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## Algal and Nanoparticles of Silicon and Boron Foliar Application Efficiency for Maximizing Yield, and Quality Traits of Two Faba Bean Varieties

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THE use of nanotechnology as a fertilizer has been suggested in various researches as a tool for promoting progressive nutrients use efficiency, lessening nutrients losses through water irrigation and volatilization and enhancing crop yield stability. This experiment was carried out in the two growing winter seasons i.e., 2021/2022 and 2022/2023, aimed to Enhance the flowering and yield of faba bean (Vicai faba) by foliar application of algal Spirulina platensis and nanoparticles of silicon and boron to reduce flower drop, increase the number of flowers on the plant, and increase yields. A modified amount of Spirulina at a rate of 2.0 g $L^{-1}$, silicon nanoparticles at a rate of 100 ppm L-1, and Boron nanoparticles at a rate of 100 ppm L-1 either individually or combined each other on two faba bean (Nubaria-1 and Sakha-3) Cultivars by using Strips-Block design in three replications. Results indicated that the foliar spraying separately or combined increased the N, P, K, Ca, total carbohydrate and chlorophyll contents in the leaves of Nubaria-1 and Sakha-3 compared to the control. All foliar treatments decreased the shredded flowers consequently increasing the setted pods, and increased the biological and seed yields compared to the control with nonsignificant difference between the two cultivars in two seasons. The results, indicate that spraying with Sp+Si, Sp+B, and Sp+Si+B gave highest values for a number of flowering, pod weight, seed, biological, and protein yields of the two faba bean varieties. The seed yield was positively correlated with all studied traits under all treatment combinations

**Keywords:** Biofertilizers, Nanoparticles, Algae extract, correlation coefficients analysis,Faba bean cultivars

## Introduction

Faba bean (*Vicia faba L.*) is one of the most substantial winter legume crops and a great protein source for jointly human and animal feeding (Crepon *et al*., 2010). As a good rotation crop that fixes atmospheric nitrogen, it is a great candidate crop to supply nitrogen input into temperate agricultural systems. In addition, it significantly contributes to the restoration of soil fertility (Samuel *et al*., 2008 and Bendahmane *et al*., 2012). Among legumes crops,faba bean is one of the utmost important popular pulse food used in Egypt and worldwide due to its containing of 35% protein, 45% carbohydrate, and 2% fat for seeds and its ability to fix atmospheric nitrogen (Gomaa and Afifi, 2021)

According to Elwakil *et al*. (2016), the use of green chemistry in agriculture is thought to be a safe way to combat illnesses and generate high-quality seeds at a cheaper cost. According to FAO statistics from 2021, the world's farmed faba bean area was approximately 2722690 $ha^{-1}$ in 2021, yielding approximately 5964384 tons of dried seeds. The area cultivation of faba beans in Egypt reached approximately 26,382 $ha^{-1}$ in 2021, producing approximately 105,052 tons of dry

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seeds.. because of its capacity to fix nitrogen and enhance soil structure, plays a significant role in boosting food output and improving sustainable farming practices (Jensen *et al*., 2010),( Pretty and Bharucha, 2014). Therefore, maximizing the seed yield of faba beans is essential. The occurrence of shedding in faba bean plants was observed at considerable values, leading to a notable reduction in the profitable plant's seed yield. Thus, plant physiologists and breeders are researching the problem of shedding intensity in an attempt to decrease the high percentage of buds, flowering, and immature pods abscission to grow into fully grown pods in this plant.

The materials known as nanoparticles (NPs) have diameters varying from 1 to 100 nm. Agriculture and the enhancement of plant quality have seen a revolution thanks to the use and application of NPs. Applied in the agricultural field by spraying and broadcasting, conventional chemical fertilizers, pesticides, and other protective agents are maximally lost due to runoff, leaching, microbial, and photolytic degradation; as a result, they do not reach the targeted plants in sufficient or desired concentrations, resulting in significant crop losses at a significant financial cost. Numerous studies have been conducted by authors to maximize flower set and reduce pre-harvest loss of immature faba bean or other crop fries by utilizing a variety of techniques, such as plant growth regulators and mineral supplements (Bastawisy and Sorial 1998). For many crops, foliar administration of micronutrients is a more widely recognized, cost-effective, and efficient method. Accordingly, plants cultivated on some Egyptian soil produced greater growth and production when micronutrient spraying was applied (AbdEl Hamid and Sarhan, 2008, El-Desuki *et al*., 2010). Micronutrients are necessary for a variety of processes in plants, including photosynthesis, respiration, protein synthesis, carbohydrate metabolism, and the phenylpropanoid pathway. They also influence phenolic and lignin content, as well as membrane stability, in plant metabolism (Dutta *et al*., 2017). The soil's micronutrient content has drastically decreased due to cropping techniques and agricultural intensification. Micronutrient supply to the soil is also inadequate for many reasons, making it a crucial component of crop quality and productivity. Enhancing the nutritional status of plants through foliar treatment is crucial for both cost-effective and sustainable crop production. The foliar application would be a crucial component of soil fertility sustainability and might counteract the detrimental effects of nutrients removed from the soil (El-Fouly *et al*., 2010). Fertilizer application is a very practical and effective way to keep agriculture sustainable (Dewal and Pareek, 2004). Primarily, micronutrients have a role in the essential physiological functions of respiration and photosynthesis (Mengel *et al*., 2001), and their absence might hinder these crucial activities.

