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# Nutrient uptake and its distribution in faba beans grown in a hydroponic system influenced by nutrients and salinity treatment

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**ABSTRACT**

Several varieties of faba bean-(*Vicia faba* L.) including Artasi, Baladi, and Isbani are grown in Palestine in nearly every part of the country and are used as human food and animal feed. The objective of this study was to characterize the nutrient concentrations and their distribution in various parts of faba bean varieties grown in an nutrient film technique hydroponic growing system in response to nutrient and salinity addition in irrigation water. A field study was conducted in 6" polyvinyl chloride pipes in which three local faba bean varieties (Artasi, Baladi, and Isbani) were planted under hydroponic conditions. Six treatments were used including one control line, three nutrient additions lines (25%, 100%, and 300% Cooper), and two salinity additions (4.68 and 7.8 ds/m NaCl). It was found that variation in the elemental concentrations of nutrients occurred among the three varieties and different parts of the plants. The highest concentrations of macronutrients in response to the various treatments were found either in roots (mostly roots >> shoot > leaves > pods) or in leaves, however, this for micronutrients was found mostly in roots. The two highest concentrations of macronutrients in plants were calcium (203.0 mg/L) and potassium (69.02 mg/L). The two highest concentrations of micronutrients in plants were chloride (61.13 mg/L) and iron (4.75 mg/L). The highest concentration in roots was 130.29 mg/L (Ca), in shoots 132.20 mg/L (Ca), in leaves 203.00 mg/L (Ca), and in pods 63.93 mg/L (K). Five of the highest concentrations were found in the Artasi variety, followed by Baladi and Isbani (four times each). In response to salinity treatment, $NO_3$, $SO_4$, and $PO_4$ absorption were negatively affected among macronutrients. While Cu, Fe, Zn, and Mn among micronutrients were affected. In response to nutrient treatment, most macro and micronutrient elements improved contrary to salinity treatment.

*Keywords:* Faba bean (*Vicia faba*); Salinity; Nutrients; Pipe hydroponics; Nutrient uptake; Nutrient distribution

## 1. Introduction

Faba bean (*Vicia faba* L.) is one of the oldest crops in the world and an important widely cultivated legume in the Mediterranean region [1–6]. Faba bean is generally a rainfed crop grown in areas receiving more than 400 mm of rainfall, but it is generally irrigated [7,8]. Besides it considers the source of human food and animal feed. Faba beans play important role in crop rotation and soil improvement since they can fix a relatively large amount of nitrogen (60–250 kg/ha). Nitrogen fixation can occur by bacteria especially *Rhizobium leguminosarum* bacteria or other bacteria of the *Rhizobiaceae* [9].

The nutritional value of the faba bean is high due to its high protein content, which ranges from 25% to 35% [2] as well as vitamins, carbohydrates, fiber, and minerals [1]. In

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a field study which was conducted with six faba bean varieties, it was found that variation in the elemental concentrations of nutrients and protein occurred among the tested varieties and different parts of the plants. The highest concentrations of nitrogen, phosphorus, potassium, zinc, copper, and protein were found in the seeds. While the highest accumulation of calcium, magnesium, iron, or manganese was found in the leaves [10]. These results agree with the findings of several other studies on the level and status of nutrients in faba beans [11–15].

It is well known that adequate fertilization and a balanced supply of nutrients are important factors to achieve an optimum crop yield and quality [16]. Interactions between macronutrients and/or micronutrients affect their concentrations in plants (ionome) and the quality of the fruit, with potential impacts on human nutrition. Such interactions may take place in the soil and within the plant [17].

Increasing nutrients in irrigation water will mostly lead to improving the nutritional quality of the agricultural product and consequently improve the health status of people in the world. However, increasing salinity in irrigation water would inhibit plant growth and yield. Therefore, if both are present, it is important to know and understand the impact on the food quality as well as nutrient uptake in it and their effects on plant yield and growth.

