertilization packages for semi-arid, saline-prone environments that is in the same line with **Ali et al. 2025** and **Elshayb et al.,2024** who informed that The superiority of the nano–chitosan combination (NPKnps + Chitosan) over other treatments in P, K, micronutrients, and soil organic matter indicates a synergistic interaction between nano slow release and chitosan mediated root zone delivery with reduced losses, supporting more efficient fertilization packages for semi-arid, salinity prone environments

## Conclusion

Nano and chitosan fertilization consistently surpassed mineral-only and control treatments, improving faba bean physiological characteristics and yield potential while increasing soil nutrient availability. The NPKnps + Chitosan platform worked best because it increased OM, available N, P, K, Zn, and Mn, while keeping EC close to baseline and lowering pH slightly. Chitosan alone increased the availability of micronutrients and organic matter, showing that it can work as a bio stimulant and carrier to improve conditions in the rhizosphere. Mixed regimes (50% NPKnps + 50% NPKmin; NPKmin + Chitosan) gave balanced gains and were effective for fertilizing semi-arid, alkaline soils like Sabha.

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## Compliance with ethical standards

### *Disclosure of conflict of interest*

The authors declare that they have no conflict of interest.

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## References

1. Abdel Kader, H. E. (2025). Impact of Humic Acid and Foliar Application of Chitosan on Growth, Yield, and Seed Quality of Faba Bean Crop (*Vicia faba* L.). *Assiut Journal of Agricultural Sciences*, 56(3), 14-28.
2. Abisankar, M., Augustine, R., Manuel, R. I., & Kumar, S. M. (2024). Morphological and Productivity Response of Chickpea (*Cicer arietinum* L.) to Nano Biofertilization. *Legume Research: An International Journal*, 47(12).
3. Abou-youseff, A. M., Abou El-Khair, R. A., El-Mohtasem, M. O., & Shower, S. S. (2022). Impacts of Nano-Fertilizers and Chemical Fertilizers on Plant Growth and Nutrient Uptake by Faba Bean (*Vicia faba* L.) Plant. *Al-Azhar Journal of Agricultural Research*, 47(1), 216-229. <https://doi.org/10.21608/ajar.2022.266504>

4. Alencar, R. S. D., Viana, P. M. D. O., Dias, G. F., Bonou, S. I., Ribeiro, L. D., Lourenço de Araujo, Y. M., ... & Melo, A. S. D. (2025). Chitosan mitigates water stress in cowpea plants through modulation of growth, homeostasis, and antioxidant activities. *Frontiers in Plant Science*, 16, 1591920.
5. Alhasany, A. R., Aljaberi, M. A. R., Noaema, A. H., Hadi, S. F., & Sawicka, B. (2024). Mineral and nanopotassium fertilization effects on growth and yield traits of faba bean (*Vicia faba* L.). *SABRAO Journal of Breeding and Genetics*, 56(6), 2488-2494. <http://doi.org/10.54910/sabrao2024.56.6.30>
6. Ali, A., El Danasoury, M. M., El Shaer, M. A., & Abdel-Aziz, H. M. M. (2025). Effect of chitosan nanoparticles either alone or loaded with NPK on growth and productivity of pea plants in the field. *Egyptian Journal of Botany*.
7. Alshammari, W. B., Alshammery, K., Lotfi, S., Altamimi, H., Alshammari, A., Al-Harbi, N. A., & Abdelaal, K. (2024). Improvement of morphophysiological and anatomical attributes of plants under abiotic stress conditions using plant growth-promoting bacteria and safety treatments. *PeerJ*, 12, e17286.
8. Costales-Menéndez, D., Falcón-Rodríguez, A. B., García-Domínguez, R., & Capdevila-Valera, J. Z. (2020). Effect of chitosan foliar spray on the vegetative development of inoculated soybean. *Cult. Trop*, 41, e07.
9. Easwaran, C., Christopher, S. R., Moorthy, G., Mohan, P., Marimuthu, R., Koothan, V., & Nallusamy, S. (2024). Nano hybrid fertilizers: A review on the state of the art in sustainable agriculture. *Science of the Total Environment*, 929, 172533.
10. El-Blasy, S. S., Zian, A. H., El-Gendy, H. M., Hafez, M., Bourouah, M., Abd-ElGawad, A. M., & Rashad, Y. M. (2024). Potential of chitosan and silver nanoparticles as fungicides against chocolate spot of faba bean: physiological, ultrastructural and toxicity studies. *Cogent Food & Agriculture*, 10(1), 2413400.
11. Elshayb, O. M., Ghazy, H. A., Wissa, M. T., Farroh, K. Y., Wasonga, D. O., & Seleiman, M. F. (2024). Chitosan-based NPK nanostructure for reducing synthetic NPK fertilizers and improving rice productivity and nutritional indices. *Frontiers in Sustainable Food Systems*, 8, 1464021.
12. El-Sheref, G. F., Mansour, A. M., & Ibrahim, R. A. (2025). Enhances Soil Health and improving mineral phosphorous Fertilizer use Efficiency for Faba Bean Plants (*Vicia faba* L.) using Organic and Bio-Fertilizers. *Journal of Soil Sciences and Agricultural Engineering*, 16(1), 1-8.
13. EU Nitrogen Expert Panel. (2016). Nitrogen Use Efficiency (NUE) – Guidance Document for assessing NUE at farm level. Wageningen University, Alterra.
14. Fadal, L. T., Al-Rikabi, G. Z. K., & Atiyah, H. A. (2023). Effect of adding nano-NPK fertilizer and humic acid on some vegetative growth characteristics and active components of myrtle *Myrtus communis* L.
15. Faqir, Y., Ma, J., & Chai, Y. (2021). Chitosan in modern agriculture production. *Plant, Soil and Environment*, 67(12), 679-699.
16. Fouda, S. E., El-Saadony, F. M., Saad, A. M., Sayed, S. M., El-Sharnouby, M., El-Tahan, A. M., & El-Saadony, M. T. (2022). Improving growth and productivity of faba bean (*Vicia faba* L.) using chitosan, tryptophan, and potassium silicate anti-transpirants under different irrigation regimes. *Saudi Journal of Biological Sciences*, 29(2), 955-962.
17. Galal, M., Rahhal, M., El-Argawy, E., & El-Korany, A. (2021). Efficacy of chitosan and chitosan nanoparticles to control chocolate spot disease on faba bean under field conditions. *Journal of Agricultural and Environmental Sciences*, 20(3), 20-31.
18. Hameed, H., Nagaraju, V., Marimuthu, S., Balakrishnan, M., Raviraj, A., & Ambrose, K. (2024). A review on nano enabled controlled release fertilizers and their nutrient release mechanisms. *Journal of Agricultural Engineering*, 61(5spl), 722-733.
19. Hoffmann, W. A., & Poorter, H. (2002). Avoiding bias in calculations of relative growth rate. *Annals of Botany*, 90(1), 37-42.
20. HUSSAIN, M. A., MOSA, R. E., & NOORI, M. M. (2021). RESPONSE OF FABA BEAN YIELD AND YIELD COMPONENTS TO DIFFERENT LEVELS OF NANO FERTILIZER. *Journal of Duhok University*, 24(2), 171-176. ISO 690
21. Ji, J., Lu, X., Ma, H., Jin, X., Jiang, S., Cui, H., & Yang, Y. (2025). Estimation of plant leaf water content based on spectroscopy. *Frontiers in Plant Science*, 16, 1609650.
22. Liu, Z., Xing, Y., Jin, D., Liu, Y., Lu, Y., Chen, Y., & Zhang, X. (2022). Improved nitrogen utilization of Faba Bean (*Vicia faba* L.) roots and plant physiological characteristics under the combined application of organic and inorganic fertilizers. *Agriculture*, 12(12), 1999. ISO 690
23. Malarkodi, K., Divya, V., Natarajan, K., Navamaniraj, K. N., & Ganesan, K. Assessing the Effects of Chitosan on Groundnut (*Arachis hypogaea* L.) Growth and Productivity. *Legume Research-An International Journal*, 1, 7.
24. Murrell, T. S., Mikkelsen, R. L., Sulewski, G., Norton, R., & Thompson, M. L. (2021). Improving potassium recommendations for agricultural crops (p. 455). Springer Nature.