Boron (B) is essential for the growth and development of plants as well as for the stages of sexual reproduction, since it promotes the formation of seeds and fruits, germination of pollen and its tube elongation, and flower creation. Numerous activities in vascular plants, including root elongation, indole acetic acid (IAA) oxidase activity, sugar translocation, carbohydrate metabolism, and nucleic acid synthesis, are affected differently when it is deficient (Pilbeama and Kirkbya 1983 and Camacho-Cristobal et al., 2008). Vegetable plants benefit from little amounts of B, but larger concentrations can be harmful to all living things, including plants. It inhibits growth, especially that of shoots, and results in chlorosis of the margins and tips of mature leaves (Gupta et al., 1985). In commercial plant production, providing a sufficient Boron supply is particularly important for yield formation (pollination) (Khayyat *et al*., 2007; Wojcik *et al*., 1999) and fruit quality (Wojcik *et al*., 1999; Dordas, 2006; Dordas *et al*., 2007). Boron deficiency in crops is more widespread than the deficiency of any other micronutrient (Gupta, 1993, Pilbean and Kirkby 1983). The foliar application with micronutrients especially boron not only has major effects on flower formation, carbohydrate, and protein metabolism, increases pollen germination and pollen tube growth, and yield (Gerendas and Sattelmatcher, 1990), but also is for chloroplast formation and sink limitations (Tersahima and Evans, 1988), the transfer of carbohydrates, enhanced reproduction, and pollen grain germination all depend on boron (B). It also serves as a potassium ratio regulator and prefers to maintain calcium in a soluble form inside the plant. The construction of cell walls (O'Neill *et al*., 2004), the activities of cellular membranes (Goldbach *et al*., 2001), and anti-oxidative defense mechanisms (Cakmak and Romheld, 1997) are all significantly impacted by boron. A global issue for field crop productivity is boron deficit (Wei *et al*., 1998), and various soil variables influence the availability of Boron to plants (Goldberg *et al*., 2000).

The second most common element in the crust of the earth is silicon, which is found in plants in typical amounts (from less than 0.1 percent to more than 10.0%), mostly serving to fortify the cell wall. Three groups are identified among plant species based on their Si level.Supplemental silicon (Si) has been shown to increase production and lessen biotic and abiotic stressors on plants (Epstein, 1999). Furthermore, several studies have demonstrated that Si is useful in reducing salinity in a variety of plant species, including tomato (Romero-Aranda *et al*., 2006), wheat (Ahmad *et al*., 1992; Tuna *et al*., 2008), cucumber (Adatia and Besford, 1986; Zhu *et al*., 2004), maize (Moussa, 2006), and tomato (Liang *et al*., 1996; Liang *et al*., 2003). The yields and nutritional status of the two flax cultivars were enhanced by silicon foliar treatments from the two sources than with the control (Shedeed *et a*l., 2016).

Blue-green algae known as spirulina (Arthrospira platensis) are highly valued for their high nutritional content and are used extensively as food for humans and animals. They are also of significant interest to the biotechnology and pharmaceutical industries (Papadaki *et al*., 2017 , Spolaore *et al*., 2006 ). High-bioavailability proteins make up between 60 and 70 percent of the dry mass of spirulina.Because it is the terrestrial and aquatic creature with the largest protein content, richest aminogram, and best digestibility (Soni *et al*., 2017 ), it is commonly used to provide humans, animals, and plants with essential amino acids. Additionally, it has vitamins (Papadaki *et al.,* 2017), phycobiliproteins (Papadaki *et al*., 2017, Campanella *et al*., 1999 ), carbohydrates, calcium, iron, manganese, zinc, nitrogen, phosphorus, potassium, and carbs (Wuang *et al*., 2016 ). It also includes important polyunsaturated fatty acids. It is a great biological complement because of its great richness in α- and ß-carotenes (Papadaki et al 2017, Pagnussatt *et al*., 2016 ), phycocyanin, significant amounts of α-linolenic acid (polyunsaturated fatty acid with various beneficial effects), a high concentration of phytohormones, trace elements, antioxidants, and polysaccharides (Anitha and Kalpana 2016 ). Moreover, lipids, xanthophylls, and chlorophyll a have been found in these algae (Sharma *et al*., 2014 ). Application of Spirulina and its extracts in agriculture With the evolution of sustainable agriculture, the use of Spirulina has been increasing for these purposes. It has been shown to activate the immune system of plants, generating higher productions, of higher quality and more resistant to diseases and environmental stress, as well as greater germination and rooting when applied to the soil. When comparing a Spirulina-based fertilizer with a chemical fertilizer, some authors have found that although it has a lower NPK content. The fertilizer based on these algae stimulates the growth of crops in a similar way to the chemical fertilizer, because it has higher amounts of other elements (calcium, iron, manganese, zinc and selenium) that help moderate the amounts of nutrients required by plants (Wuang *et al*., 2016 ). Thus, in Amaranthus gangeticus, it has been found that the imbibition of the seeds and the foliar application of Spirulina extracts increased the protein (Anitha and Kalpana 2016) and iron levels in the plants (Kalpana *et al*., 2014 ). The application of a commercial fertilizer based on Spirulina increased the yield of the plants without affecting the foliar levels of N, P, K and Na or its quality indicators (Dias *et al*., 2016). Foliar application of a similar fertilizer maintained the quality. In beans, the foliar application of an aqueous extract stimulated growth, chlorophyll, nitrogen, phosphorus and potassium concentrations; as well as the quantity and quality of the seeds (Seif *et al*., 2016 ). On the other hand, green algae and cyanobacteria are involved in the production ofmetabolites such as plant hormones, polysaccharides, antimicrobial compounds, among others, which play an important role in plant physiology and in the proliferation of microbial communities in the soil (Renuka *et al*., 2018 )

Green-blue microalgae known as cyanobacteria, or Spirulina platensis, have the potential to improve soil fertility, crop growth and yield, and environmental quality in sustainable agriculture. Beyond those applications, there has been a rise in interest recently in using them in agriculture as biostimulants and fertilizers for plant growth.

In sustainable agriculture, green-blue microalgae called cyanobacteria, or Spirulina platensis, have the potential to enhance soil fertility, crop development and yield, and environmental quality. Beyond these uses, their usage as fertilizers and biostimulants for plant growth in agriculture has attracted more attention recently (Anitha *et al*., 2016; El Sherif, 2020; Yanni, 2020; Godlewska *et al*., 2019). The nitrogen and protein contents of the maize grains and peanut seeds were also enhanced by the foliar application of 300 g of algae extract per feddan.