The relationship between salinity and trace element (micronutrients) nutrition is complex and salinity may increase, decrease, or have no effect on the micronutrient concentration in plant shoots. Most studies on horticultural crops, regardless of whether they were conducted in soils or solution cultures, indicate that salinity reduces Mn concentration in shoot tissue. Examples include beans [18,19].

Studies on plants of the family *Fabaceae* have suggested that salinity levels may stimulate root growth [20–22]. As an example, in a study on the impact of salinity on five faba bean varieties, it was found that based on their yield, four faba bean varieties were tolerant and one sensitive variety [23].

As the salinization of groundwater used in irrigation in Palestine is increasing and fertilizer use is restricted, it is of great importance to study the impact of fertilizer and salinity application not only on yield and growth but also on product quality (nutrient content and distribution) [24].

Israel's restrictions on the importation of fertilizers have had a detrimental impact on Palestinian agriculture, creating problems ranging from low productivity and soil degradation to high costs as a result of using inferior alternatives, which are often diluted, adulterated, smuggled, or otherwise inappropriate [25,26].

This study is being focused on a major foodstuff in Palestine, faba beans, which is one of the essential legume crops grown in Palestine, mainly under rainfed conditions. Many Palestinian faba bean farmers grow landraces such as Baladi and Artasi meanwhile others grow imported varieties because of their high productivity such as Isbani. In 2008, the annual production of faba bean in Palestine varies from year to year and from location to location, with a total production of 3917 tons cultivated on 507 ha [27].

In the first part of this study [24], it has been reported that in an experiment applying two salinity levels (4.68 and 7.8 ds/m NaCl), three levels of Cooper nutrients solution (100%, 25%, 300%), on three faba beans varieties (Baladi, Artasi, and Isbani) grown in an nutrient film technique (NFT) hydroponic growing system indicated that increasing nutrient concentration, increase plant height, leave's area, number of leaves, and number of pods, but decreased root length in the three varieties and there is no significant difference between (25% and 100%) Cooper solution in vegetative growth, while in the 300% Cooper solution, there is a significant decrease in vegetative growth but no pods were produced in the three varieties. It was also found that the application of sodium chloride (4.68 ds/m) caused reductions in plant height, the number of leaves, leave's area, and the number of pods produced but increased the root length.

Soil-based agriculture is now facing major challenges due to urbanization, industrialization, climate change, environmental degradation, etc. Among different problems, the most important one is the decline in per capita land availability. With over six billion people on earth, the per capita land availability is currently 0.25 hectares and by 2050 it will be 0.16 hectares [28].

One important advantage of hydroponic systems is the use of appropriate and specific nutrient solutions for each type of plant which needs experience and is relatively costly. Faba beans might be grown vertically or horizontally in a hydroponic system saving and adapting to available space [9]. Appropriate concentrations of nitrogen, potassium, phosphorus, calcium, magnesium, and sulfur as well as smaller amounts of other elements, are required in the nutrient solution's composition [28]. Hydroponics is a viable technology for using brackish water in water-scarce regions [29]. An additional most significant advantage of hydroponic farming is the ability to grow crops in near-optimal conditions using Controlled Environment Agriculture (CEA) technology [9].

A hydroponic system is an essential component of a commercial planting factory. Current commercial hydroponics for greenhouse crop production includes NFT and deep-water culture systems that are suitable for small crops such as leafy greens [30].

With the limited use of NFT hydroponic growing systems for agricultural production in Palestine and the increased salinization of many groundwater wells in eastern parts of Palestine, it is essential to demonstrate, understand and evaluate the factors that affect the yield, and growth of faba beans and nutrient uptake and distribution. This experience would be an example for Palestinian farmers to extend it to other crops.

This study was undertaken in northern Palestine to examine, investigate, and identify nutrient uptake (macro-N, P, K, Mg, S, and Ca and micro-Cu, Fe, Mn, Na, and Zn nutrients) and its distribution in three faba bean varieties grown in an NFT hydroponic growing system influenced by three concentrations of Cooper nutrient solution and two salinity treatment levels.

