

A Comparative Evaluation of Nano, Mineral NPK, and Chitosan Effects on Yield Components of Two Faba Bean (*Vicia faba* L.) Varieties in Wadi Etba, Libya

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تقييم مقارن لتأثير أسمدة NPK النانوية والمعدنية والشيتوزان في مكونات المحصول لصنفين من الفول (*Vicia faba* L.) في وادي عتبة، ليبيا

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Abstract:

A field experiment was conducted during the 2024/2025 growing season in Wadi Etba, Libya, to evaluate the effects of mineral and nano NPK-fertilizers and chitosan on yield components of two faba bean varieties (local and imported) Seven treatments were tested: control, recommended mineral NPK (NPK M), recommended nano NPK (NPK N), chitosan, 50% NPK N + 50% NPK M, NPK M + chitosan, and NPK N + chitosan, arranged in a randomized complete block design with three replicates.

The results revealed significant effects of fertilization treatments and cultivars on all studied yield components and seed yield. The imported cultivar consistently outperformed the local one across all parameters. The combined application of NPK N + chitosan recorded the highest values for yield components, including number of pods per plant (25 and 22), number of seeds per pod (6.3 and 5.6), 100-seed weight (98 and 93 g), seed weight per plant (53 and 46 g), seed yield (4.6 and 4.0 t ha⁻¹), and harvest index (58% and 54%) for imported and local cultivars, respectively. followed by the combined application of 50% NPK N + 50% NPK M.

Combined nano NPK and chitosan improved yield performance and nutrient use efficiency than either treatment applied individually, suggesting that their integration could be an effective strategy for enhancing faba bean productivity under semi-arid conditions. The findings highlight the potential of integrated nano-fertilization strategies as a promising and sustainable approach to enhancing faba bean productivity while improving fertilizer-use efficiency and reducing dependence on conventional mineral fertilizers.

Keywords: Leguminous Crops, Nano Fertilizer, Sustainable Fertilization, Yield Improvement.

الملخص

اجريت تجربة حقليّة خلال الموسم الزراعي 2025/2024 في وادي عتبة، ليبيا، بهدف تقييم تأثير الأسمدة المعدنية والنانوية للنيتروجين والفوسفور والبوتاسيوم والشيتوزان على مكونات المحصول لصنفين من الفول (محلي ومستورد). اشتملت

التجربة على سبع معاملات هي: معاملة المقارنة (الشاهد)، السماد المعدني الموصي به NPK (NPK M)، السماد النانوي الموصي به NPK (NPK N)، الشيتوزان، 50% NPK نانوي + 50% NPK معدني، NPK معدني + شيتوزان، و NPK نانوي + شيتوزان، وذلك ضمن تصميم القطاعات العشوائية الكاملة (RCBD) بثلاث مكررات. أظهرت النتائج وجود تأثيرات معنوية لمعاملات التسميد ونوع الصنف على جميع مكونات المحصول ومحصول البذور المدروسة. كما تفوق الصنف المستورد بشكل مستمر على الصنف المحلي في جميع الصفات المدروسة. وسجلت المعاملة المشتركة NPK نانوي + شيتوزان أعلى القيم لمكونات المحصول، بما في ذلك عدد القرون للنبات (25 و 22)، وعدد البذور في القرن (6.3 و 5.6)، ووزن 100 بذرة (98 و 93 جم)، ووزن البذور للنبات (53 و 46 جم)، ومحصول البذور (4.6 و 4.0 طن هكتار⁻¹)، ودليل الحصاد (58% و 54%) للصنفين المستورد والمحلي على التوالي. تلتها معاملة 50% NPK نانوي + 50% NPK معدني.

أظهرت النتائج أن التطبيق المشترك لسماد NPK النانوي والشيتوزان تحسناً أكبر في أداء المحصول وكفاءة استخدام العناصر الغذائية مقارنة باستخدام كل منهما على حدة، مما يشير إلى أن دمجهما يمكن أن يمثل استراتيجية فعالة لتعزيز إنتاجية الفول تحت الظروف شبه الجافة. كما تشير الدراسة إلى أن اعتماد استراتيجيات التسميد النانوي المتكاملة قد يوفر نهجاً مستداماً لتحسين إنتاج الفول مع تقليل الاعتماد على الأسمدة المعدنية التقليدية.

الكلمات المفتاحية: المحاصيل البقولية، التسميد النانوي، التسميد المستدام، تحسين المحصول.