Additionally, the iron, zinc, manganese, and copper contents of the maize and peanut crops were markedly enhanced by this treatment (Nofal *et al*., 2016).

The present study was designed to study the impact of applying foliar spray containing algae extract spirulina, nanoparticles of boron, and silicon efficiency of faba bean cultivars to obtain maximum productivity.

## Materials and Methods

*Field experiment*

The current study was conducted during two consecutive winter seasons of 2021/2022 and 2022/2023, at the experimental farm of the Agronomy Department, Faculty of Agricultural, Assiut University, Egypt. The experiment was carried out using a randomized complete block design (RCBD) in a strip block arrangement with three replicates. The physical and chemical properties of the experimental site are shown in **Table 1**.

*Treatment combinations*

A. **Synthesis of Bio-Silica Nanoparticles (BSNPs):** Nanotech Egypt Co. (Dreamland, Egypt) supplied silicon dioxide ($SiO_2$) nanoparticles (NPs) with a 29-nm diameter and in a spherical shape (hydrophilic, 99.99% purity),

B. Nano Chelated Boron Fertilizer: made using "advanced chelate technology," this fertilizer is totally soluble in water, has 9% chelated boron, and is absorbed at pH 3–11. accelerating the chemicals' journey from the photosynthetic site to the point of intake. It prevents pods from dropping and increases pod output.

C. The Phycology Lab of the Faculty of Science at Assiut University in Egypt provided the strain MIYE 101 of Spirulina platensis (Gomont) Gentler. An inverted divert light microscope was used to identify the microalga up to species using the keys of (Vymazal, 1995). The diameter of cylindrical cells, which range from 8 to 10 µm, make up the trachoma breadth. These cells are smaller than wide cells.

**The used eight treatments i.e** 1- Control (Tap water) as control ( C ), 2- *Spirulina* (Sp), at a rate of 2.0 g $L^{-1}$, 3- Silicon nanoparticles (Si) at a rate of 100 ppm $L^{-1}$, 4- Boron nanoparticles (B) at a rate of 100 ppm $L^{-1}$, 5- Silicon nanoparticles and Boron nanoparticles (Si+B) at rate of 100 ppm $L^{-1}$for both of them, 6- Spirulina (2.0 g $L^{-1}$ )+ Silicon nanoparticles (100 ppm $L^{-1}$) (SP+Si), 7- Spirulina (2.0 g $L^{-1}$) + Boron nanoparticles at rate of (100 ppm $L^{-1}$) (SP+B), and 8- Spirulina (2.0 g $L^{-1}$) + Silicon nanoparticles (100 ppm $L^{-1}$) + Boron nanoparticles (100 ppm $L^{-1}$) (SP+Si+B), were randomly arranged in vertically plot. Furthermore, two faba bean cultivars i.e. **Nubaria-1** and **Sakha-3** were randomly distributed horizontally plot. Five ridges, each three meters long and sixty centimeters apart, made up the plot. One plant per hill, spaced 15 cm apart, was the seed spacing used for both sides of the ridge.

**The dates of sowing** the faba bean seeds were 20 and 19 October of 2021/2022 and 2022/2023, respectively. The Egyptian Ministry

**TABLE 1. Some physical and chemical properties of the experimental Soil.**

| Season | 2021-2022 | 2022-2023 |
|---|---|---|
| Mechanical analysis | | |
| Sand | 26.3 | 26.4 |
| Silt | 24.2 | 24.4 |
| Clay | 49.5 | 49.2 |
| Soil type | Clay loam | Clay loam |
| Chemical analysis | | |
| PH | 7.81 | 7.67 |
| Organic matter % | 1.74 | 1.72 |
| Total N% | 0.08 | 0.09 |
| Total $CaCO_3$% | 1.17 | 1.24 |

of Agriculture's instructions were followed for all other cultivar practices. During the two seasons, faba bean plants were sprayed three times with the treatments at 35, 50, and 65 days following the sowing date.

*Characters studies :*

*I. Chemical constituents*

The plant samples were digested by sulfuric to perchloric acids. total N was measured by a CHNS analyzer (Elementar, Vario EL, Germany). The C/N ratio in stevia leaves was calculated after the determination of C and N by a CHNS analyzer (Elementar, Vario EL, Germany). Total soluble sugar was extracted by phenol and sulfuric acid method (Nielsen, 2010). The measurement of chlorophyll was done using SPAD 502 plus. The digested plant samples were analyzed for N, P, Ca, and K according to the standard methods described by Burt (2004). This analysis was done on the first season only.

*II. Yield and its attributes*

The ten plants were randomly chosen from the central row of each plot and were marked in the field from the start of flowering to harvest time in both seasons to estimate.

1- Number of opened flowering/plant.

Counting was started at 50 days of plant age with 3-days intervals until 100 day.

2- Pods weight/plant (g).

3- Seed yield/plant (g).

Were recorded at harvest time.

4- Biological, Straw, Seed, and protein yields $ha^{-1}$.

- The whole plot was harvested and left for drying until the moisture content of seeds reached 12% then weighted and estimated biological yield and converted to ton $ha^{-1}$.

- Total N was determined using the micro-Kjeldahl method according to A.O.A.C (2005).

- The protein in seeds was expressed by multiplying the total N% by a factor of 6.25. Protein yield (Kg $ha^{-1}$.) multiplied by protein% × seed yield Kg $ha^{-1}$.

*Statistical analysis*

All data subjected to the analysis of variance for strips block design followed by compared means with LSD at level probability 5% according to Gomez and Gomez, 1984. The correlation coefficients among studied traits for both growing seasons were computed using R Studio (R Studio 2020).