## 2. Materials and methods

### 2.1. Experimental plan

The experiment had been divided into six groups, each group consisting of three lines, each line containing four replicates from one of the three varieties (Artasi, Baladi, Isbani). For the three varieties six experimental lines will be grown as:

- TRT 0: Treatment group number one was the (control) containing water only without any addition of minerals.
- TRT 1: Treatment group number two contained 25% Cooper solution dissolved in 160 L of water.
- TRT 2: Treatment group number three contained 100% Cooper solution (full plant requirements) dissolved in 160 L of water.
- TRT 3: Treatment group number four contained 3 times Cooper solution (3 times plant requirements) dissolved in 160 L of water.
- TRT 4: Treatment group number five contained salinity (4.68 ds/m NaCl) dissolved in 160 L of water.
- TRT 5: Treatment group number six contained salinity (7.8 ds/m NaCl) dissolved in 160 L of water.
  The experiment was conducted using four replicates.

### 2.2. Hydroponic system

The hydroponic system consists of a reservoir to hold nutrients, a pump to circulate the nutrient, a growing tray and pots for the plants to be held in, and some sort of growing media. Six reservoirs were used, one was used for each treatment. 2 m long polyvinyl chloride (PVC) 6-inch pipes were used. Every treatment for the three varieties is connected to one reservoir and each pipe contains 4 replicate plants of the same variety. Fig. 1 shows a schematic of the hydroponic system.

The 6-inch PVC pipe was drilled in the centerline with four equally spaced 4-inch holes. A perforated plastic pot was placed in each of the four holes (Fig. 2). A 1-inch drain was installed in the bottom of the 6-inch PVC pipe to allow excess water to drain back to the nutrient solution reservoir.

An internal spray ½-inch flexible, polyethylene tube provided with nozzles was placed inside each pipe. The tube was tied to the upper part of the 6-inch pipe and the spray nozzle centered over the planting pot. A plastic reservoir for the nutrient solution with an attached pump was connected to the ½-inch polyethylene tube. The hydroponic system was installed and placed in Al-Yamoun village, northern Palestine. Fig. 3 shows a picture of the hydroponic system before the start of the experiment.

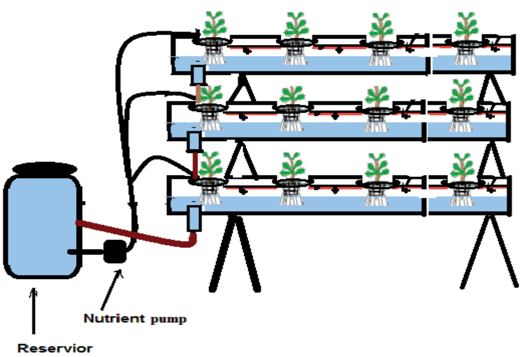


Fig. 1. Schematic of the hydroponic system.

### 2.3. Experimental set-up

There were six treatments: one blank (control), two salinity treatments, and three nutrient treatments. Each of the six treatments was conducted in 3 pipes for the three faba bean varieties and each pipe had four replicates of the same variety. This makes the total number of 2 m PVC pipe treatment lines used to 18 and the number of plants to 72 pots (Figs. 3 and 6). Consequently, the experiment was setup in a Completely Randomized Design (CRD) (Table 1).

### 2.4. Germination of faba beans

Seeds of the three varieties of faba beans were obtained from a local supplier. Seeds were manually cleaned from any foreign seeds or materials as possible and washed, then soaked in water for 24 h. A 20 cm long × 10 cm wide × 5 cm deep plastic tray was used to germinate faba bean seeds. Seeds were planted in peat moss (dead fibrous material soil) for germination. Soon after that, seeds were sprayed with water for a few seconds, then spraying with water of faba bean seeds was repeated twice daily for 30 d. At the end of the month, the faba bean completed germination and emergence and ready for the vegetative stage (seedling reaches the height of 10 cm – this stage is shown in Fig. 4). Then the seedlings were transferred into plastic pots in the 6-inch PVC pipes.