Introduction

Faba bean (*Vicia faba* L.) is a leguminous crop of world importance with high protein content, capacity to enhance soil nitrogen through biological fixation, and its great contribution to food security and sustainable agriculture. In recent years, more sophisticated nutrient management systems have emerged which aim to increase crop production and make nutrients more efficient in the use. A promising solution to enhanced nutrient delivery and uptake in crops such as faba bean and allied legumes is Nano fertilizers, particularly nano-NPK fertilizers (Omer *et al.*, 2025; Kamel, 2025).

Unlike conventional mineral fertilizers, which dissolve rapidly after application and are often associated with substantial nutrient losses through leaching, volatilization, runoff, and soil fixation, resulting in relatively low nutrient use efficiency, nano-fertilizers are engineered with particle sizes ranging from 1 to 100 nm or formulated using nanostructured carriers that enable controlled and targeted nutrient delivery. Owing to their extremely small particle size, high specific surface area, enhanced reactivity, and improved interaction with plant tissues, nano-fertilizers facilitate gradual nutrient release, enhance nutrient absorption and translocation, and synchronize nutrient availability with crop demand. These characteristics improve nutrient use efficiency, reduce fertilizer application rates and environmental contamination, promote plant growth, physiological performance, and yield more effectively than conventional mineral fertilizers. Consequently, nano-fertilizers have emerged as a promising sustainable alternative for modern agriculture, particularly under nutrient-limited and environmentally stressful conditions (Bindraban *et al.*, 2018; González-Feijoo *et al.*, 2024; Semenova *et al.*, 2024; Ayenew *et al.*, 2024; Couto Junior *et al.*, 2025).

Chitosan, being a natural biopolymer, has been increasingly investigated in modern agricultural practice as a plant growth promoter and bio stimulant for improving the intake of nutrients, physiological activities and tolerance to biotic and abiotic stresses in plants without harming them. (Román-Doval *et al.*, 2023; Maluin *et al.*, 2020).

(Omer *et al.*, 2025) observed that the broader application of nanotechnology in the improvement of physiological functions and nutrient absorption has shown that nano fertilizer treatments could be used to improve nitrogen, phosphorus and potassium uptake in faba bean, resulting in increased shoot and seed yields even in unfavorable environments, NPK Nano fertilizers can significantly enhance vegetative growth, yield, and nutrient uptake in faba bean. For example, the use of combined nano-fertilizers significantly increased plant height, number of branches, pod weight, and 100-seed weight compared to conventional methods (Kamel, 2025). Furthermore, the application of nano potassium in a foliar application study has been shown that the morphological traits like plant height, number of branches, number of leaves, leaf area and pod weight have improved significantly, especially under stressful situations like salinity according to (Alsamak and Noori, 2025).

Pandao *et al.* (2024) reported that the critical requirement of balanced nutrient delivery, which implies that the application of traditional NPK fertilization is more beneficial than Nano fertilizers in terms of optimizing crop production and efficiency in nutrient recovery in chickpea cultivation. In contrast Abou-Yousef *et al.* (2022) established that low-dose nano-fertilizer application was the most efficient in faba bean, with 25% of the

recommended dose of the NPK showing the best growth and yield measurements, compared to the higher doses and traditional fertilizers.

Abdel Kader (2025) noted that the use of chitosan increased vegetative growth, yield components and seed quality especially when humic acid was used alongside it in the field. This was largely ascribed to an increase in metabolic activity and assimilation of nutrients. Similarly **Dawood (2024)** indicated that foliar application of chitosan had a significant positive impact on growth parameters, photosynthetic efficiency, and drought tolerance of faba bean. Research of legume crops shows that chitosan enhances salinity stress tolerance by maintaining osmotic balance and increasing photosynthetic pigments (**Alenazi et al., 2024**).

Fouda et al. (2022) showed that using chitosan, along with antitranspirants, enhanced growth, water relations, and yield of faba bean under various irrigation regimes. Moreover, chitosan enhances plant growth and productivity under a variety of different mechanisms, including increased photosynthesis, increased nutrient use efficiency, and plant defense pathway activation affording to (**Asl et al., 2021; Malerba and Cerana, 2021**).

Therefore, the current research set out to determine whether the use of nano-formulated fertilizers and chitosan used alone or in combination with conventional mineral NPK could increase yield performance and yield components, as well as the use efficiency of nutrients by two faba bean varieties (local and imported) under semi-arid conditions in Wadi Etba, Libya, and to identify the most appropriate integrated fertilization strategy to use to achieve sustainable faba bean production under semi-arid conditions.