## Results and Discussions

*Leaf mineral, Sulable carbohydrates, and chlorophyll contents.*

The studied faba bean varieties, i.e., Nubaria-1 and Sakha-3, showed significant ($p < 0.05$) response to the foliar addition of Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).the results of the current study, noticed in Table 2, show that adding SP had a significant effect on improving the concentration of nutrients within the leaf tissues of faba bean varieties. The foliar spring of SP increased the P, K, and Ca contents in leaves of Nubaria 1 by 38, 54, and 66%, respectively, compared to the control. Sakha-3, variety, showed the same trend in response to SP and NPs where P, K, and Ca in the leaf tissues increased by 66,50, and 66%, respectively, in comparison to the control, the plants treated with SP alone or in combination with Si and B nanoparticles generally had the highest values of P, K, and Ca contents. The leaf content of Si and B in Nubaria-1 and Sakha-3 varieties was affected significantly ($p < 0.05$) by the foliar application of Si and B nanoparticles. The sole application of Si increased the Si content by 41 and 53% for Nubaria-1 and Sakha-3, respectively, compared to the control. The sole application of B increased the B content by 128 and 113% for Nubaria-1 and Sakha-3, respectively, compared to the control. In general, all the treatments combinations that contained Si caused increases in the leaf Si content, as well as the treatments that contained B significantly, increased leaf B content in comparison to the untreated plants. The leaf-biochemical compounds, i.e., chlorophyll, soluble carbohydrates, and C/N ratio, in the studied faba bean varieties, were affected significantly ($p < 0.05$) by the foliar pplication of SP, Si, and B. The results of the current study, in **Table 3** indicate that spraying with this foliar application gave the highest values for soluble carbohydrates and chlorophyll contents. The foliar spraying of SP+Si, SP+B, and SP+Si+B increased the soluble carbohydrates in the leaves of Nubaria 1 by 47, 50, and 51%, respectively, compared to the control, while these increases were 47, 50, and 59%, respectively, in the case of Sakha-3. In addition to that the foliar spring of SP+Si, SP+B, and SP+Si+B increased the total chlorophyll in the leaves of Nubaria-1 by 20,24, and 29% %, respectively, compared to the control. The total chlorophyll in the leaves of Sakha-3 increased by 34, 34, and 44%, respectively, compared to the control as a result of SP+Si, SP+B, and SP+Si+B addition. The foliar spraying of SP+Si, SP+B, and SP+Si+B increased the C/N ratio in Nubaria-1 leaves by 43, 41, and 53%, respectively, compared to the control, while these increases were 26, 28, and 38%, respectively, in the case of Sakha-3. In general, the sole application of SP, Si, and B increased the soluble carbohydrates, chlorophyll, and C/N ratio in the leaves of faba bean varieties compared to the control, but the maximum increases were found in the combination of SP+Si+B.

**TABLE 2. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on leaf mineral content of N, P, K, Ca, Si, and B (the combined of two seasons).**

| Treatments | N (g kg$^{-1}$) | | P (g kg$^{-1}$) | | K (g kg$^{-1}$) | | Ca (mg kg$^{-1}$) | | Si (mg Kg$^{-1}$) | | B (mg Kg$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nubaria1 | Sakha-3 | Nubaria-1 | Sakha-3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 |
| C | 26.33 | 28.33 | 1.69 | 1.60 | 24.00 | 22.67 | 22.00 | 20.67 | 186.67 | 190.00 | 15.33 | 15.33 |
| SP | 30.00 | 29.00 | 1.72 | 1.63 | 25.33 | 24.00 | 23.33 | 23.67 | 206.67 | 200.00 | 16.33 | 16.00 |
| Si | 30.00 | 29.67 | 1.75 | 1.64 | 26.00 | 24.67 | 24.00 | 27.67 | 210.00 | 210.00 | 19.67 | 23.00 |
| B | 30.00 | 30.67 | 1.80 | 1.70 | 27.33 | 25.67 | 29.67 | 29.33 | 220.00 | 226.67 | 21.00 | 24.00 |
| Si+B | 30.33 | 31.00 | 2.38 | 2.56 | 34.33 | 36.00 | 40.33 | 40.33 | 296.67 | 286.67 | 33.33 | 33.33 |
| SP+Si | 31.33 | 31.67 | 2.50 | 2.60 | 36.00 | 36.00 | 40.33 | 40.67 | 340.00 | 305.00 | 35.00 | 34.00 |
| SP+B | 32.00 | 32.67 | 2.50 | 2.69 | 37.00 | 37.67 | 42.00 | 42.33 | 360.00 | 396.67 | 35.00 | 35.00 |
| SP+Si+B | 32.67 | 33.33 | 2.64 | 2.86 | 38.00 | 39.67 | 44.67 | 45.33 | 386.67 | 416.67 | 37.67 | 36.00 |
| **L.S.D Var** | 2.25 | | 0.29 | | 10.74 | | 1.00 | | N.S | | N.S | |
| **L.S.D sprin. Sys.** | 3.97 | | 0.40 | | 6.31 | | 6.38 | | 36.13 | | 4.76 | |
| **L.S.D Var*sprin. Sys** | 6.50 | | 0.50 | | 9.43 | | 6.66 | | N.S | | N.S | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