25. Nandini, T., Sudhalakshmi, C., Sivakumar, K., Parameswari, E., & Thangamani, C. (2025). A review-chitosan nanoparticles towards enhancing nutrient use efficiency in crops. *International Journal of Biological Macromolecules*, 141433.
26. Omer, A. M., Osman, M. S., Ibrahim, S. M., & Badawy, A. A. (2025). Nanoparticle-based strategies for enhancing faba bean (*Vicia faba* L.) growth and stress tolerance in saline soils. *Biocatalysis and Agricultural Biotechnology*, 103630.
27. Pandao, M. R., Deshmukh, P. W., Bhoyar, S. M., & Sajid, M. Enhancing chickpea yield and nutrient efficiency in vertisols using nano diammonium phosphate.
28. Patra, P., Kumar, A., Kar, S., Kerketta, N. S., & Singh, N. K. (2024). Effect of NPK and biofertilizers on germination of Lentil (*Lens culinaris*) in sandy loam soil of Jharkhand. *International Journal of Advanced Biochemistry Research*, SP-8(2), 175-177.
29. Rani, N., Tiwari, A., Saini, K., & Maity, D. (2025). Nanofertilizers for Nutrient Enhancement in Plants and Sustainable Agriculture. In *Application of Nanotechnology for Sustainable Agriculture and Food Security Volume 1: The Role of Nanofertilizers and Nanopesticides* (pp. 45-75). American Chemical Society.
30. Raut, A. N., Deotale, R. D., Gopale, R. O., Baviskar, S. B., & Madkes, V. S. (2022). Evaluation of chitosan concentrations for improving chemical, biochemical and yield contributing parameters and yield of chickpea.
31. Riseh, R. S., Vazvani, M. G., & Kennedy, J. F. (2023). The application of chitosan as a carrier for fertilizer: A review. *International journal of biological macromolecules*, 252, 126483.
32. Rojas-Pirela, M., Carillo, P., Lárez-Velásquez, C., & Romanazzi, G. (2024). Effects of chitosan on plant growth under stress conditions: similarities with plant growth promoting bacteria. *Frontiers in Plant Science*, 15, 1423949.
33. Sheta, M. H., El-Khair, A., Ramadan, A. M., Shower, S. S., & Salim, F. J. (2025). Comparative Efficiency of Nano and Chelated Forms of Iron, Zinc and Manganese for Improvement of Yield and Water Use Efficiency of Faba Bean Grown under Drought Stress. *Egyptian Journal of Soil Science*, 65(1), 597-618.
34. Thamarsha, A. K. A. N. W. M. R. K., Kumar, N., Pratibha, Mor, K., Upadhyay, A., Sudhani, H. P., & Pamu, V. S. (2024). A review of functional properties and applications of legume-based edible coatings. *Legume Science*, 6(4), e70004..

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