Material and methods

1-Experimental Site

A field experiment was conducted during the **2024/2025** growing season in Wadi Etba, Southern Libya, to evaluate the effects of mineral NPK fertilizer, nano NPK fertilizer, and chitosan on the yield components and seed yield of two faba bean (*Vicia faba* L.) cultivars under the semi-arid environmental conditions of southern Libya. The experimental site is characterized by a hot arid climate with low annual rainfall and high temperatures prevailing throughout most of the growing season.

2- Soil Sampling and Analysis

Before land preparation, composite soil samples were collected from the experimental field at a depth of 0–20 cm to determine the initial physical and chemical properties of the soil. Additional soil samples were collected after harvest to evaluate the effect of the fertilization treatments on soil fertility. All soil samples were air-dried, gently crushed, passed through a 2-mm sieve, and analyzed at the Soil and Plant Analysis Laboratory, Research Center, Sebha University, Libya.

3. Physical and Chemical Soil Analysis

3.1 Physical Analysis

Soil texture was determined using the hydrometer method according to Gee and Bauder (1986). The soil textural class was identified using the USDA textural triangle.

3.2 Chemical Analysis

Soil pH was measured in a 1:2.5 soil-to-water suspension using a digital pH meter according to Jackson (1973).

Soil electrical conductivity (EC) was determined in a 1:2.5 soil-to-water extract using an electrical conductivity meter according to Jackson (1973).

Organic matter (OM) was determined using the Walkley and Black wet oxidation method according to Walkley and Black (1934).

Total nitrogen (N) was determined according to Jackson (1973).

Available phosphorus (P) was determined using the sodium bicarbonate (Olsen) extraction method according to Olsen et al. (1954).

Available potassium (K) was extracted with 1 N ammonium acetate and determined according to Jackson (1973).

Exchangeable Na, Mg, and Ca were extracted using 1 M ammonium acetate (NH₄OAc) buffered at pH 7.0 and determined by atomic absorption spectrophotometry, while soil organic carbon (SOC) was determined by dry combustion (ISO/TS 22171, 2023; ISO 10694, 1995).

All soil analyses were carried out according to the standard analytical procedures routinely adopted by the Soil and Plant Analysis Laboratory, Research Center, Sebha University, Libya.

Table 1. Initial physical and chemical properties of the experimental soil before sowing 2024/2025 season.

Chemical properties	
PH	8
EC (dS m ⁻¹)	2.99
Organic matter (%)	0.5
Total N (mg kg ⁻¹)	26.0
Total C (%)	1.05
P (mg kg ⁻¹)	6.8
K (mg kg ⁻¹)	10.0
Na (mg kg ⁻¹)	0.25
Mg (mg kg ⁻¹)	0.04
Ca (mg kg ⁻¹)	0.16
Physical properties	
Sand (%)	97
Silt (%)	1.7
Clay (%)	1.3
Water-holding capacity (%)	21.6

4. Plant Materials and Land Preparation

Two faba bean (*Vicia faba* L.) cultivars were used in this study: a locally cultivated cultivar commonly grown in southern Libya and an imported Spanish cultivar, both obtained from the local agricultural market.

The experimental field was plowed and cleaned of the residues of the previous barley crop before sowing. The land was then leveled and divided into experimental plots according to the experimental layout.

Each experimental plot measured 3.75 m², consisting of five rows, each 1.5 m long and spaced 0.50 m apart. Seeds were sown at a spacing of 25 cm between hills. Three seeds were planted in each hill and later thinned to two plants per hill after complete seedling establishment.

5- Experimental Design

The experiment was arranged as a factorial experiment in a Randomized Complete Block Design (RCBD) with three replications. The first factor consisted of seven fertilization treatments, whereas the second factor consisted of two faba bean cultivars.

The treatments were as follows:

- Control.
- Mineral NPK fertilizer (recommended dose).
- Nano NPK fertilizer (recommended dose).
- Chitosan.
- 50% Mineral NPK + 50% Nano NPK.
- Mineral NPK + Chitosan.
- Nano NPK + Chitosan.