**TABLE 3. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on soluble carbohydrates, chlorophyll, and C/N ratio (the combinedof two seasons).**

| Treatments | Total carbohydrates | | Chlorophyll | | C/N ratio | |
|---|---|---|---|---|---|---|
| | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 |
| C | 51.00 | 53.00 | 34.67 | 32.33 | 17.67 | 19.33 |
| SP | 60.33 | 63.00 | 38.00 | 38.67 | 22.33 | 22.00 |
| Si | 65.00 | 63.33 | 39.00 | 39.00 | 22.33 | 23.00 |
| B | 67.33 | 64.00 | 40.00 | 39.00 | 22.33 | 24.00 |
| Si+B | 68.33 | 65.67 | 41.00 | 41.00 | 22.67 | 25.00 |
| SP+Si | 75.00 | 75.00 | 41.67 | 43.33 | 25.00 | 24.67 |
| SP+B | 76.33 | 76.67 | 43.00 | 43.33 | 25.33 | 24.33 |
| SP+Si+B | 77.00 | 81.00 | 44.67 | 46.67 | 27.00 | 26.67 |
| **L.S.D Var** | 3.74 | | 1.53 | | 2.64 | |
| **L.S.D sprin. Sys.** | 4.91 | | 3.13 | | 2.01 | |
| **L.S.D Var*sprin. Sys** | 4.55 | | 3.86 | | 2.53 | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

*Number of flowering/plant, Yields and its attributes*

The results in **Table 4** indicate that spraying with SP+Si, SP+B, and SP+Si+B provided the highest values for the faba bean flowering number per plant and seed production per plant. The foliar spring of SP+Si, SP+B, and SP+Si+B increased the number of flowering /plant of Nubaria-1 by 34, 42, and 45% respectively, while in the second year, the increases were 32, 34 and 42 % respectively. The foliar spring of SP+Si, SP+B, and SP+Si+B increased the number of flowering / plant of Sakha-3 by 35, 42 and 45% % respectively, while in the second year, the increases were 10, 7, and 12 % respectively. The foliar spring of SP+Si, SP+B, and SP+Si+B increased the seed yield of Nubaria-1 by 41,75 and 77% respectively, while in the second year, the increases were 67, 107, and 114% respectively. The foliar spring of SP+Si, SP+B, and SP+Si+B increased the seed yield of Sakha-3 by 71, 81, and 92% % respectively, while in the second year, the increases were 85, 111, and 155% respectively. The previous result could touch many of the studied traits in faba bean such as, pods weight/plant, of plant in faba bean, all foliar sprayings decreased significantly the shedded flowers especially in the first season, consequently increasing significantly the setted pods and seed yield. **Tables 5, 6** and **7** reveal that the highest mean values for biological yield (8.78 and 9.63 ton/ha) were recorded for SP+Si+B of Nubaria-1 and Sakha-3, respectively under two seasons as compared with other treatments. Mean the lowest biological yields (7.10 and 7.89) were recorded for control treatment (without spraying). These findings are in agreement with Desoky *et al*., (2020) Rady *et al*., (2019) and those obtained by Rady *et al*., (2023). Also, the **Table 7** shows that the highest mean values for protein yield (810.4 and 849.5 Kg $ha^{-1}$.) were recorded for (SP+Si+B) treatment of Nubaria-1 and Skha-3, respectively under the mean of the two seasons. Mean the lowest protein yield (504.3 and 590.6 Kg $ha^{-1}$.) were recorded for the control treatment (without spraying) of Nubaria-1 and Sakha-3, respectively. These findings are in line with those reported by Gomaa *et al*., (2016) on the other hand, there was a significant difference among the two cultivars in some traits for some seasons. Meanwhile, the lowest ones were achieved by planting Nubaria-1 cultivars with an average of two seasons. Similarly, variations, among cultivars were reported by Tawfik *et al*., (2018), El-Sherbeni (2021), and Morsy and Mehanna (2022).

Faba bean responded significantly to the foliar application of *Spirulina* and nanoparticles of silicon and boron. All the tested treatments gave higher seed yield than the control with clear superiority of the combined spraying of *Spirulina* and nanoparticles of silicon (Si) and boron (B). The addition of Si and B nanoparticles along with the *Spirulina* increased the uptake of essential nutrients, i.e., Ca, K, P, and B , besides enhancing the uptake of Si. Si enhanced the faba bean's (*Vicai faba*) flowering and seed production. Si greatly improves the cell's membrane stability and mechanical strength (Spinoni *et al*., 2018; Desoky

**TABLE 4. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on number of flowering/plant and pods weight/plant (g) in the two seasons and the average.**

| Treatments | Number of flowering/plant | | | | Average | | Pods weight/plant (g) | | | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021-2022 | | 2022-2023 | | Nu-1 | S-3 | 2021-2022 | | 2022-2023 | | Nu-1 | S-3 |
| | Nubaria-1 | Sakha-3 | Nubaria-1 | Sakha-3 | | | Nubaria-1 | Sakha-3 | Nubaria-1 | Sakha-3 | | |
| C | 122.70 | 107.50 | 117.60 | 133.20 | 120.15 | 120.35 | 30.87 | 30.35 | 28.73 | 30.71 | 29.80 | 30.53 |
| SP | 133.00 | 140.20 | 125.80 | 133.70 | 129.40 | 136.95 | 34.88 | 35.05 | 30.61 | 36.40 | 32.75 | 35.73 |
| Si | 141.30 | 141.20 | 132.90 | 136.20 | 137.10 | 138.70 | 37.12 | 41.21 | 33.72 | 40.75 | 35.42 | 40.98 |
| B | 142.80 | 142.90 | 135.50 | 138.90 | 139.15 | 140.90 | 40.32 | 47.76 | 40.77 | 48.13 | 40.55 | 47.95 |
| Si+B | 164.30 | 145.30 | 154.60 | 145.60 | 159.45 | 145.45 | 43.07 | 53.30 | 42.45 | 51.62 | 42.76 | 52.46 |
| SP+Si | 173.90 | 152.90 | 157.60 | 145.90 | 165.75 | 149.40 | 52.49 | 55.97 | 48.85 | 53.96 | 50.67 | 54.97 |
| SP+B | 157.50 | 143.90 | 140.30 | 141.40 | 148.90 | 142.65 | 55.86 | 58.24 | 49.75 | 55.85 | 52.81 | 57.05 |
| SP+Si+B | 177.60 | 156.00 | 166.50 | 148.60 | 172.05 | 152.30 | 62.58 | 59.53 | 59.45 | 59.58 | 61.02 | 59.56 |
| **L.S.D Var** | 23.60 | | 9.10 | | | | 3.0196 | | 6.65 | | | |
| **L.S.D sprin. Sys.** | 26.00 | | 10.60 | | | | 2.47 | | 2.71 | | | |
| **L.S.D Var*sprin. Sys** | 46.33 | | 22.10 | | | | 3.17 | | N.S | | | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

*et al*., 2020). Additionally, Si preserves the tolerance defense system, mineral nutrition, photosynthetic efficiency, and membrane integrity (Spinoni *et al*., 2018; Desoky *et al*., 2020). Consequently, because Si has advantageous physicomechanical properties, it may be utilized to increase plant growth and production (Rady *et al*., 2019). Since nano-silicon is smaller than bulk silicon, it has demonstrated better physicochemical qualities (Prasad *et al*., 2012; Rastogi *et al*., 2019). Furthermore, nano-silicon has a higher surface area, greater surface reactivity and solubility, and a range of well-characterized surface properties compared to regular silicon (Qados and Moftah, 2015). Specifically, one of the most important variables influencing the adhesion, absorption, and transportation of particles into plant cells is thought to be particle size (Smith *et al*., 2008; Wang *et al*., 2009). Additionally, plant cells engage in interactions with nanoparticles that facilitate the transportation of different substances that regulate multiple physiological processes and plant metabolism (Galbraith, 2007; Torney *et al*., 2007; Giraldo *et al*., 2014). A crucial plant micronutrient, boron (B) serves a variety of purposes in fruit set and pollination (Iwai *et al*., 2006; Zhang *et al*., 2017). Low B levels have an impact on microsporogenesis, which reduces the size, viability, and output of pollen (Pandey *et al*., 2013). Additionally, boron stimulates pollen tube

**TABLE 5. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on seed yield/plant (g)and Seed yield (ton ha$^{-1}$) in the two seasons and the average.**

| Treatments | Seed yield/plant (g) | | | | Average | | Seed yield (ton ha$^{-1}$) | | | | Average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021-2022 | | 2022-2023 | | | | 2021-2022 | | 2022-2023 | | | |
| | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 |
| C | 26.30 | 25.01 | 21.86 | 18.16 | 24.08 | 21.59 | 2.82 | 2.52 | 2.80 | 3.56 | 2.81 | 3.04 |
| SP | 27.67 | 29.36 | 28.57 | 28.27 | 28.12 | 28.82 | 3.10 | 2.94 | 3.04 | 2.57 | 3.07 | 2.76 |
| Si | 29.89 | 29.87 | 28.81 | 29.53 | 29.35 | 29.70 | 3.16 | 3.11 | 3.09 | 3.03 | 3.13 | 3.07 |
| B | 31.67 | 39.31 | 30.13 | 31.95 | 30.90 | 35.63 | 3.28 | 3.23 | 3.12 | 3.06 | 3.20 | 3.15 |
| Si+B | 36.99 | 42.66 | 36.44 | 33.56 | 36.72 | 38.11 | 3.32 | 3.52 | 3.21 | 3.13 | 3.26 | 3.33 |
| SP+Si | 46.08 | 45.17 | 45.18 | 38.28 | 45.63 | 41.73 | 3.48 | 3.63 | 3.28 | 3.41 | 3.38 | 3.52 |
| SP+B | 35.35 | 40.56 | 34.80 | 31.69 | 35.08 | 36.13 | 3.71 | 3.82 | 3.51 | 3.52 | 3.61 | 3.67 |
| SP+Si+B | 46.54 | 47.98 | 46.71 | 46.33 | 46.63 | 47.16 | 4.11 | 4.00 | 3.67 | 3.82 | 3.89 | 3.91 |
| **L.S.D Var** | 7.50 | | 2.70 | | | | N.S | | N.S | | | |
| **L.S.D sprin. Sys.** | 8.00 | | 4.80 | | | | 0.1792 | | 0.2495 | | | |
| **L.S.D Var*sprin. Sys** | 15.19 | | 6.10 | | | | N.S | | 0.26 | | | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

**TABLE 6. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on biological yield (ton ha$^{-1}$) and strow yield (ton ha$^{-1}$) in two seasons.**

| Treatments | Biological yield (ton ha$^{-1}$) | | | | Average | | Strow yield (ton ha$^{-1}$) | | | | average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021-2022 | | 2022-2023 | | | | 2021-2022 | | 2022-2023 | | | |
| | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 |
| C | 7.60 | 7.60 | 6.60 | 8.17 | 7.10 | 7.89 | 4.78 | 5.08 | 3.80 | 4.61 | 4.29 | 4.85 |
| SP | 7.86 | 8.14 | 6.54 | 8.19 | 7.20 | 8.17 | 4.76 | 5.20 | 3.50 | 5.63 | 4.13 | 5.41 |
| Si | 8.30 | 8.25 | 6.87 | 8.23 | 7.59 | 8.24 | 5.14 | 5.13 | 3.78 | 5.19 | 4.46 | 5.16 |
| B | 8.49 | 8.77 | 7.12 | 8.69 | 7.81 | 8.73 | 5.21 | 5.53 | 4.01 | 5.63 | 4.61 | 5.58 |
| Si+B | 8.81 | 8.70 | 7.55 | 8.62 | 8.18 | 8.66 | 5.50 | 5.18 | 4.34 | 5.49 | 4.92 | 5.33 |
| SP+Si | 8.83 | 8.96 | 7.69 | 8.74 | 8.26 | 8.85 | 5.35 | 5.34 | 4.41 | 5.33 | 4.88 | 5.33 |
| SP+B | 9.32 | 9.35 | 7.69 | 9.25 | 8.51 | 9.30 | 5.61 | 5.52 | 4.17 | 5.74 | 4.89 | 5.63 |
| SP+Si+B | 9.58 | 9.72 | 7.98 | 9.54 | 8.78 | 9.63 | 5.48 | 5.72 | 4.31 | 5.72 | 4.89 | 5.72 |
| **L.S.D Var** | N.S | | 0.54 | | | | N.S | | 0.7618 | | | |
| **L.S.D sprin. Sys.** | 0.66 | | 0.75 | | | | N.S | | N.S | | | |
| **L.S.D Var*sprin. Sys** | N.S | | N.S | | | | N.S | | N.S | | | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