6- Fertilization Treatments

The recommended mineral fertilization program consisted of diammonium phosphate (DAP; 18% N and 46% P₂O₅), urea (46% N), and potassium sulfate (50% K₂O). These fertilizers were applied at the recommended rates of **150 kg DAP ha⁻¹, 87 kg N ha⁻¹, and 120 kg K₂O ha⁻¹**, respectively.

Diammonium phosphate was incorporated into the soil during land preparation. Urea and potassium sulfate were applied in two equal splits: the first at approximately 2–3 weeks after seedling emergence and the second at the beginning of flowering. All mineral fertilizers (DAP, urea, and potassium sulfate) were applied as soil applications according to the designated fertilization treatments.

7- Nano NPK Fertilizer and Chitosan Application

The nano fertilizer used in this study was a commercial Nano NPK (19:19:19) formulation produced by Bio Nano Technology, enriched with micronutrients (Fe, Mg, Mn, Zn, B, and Cu), amino acids (5%), and algal extracts (0.5%).

Nano NPK was applied as a foliar spray at a concentration of 2 g L⁻¹ at 25, 40, and 55 days after sowing. For each application, 1 L of the prepared spray solution was uniformly applied to each experimental plot (3.75 m²).

Chitosan, a natural biodegradable polysaccharide derived from shrimp shell chitin, with a molecular formula of (C₆H₁₁NO₄)_n (CAS No. 9012-76-4), degree of deacetylation (DDA) of 90–95%, and viscosity below 100 cP, was applied as a foliar spray at the manufacturer's recommended rate (1 L per 350 L of water). Chitosan was sprayed 10 days after each Nano NPK application, resulting in three foliar applications during the growing season. Similarly, 1 L of the prepared chitosan spray solution was uniformly applied to each experimental plot (3.75 m²) during each application.

8- Measured Traits

At harvest, the following yield-related traits were determined:

Number of pods per plant: it was measured as the mean of three randomly selected plants from each subplot, counting all fully developed pods (Abdalla et al., 2015).

Number of seeds per pod: it was measured as the mean of three pods taken randomly from each of the selected plants in the subplot (Abdalla et al., 2015).

100-seed weight (g): it was measured by weighing a sample of 100 seeds taken randomly from the seeds harvested from each subplot (Abdalla et al., 2015).

Seed weight per plant (g): it was obtained by weighing seeds from three randomly selected plants per subplot after threshing (Abdalla et al., 2015).

Seed yield (t ha⁻¹): it was calculated by extrapolating the total seed weight harvested from the subplot to hectare basis (Abdalla et al., 2015).

Harvest index (%): it was calculated as the ratio of seed yield to total aboveground biomass (seed yield + straw yield) and expressed as a percentage (Donald, 1962).

8 -Statistical Analysis

All experimental data were subjected to analysis of variance (ANOVA) appropriate for a factorial experiment arranged in a Randomized Complete Block Design (RCBD) using CoStat statistical software. Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$).

Results

The results showed that the treatment of fertilization and cultivar type had a significant influence on yield components and seed yield of faba bean. An overall dominance of the imported cultivar over the local was evident in all traits examined.

Number of pods per plant

Pod number was significantly affected by fertilization treatments and cultivar. The highest pod number was recorded under NPK N + chitosan treatment which the imported cultivar had the highest number of pods per plant

of 25 and the local cultivar had the highest number of pods per plant of 22. Conversely, the least values were recorded in the control treatment (12 and 10) pods plant⁻¹ of the imported and local cultivars; respectively combined treatments consistently outperformed single applications as compared to the individual applications of mineral fertilizers or chitosan according to (Figure 1).

Number of seeds per pod

Figure 2 showed that seeds per pod followed the same response pattern as pod number for the number of seeds per pod. The highest values were recorded under NPK N + chitosan treatment (6.3 and 5.6 seeds pod⁻¹ in the case of imported and local cultivars, respectively), and minimum values were observed under the control treatment (3.6 and 3.0 seeds pod⁻¹). The synergistic interaction between nano-fertilizers and chitosan led to a significant enhancement of the individual applications.

100 seed weight

100-seed weight increased significantly under combined treatments. NPK N + chitosan (98 g imported and 93 g local cultivar) gave the highest values, and the control (70 and 66 g respectively) the lowest values. The imported cultivar was always heavier seeded compared to the local cultivar as noted in Figure 3.

Weight of seed/plant

Figure 4 indicated that the seed weight per plant exhibited the same trend, as the NPK N + chitosan treatment gave the highest values (53 and 46 g of imported and local cultivars, respectively). On the other hand, the control treatment produced the least weight of the seed per plant (23 and 20 g). The decline in values, which is gradually observed in treatments, emphasizes the significance of combined fertilization strategies.