**TABLE 7. Effect of Spirulina (SP), silicon (Si), and boron nanoparticles (B) on Protine%and Protein yield (Kg $ha^{-1}$) in two seasons.**

| Treatments | Protine% | | | | Average | | Protein yield (Kg $ha^{-1}$) | | | | average | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021-2022 | | 2022-2023 | | | | 2021-2022 | | 2022-2023 | | | |
| | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 | Nubaria 1 | Sakha3 | Nubaria 1 | Sakha3 | Nu-1 | S-3 |
| C | 28.10 | 28.78 | 27.53 | 31.21 | 27.81 | 29.99 | 511.13 | 468.15 | 497.38 | 713.09 | 504.25 | 590.62 |
| SP | 29.45 | 29.46 | 29.12 | 31.35 | 29.28 | 30.40 | 592.02 | 566.89 | 568.30 | 517.64 | 580.16 | 542.27 |
| Si | 30.47 | 30.81 | 29.79 | 31.49 | 30.13 | 31.15 | 626.67 | 620.93 | 597.07 | 618.66 | 611.87 | 619.79 |
| B | 30.81 | 30.81 | 29.90 | 31.82 | 30.36 | 31.31 | 647.33 | 641.61 | 601.73 | 629.86 | 624.53 | 635.73 |
| Si+B | 30.81 | 30.81 | 30.61 | 32.17 | 30.71 | 31.49 | 658.59 | 699.19 | 634.41 | 653.50 | 646.50 | 676.35 |
| SP+Si | 31.48 | 32.16 | 30.81 | 32.50 | 31.15 | 32.33 | 707.55 | 753.14 | 649.18 | 714.45 | 678.36 | 733.80 |
| SP+B | 32.16 | 33.52 | 30.81 | 32.84 | 31.48 | 33.18 | 770.16 | 824.16 | 697.20 | 745.52 | 733.68 | 784.84 |
| SP+Si+B | 33.18 | 33.85 | 31.15 | 33.51 | 32.16 | 33.68 | 878.86 | 873.96 | 741.84 | 825.12 | 810.35 | 849.54 |
| **L.S.D Var** | N.S | | 1.16 | | | | N.S | | 68.17 | | | |
| **L.S.D sprin. Sys.** | N.S | | N.S | | | | 129.16 | | 106.42 | | | |
| **L.S.D Var*sprin. Sys** | N.S | | N.S | | | | N.S | | N.S | | | |

Control (C), Spirulina (SP), silicon nanoparticles (Si), and boron nanoparticles (B).

**TABLE 8 . Correlation matrix between nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), silicon (Si), boron (B), C/N ratio (C/N), soluble carbohydrates (TC), chlorophyll (Chlo), Number of flowering/ plant (NFP), Pods weight /plant (PWP), Seed yield/ plant (SYP), seed yieldton/ha (SY), Biogical yield ton/ha (BY), Strow yieldton/ha (TY), Protine% (P%) and Protine yield kg/ha (PY) as Average of two seasons and varieties.**

| | N | P | K | Ca | Si | B | C/N | TC | Chlo | NFP | PWP | SYP | SY | BY | TY | P% | PY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **N** | - | | | | | | | | | | | | | | | | |
| **P** | 0.77 | - | | | | | | | | | | | | | | | |
| **K** | 0.67 | 0.96 | - | | | | | | | | | | | | | | |
| **Ca** | 0.69 | 0.94 | 0.95 | - | | | | | | | | | | | | | |
| **Si** | 0.45 | 0.36 | 0.26 | 0.28 | - | | | | | | | | | | | | |
| **B** | 0.07 | 0.27 | 0.32 | 0.21 | 0.10 | - | | | | | | | | | | | |
| **C/N** | 0.34 | 0.57 | 0.59 | 0.63 | 0.57 | 0.57 | - | | | | | | | | | | |
| **TC** | 0.42 | 0.75 | 0.77 | 0.72 | 0.52 | 0.68 | 0.89 | - | | | | | | | | | |
| **Chlo** | 0.42 | 0.72 | 0.72 | 0.69 | 0.61 | 0.64 | 0.88 | 0.95 | - | | | | | | | | |
| **NFP** | 0.33 | 0.46 | 0.41 | 0.42 | 0.70 | 0.59 | 0.81 | 0.80 | 0.78 | - | | | | | | | |
| **PWP** | 0.30 | 0.54 | 0.52 | 0.53 | 0.53 | 0.74 | 0.86 | 0.89 | 0.87 | 0.78 | - | | | | | | |
| **SYP** | 0.39 | 0.58 | 0.51 | 0.50 | 0.75 | 0.62 | 0.84 | 0.87 | 0.88 | 0.90 | 0.91 | - | | | | | |
| **SY** | 0.34 | 0.55 | 0.58 | 0.56 | 0.53 | 0.69 | 0.80 | 0.87 | 0.84 | 0.72 | 0.91 | 0.83 | - | | | | |
| **BY** | 0.37 | 0.49 | 0.45 | 0.46 | 0.42 | 0.68 | 0.76 | 0.76 | 0.74 | 0.57 | 0.89 | 0.74 | 0.78 | - | | | |
| **TY** | 0.30 | 0.32 | 0.24 | 0.26 | 0.24 | 0.48 | 0.52 | 0.47 | 0.47 | 0.32 | 0.64 | 0.49 | 0.41 | 0.89 | - | | |
| **P%** | 0.35 | 0.53 | 0.53 | 0.53 | 0.48 | 0.65 | 0.85 | 0.84 | 0.81 | 0.63 | 0.90 | 0.77 | 0.84 | 0.97 | 0.80 | - | |
| **PY** | 0.37 | 0.57 | 0.59 | 0.58 | 0.54 | 0.69 | 0.83 | 0.89 | 0.86 | 0.70 | 0.94 | 0.83 | 0.99 | 0.86 | 0.55 | 0.92 | - |