Seed yield

Fertilization practices were very effective in improving seed production. The NPK N + chitosan (4.6 t ha⁻¹ imported and 4.0 t ha⁻¹ local cultivar) gave the highest yield, followed by the 50% NPK N + 50% NPK M treatment. Control treatment had the lowest yield (2.2 and 1.9 t ha⁻¹). The excellence of the imported cultivar was observed in all treatments as Presented in Figure 5.

Harvest index

Treatments also had a significant impact on harvest index. The greatest values were recorded with NPK N + chitosan (58% and 54% with imported and local cultivars, respectively) and the lowest with the control treatment (39% and 36%). This means that assimilate partitioning to the seed under integrated fertilization is improved as stated by Figure 6. be the reason behind the drastic gains in yield and yield components that are seen during these treatments.

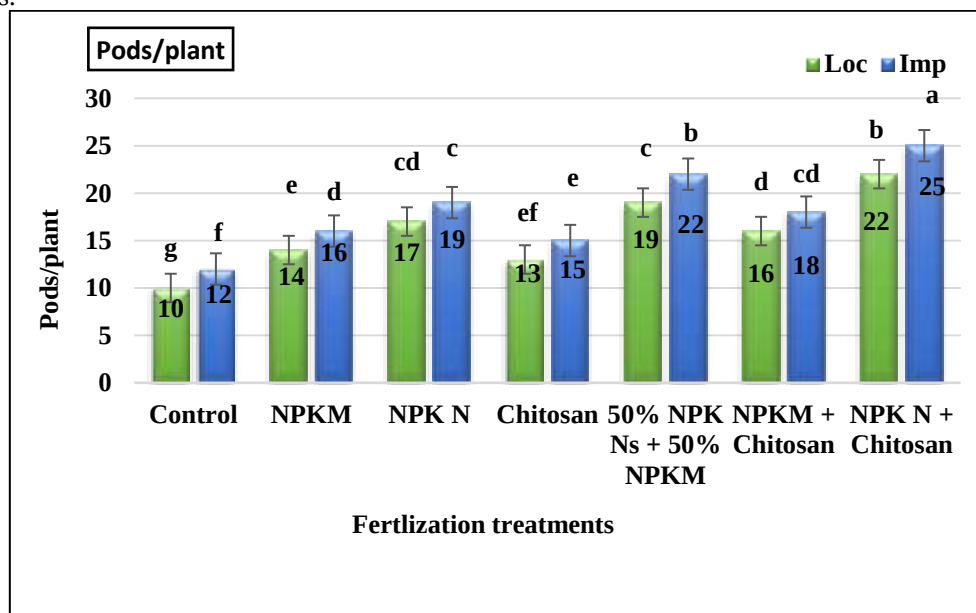


Figure 1: Effect of fertilization treatments on the number of pods per plant in local and imported faba bean varieties.

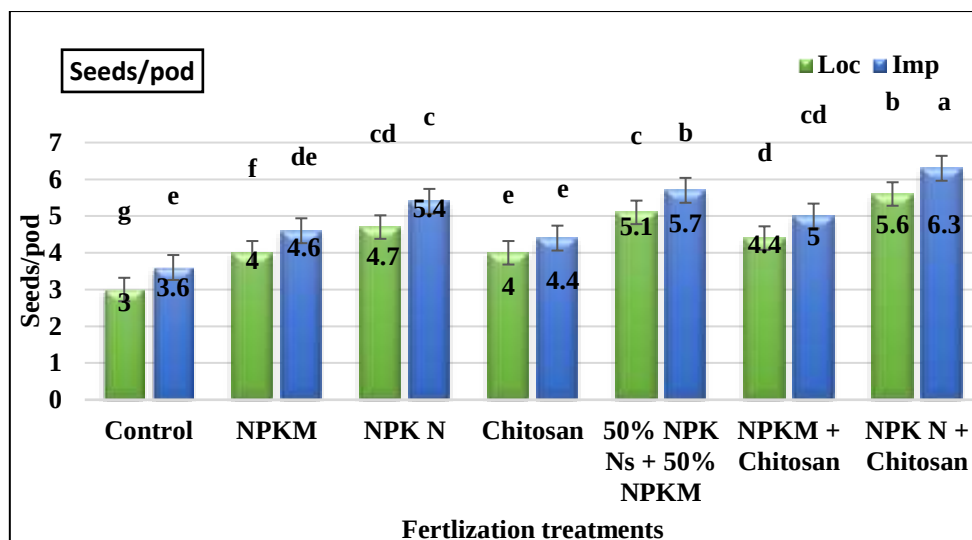


Figure 2: Effect of fertilization treatments on the seeds per pods in local and imported faba bean varieties.

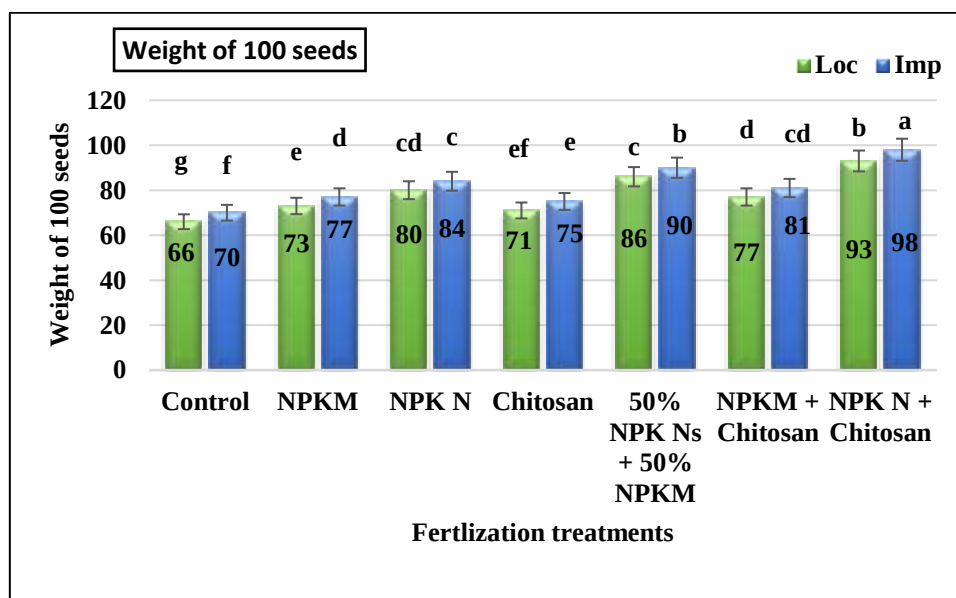


Figure 3: Effect of fertilization treatments on the weight of 100 seeds in local and imported faba bean varieties.

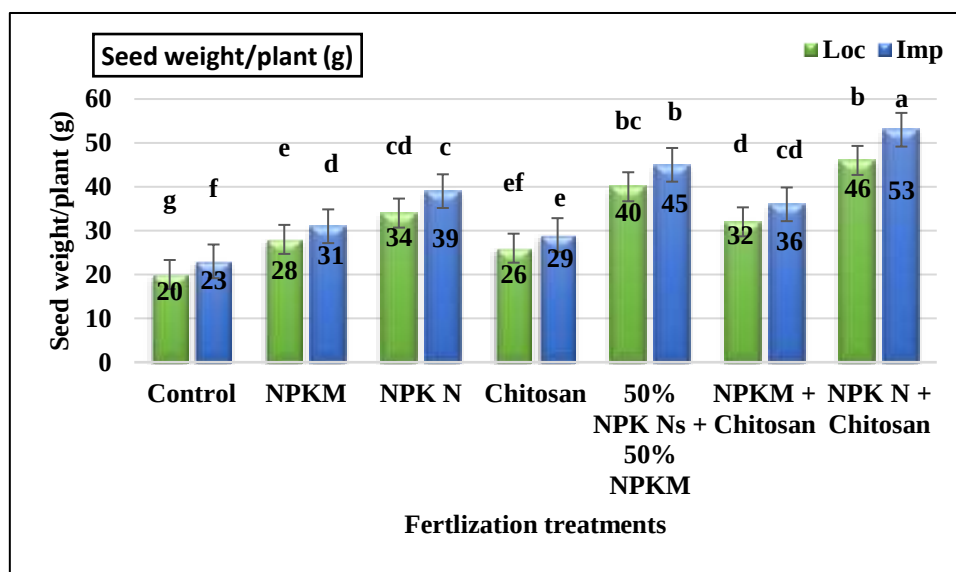


Figure 4: Effect of fertilization treatments on the Seed weight/plant (g) in local and imported faba bean varieties.