development and germination of pollen (Sharafi and Raina, 2020), whereas a B shortage can prevent pollen tube formation and reduce the flexibility of pollen-tube cell walls (Sharafi and Raina, 2020). Inadequate B levels may hinder the transmitting tissue's growth and hinder fertilization (Iwai *et al*., 2006). Flowers with higher B concentrations have higher early fruit set, fruit retention, and ultimate fruit set or yield (Wojcik, 2008).

*Spirulina platensis*, is a photosynthetic blue-green microalgae that has been used commercially as animal feed, biofertilizer, and food source due to its high nutritional content and biostimulant properties (Sanchez *et al*., 2003). To improve crop growth and productivity, microalgae biostimulants, such as SP, are applied in tiny amounts in conjunction with inorganic fertilizers (Ronga *et al*., 2019; Rady *et al*., 2023), most likely via improving the amount of chlorophyll, antioxidants, metabolism, and harvested items' shelf life (Rouphael and Colla, 2018; Rady *et al*., 2023). A promising biofertilizer known as S. platensis extract (SPE) has been found. While the crops are still in the vegetative development stages, they can be administered topically to a range of crops, such as maize, barley, cotton, tomato, oats, lettuce, chili pepper, and sugarcane (Garcia-Gonzalez and Sommerfeld, 2016; Rady *et al*., 2023). Moreover, it is abundant in nutrients and phytohormones (such as auxins, gibberellins, and cytokinins) that promote plant development and yield (Yanni *et al*., 2020). It also includes amino acids, which are important for the production of vitamins and chlorophyll, the detoxification of heavy metals and other toxins, the absorption, translocation, and metabolism of nutrients, and stress alleviation (Hussain *et al*., 2018; Rady *et al*., 2023). Furthermore, amino acids maintain the structure of proteins required for cell division and growth stimulation (Souri and Hatamian, 2018). As stated by Rady *et al*. (2023) and Khalil and El-Noemani (2015), the beneficial effects of SP biofertilizers may arise from the fact that they meet plants' nutrient needs through their influence on physiological processes in plants, such as photosynthetic activity and carbohydrate utilization. As a result, SP enhanced the soil's biological, physical, and chemical properties, which in turn encouraged the formation and development of roots. As a result, SPE may be applied as a unique tactic to increase crop yield in both easy and difficult circumstances. Our investigation led us to the conclusion that the good consequences were produced by the abundance of SPE in N, P, K, Ca, Mg, Zn, Mn, Fe, vitamins, amino acids, proline, salicylic acid, and gallic acid (Rady *et al*., 2023).

*Estimation of correlation coefficients analysis:* **-**

Correlation coefficients were estimated among seventeen traits (**Table 8).** It had a positive correlation between all studied traits i.e C/N ratio, total soluble sugar, chlorophyll. N, P, Ca, K, Si, B, number of opened flowering/plant, pod weight/plant, seed yield/plant (g), seed yield (ton/ha), biological yield (ton $ha^{-1}$), strow yield (ton $ha^{-1}$), protine%, and protein yield (Kg $ha^{-1}$). The strong correlation between seed yield and its attributes.

## Conclusions

From the obtained results and from the economic point view under the same conditions of this research it is recommended that Flowering in beans represents one of the most important challenges facing farmers. Boron (B) and silicon (Si) are among the most effective tools in reducing flowering problems in plants and yields. In the current study, B and Si nanoparticles were used to improve flowering rates and yields in faba bean. The effect of *Spirulina* has also been tested to increase the efficiency of B and Si nanoparticles. The addition of Si and B nanoparticles along with the *Spirulina* increased the flowering biological, straw, and seed yields of faba bean. Overall, the results of this study explained that using Spirulina algae extract and nanoparticles of silicon and boron foliar application is a good solution for improving yields of faba bean.

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## كفاءة الرش الورقى بالطحالب الخضراء وجزيئات السيليكون والبورون النانوية لتعظيم انتاجية المحصول وصفات الجودة لصنفين من الفول البلدى

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اجرى هذا البحث خلال شتاء موسمى٢٠٢١/ ٢٠٢٢ ، ٢٠٢٢/٢٠٢٣ . بهدف تقييم تأثير الرش الورقي بطحلب الاسبيرولينا بمعدل ٢ مل/لتر، و جسيمات السيليكون النانوية بمعدل ١٠٠ جزء في المليون/ لتر. وجسيمات البورون النانويه بمعدل ١٠٠ جزء في المليون/ لتر ، سواء بصورة فردية أو خليط فيما بينها مع استخدام صنفين من الفول البلدي (نوبارية١- سخا٣) . واوضحت النتائج ان الرش الورقي بصورة فردية أو مجتمعة تفوق معنوياً في محتوى الأوراق من النيتروجين، والفوسفور والبوتاسيوم، والكالسيوم، والكربوهيدرات بالاضافة الى الكلوروفيل.كما ادى الرش بهذه المواد بحالة منفردة او مجتمعة الى تقليل نسبة التساقط للازهار،وبالتالى زيادة عدد القرون والمحصول البيولوجى والقش والبذور ونسبة البروتين كما لوحظ عدم وجود فروق معنويه بين الصنفين فى بعض الصفات وفى كلا الموسمين.

وبصفة عامة كان الارتباط موجب وعالى المعنويه بين المحصول والصفات الاخرى تحت كل معاملات الرش سواء بحالة منفردة او مجتمعة .