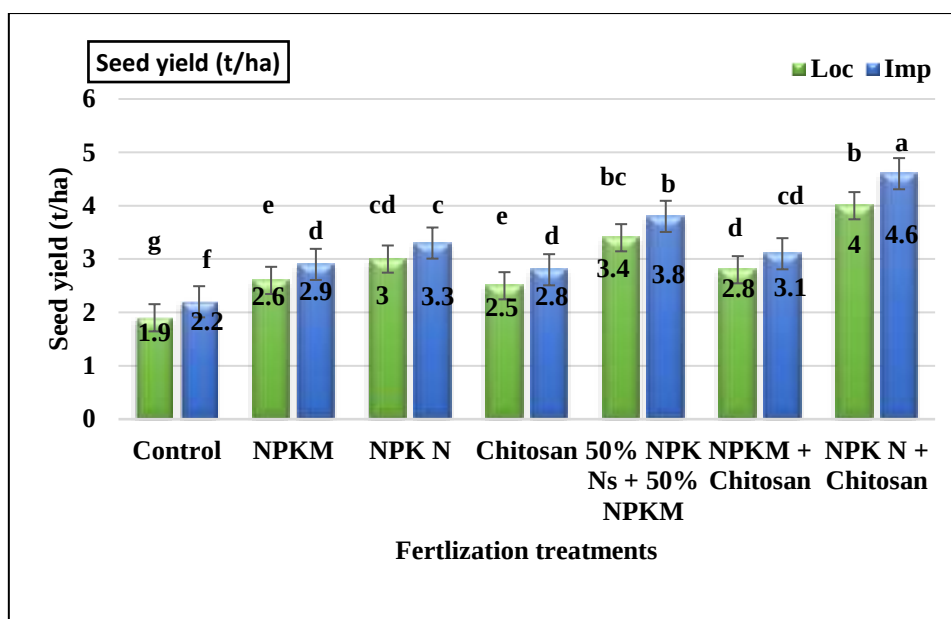


Figure 5: Effect of fertilization treatments on the Seed yield (t/ha) in local and imported faba bean varieties.

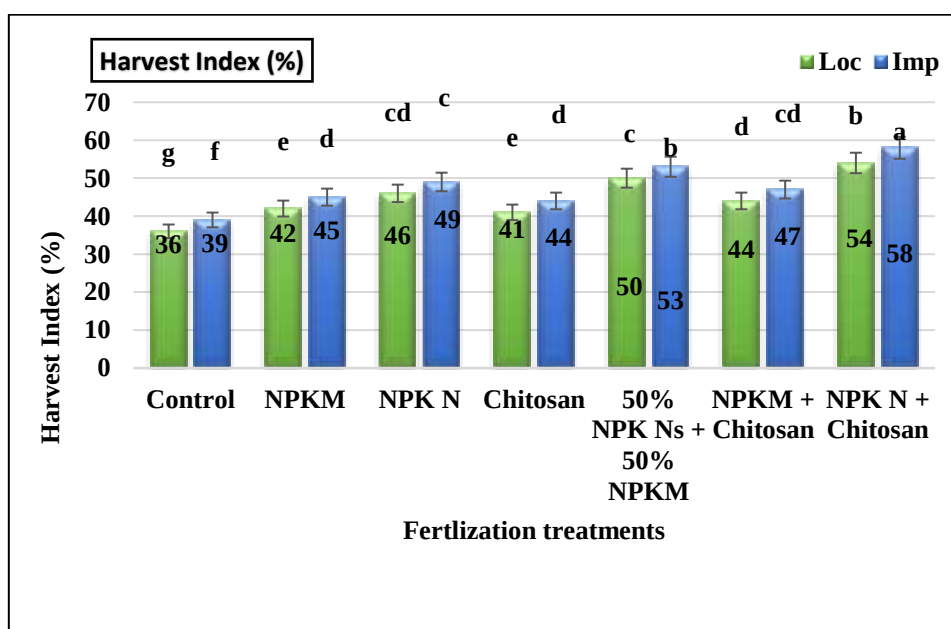


Figure 6: Effect of fertilization treatments on the Harvest Index (%) in local and imported faba bean varieties.

Discussion

Fertilization treatments and cultivar type had a significant effect on **pod number**. The combination of NPK N and chitosan achieved the highest values and the lowest values were obtained in the control treatment. This finding aligns with the report of **Alhasany et al. (2024)** and **Kamel (2025)**, who reported that nano-fertilizers enhance nutrient availability and reproductive development in legumes. Likewise, **Abdel Kader (2025)**, and **Fouda et al. (2022)** reported that chitosan decreases flower abscission and increases pod development in faba bean in faba bean.

The response may be attributed to improved source–sink relationships and the synergistic action of enhanced nutrient supply provided by nano-fertilizers together with the physiological regulation induced by chitosan. Nano-fertilizers enhance the availability and uptake of essential nutrients such as nitrogen and potassium, which play a critical role in flower initiation and reproductive development. Meanwhile, chitosan improves hormonal balance and stress tolerance, resulting in greater flower retention and pod set.

In the **seeds per pod**, the highest values were also obtained under NPK N + chitosan treatment for seeds per pod. Compared to previous studies **Nigam et al. (2025)**, **Abou-Yousef et al. (2022)**, and **Islam et al. (2023)** demonstrated that nano-fertilizers should be used in enhancing seed set via nutrient availability during flowering. Moreover, chitosan has been reported to enhance fertilization and decrease flower abortion in legumes (**Fouda et al., 2022; Alenazi et al., 2024**).

This enhancement can be attributed to the improved pollen viability and enhanced nutrient availability in the reproductive phase. The combination of nano-fertilizers and chitosan guarantees the effective delivery of nutrients and physiological stability, leading to better fertilization efficiency and seeds per pod.

100-seed weight increased significantly under combined treatments under combined treatments, especially NPK N + chitosan. **Abou-Youssef et al. (2022)**, **Aziz and Zrar (2021)**, and **Plant Archives (2024)**, who showed that nano-fertilizers enhance the seed filling and the dry matter accumulation of legumes, provided the same findings. Similarly, **Abdel Kader (2025)** and **Alenazi et al. (2024)** discovered that chitosan has the capacity to increase seed development and seed size in both ideal and adverse conditions.

This response can be attributed to enhanced production of assimilates and partitioning in favor of growing seeds. Nano-fertilizers enhance photosynthetic performance and nutrient absorption whereas chitosan improves metabolic activity and antioxidant defense, leading to improved seed filling and seed weight.

Combined treatments led to significantly higher seed weight per plant. This matches the conclusions of **Abou-Yousef et al (2022)** and **Nigam et al. (2025)** who's reported that the vegetative biomass and yield of plant. On the same note

May be due to enhance source–sink relationship as nano-fertilizers facilitate assimilate production and chitosan facilitates allocation of assimilates to reproductive organs, thus higher seed biomass accumulation.

The application of fertilization treatments. The optimal **seed yield** was obtained through the combination of NPK N and chitosan. The result supports the findings of **Abou-Yousef et al. (2022)**, **Aziz and Zrar (2021)** and **Plant Archives (2024)** which demonstrate that nano-fertilizers enhance yield through improved nutrient utilization efficiency. Chitosan leads to better yield results because it helps plants create more flowers while defending them against environmental pressures (**Abdel Kader, 2025; Fouda et al., 2022; Alenazi et al., 2024**). The combined effect works because it boosts both vital body functions of organisms and their ability to deliver resources to their developing seeds. The continuous release of nutrients through nano-fertilizers combined with chitosan's ability to improve plant functions and reduce stress limitations leads to increased economic productivity.

Fertilization treatments especially combined NPK N + chitosan greatly increased the harvest index. These results are similar to **Abou-Yousef et al. (2022)**, **Kanthiya and Sharma (2024)**, showing increasing allocation of biomass upon application of nano fertilizer. Likewise, **Asl et al., (2021)** and **Rojas-Pirela et al. (2024)** have demonstrated that chitosan enhance assimilate partitioning towards reproductive organs of legume plants.

Nano-fertilizers can enhance yield and biomass production; whereas chitosan contributes by improving physiological efficiencies and stress induced losses, leading to higher economic yield.

Conclusion

The combination of NPK N and chitosan strongly improved the yield components, seed yield and harvest index of faba bean under semi-arid conditions. Among the cultivars tested, the introduced cultivar produced significantly better yield than the local cultivar in all the traits considered. This implies that integrating nano-fertilization technology with bio-stimulants like chitosan may be sustainable strategy to boost the faba bean productivity and improve nutrient utilization efficiency by reducing dependency of local cultivars on mineral fertilizers in semi-arid regions.

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