As an example, Fig. 5 shows Artasi variety pods at harvest grown in line (3) (100% Cooper nutrient solution).

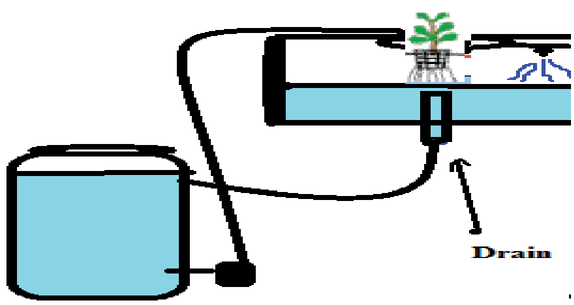


Fig. 2. Schematic of the nutrient solution reservoir, the pump, and the supply tube.

Fig. 3. Picture of the installed hydroponic system.

### *2.5. Preparation of salinity and nutrient solutions*

NaCl solution was prepared by dissolving 5 g of NaCl in 1 L water to have a concentration of 5,000 ppm, equivalent to 7.8 ds/m NaCl, and dissolving 3 g of NaCl in 1 L water to have a concentration of 3,000 ppm which is equivalent to 4.68 ds/m NaCl.

Cooper nutrient solution was chosen among the various available nutrient solutions for this experiment because of its nutrient composition (Table 2).

Table 3 shows the concentrations and source of elements in the nutrient solution, which is calculated based on parts per million (ppm).

Table 1
Description of experimental set-up

| Treatment | Variety | Replicate | Total pots |
|---|---|---|---|
| Blank | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Salinity I | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Salinity II | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Nutrient Conc. I | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Nutrient Conc. II | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Nutrient Conc. III | V1: Artasi | 4 | |
| | V2: Baladi | 4 | |
| | V3: Isbani | 4 | 12 |
| Grand total | | | 72 |

Fig. 4. Faba bean after one month of cultivation in the plastic tray.

Fig. 5. Picture of Artasi pods at harvest grown in line (3).

### *2.6. Hydroponic system operation*

The following steps were used in hydroponic system operation:

- After the faba beans seedlings were transferred to the 4-inch plastic pots in the PVC pipes after 30 d of

Table 2
Concentration ranges of various available nutrient solutions

| Nutrient | Hoagland & Arnon (1938) | Hwitt (1966) | Cooper [31] | Steiner (1984) |
|---|---|---|---|---|
| | Concentration in mg/L | | | |
| N | 210 | 168 | 200–236 | 168 |
| P | 31 | 41 | 60 | 31 |
| K | 234 | 156 | 300 | 273 |
| Ca | 160 | 160 | 170–185 | 180 |
| Mg | 34 | 36 | 50 | 48 |
| S | 64 | 48 | 68 | 2–4 |
| Fe | 2.5 | 2.8 | 12 | 336 |
| Cu | 0.02 | 0.064 | 0.1 | 0.02 |
| Zn | 0.05 | 0.065 | 0.1 | 0.11 |
| Mn | 0.5 | 0.54 | 2.0 | 0.62 |
| B | 0.5 | 0.54 | 0.3 | 0.44 |
| Mo | 0.01 | 0.04 | 0.2 | Not considered |

*Data Source*: Cooper [31].

Table 3
Concentrations of elements in 100% Cooper nutrient solution

| Element | Symbol | Conc. (ppm) | Source |
|---|---|---|---|
| Nitrogen | N | 200 | $Ca(NO_3)_2{\cdot}4H_2O$ |
| Phosphorus | P | 60 | $H_2PO_4$ |
| Kalium (Potassium) | K | 300 | $KNO_3$ |
| Calcium | Ca | 170 | $Ca(NO_3)_2$ |
| Magnesium | Mg | 50 | $MgSO_4{\cdot}7H_2O$ |
| Ferrous (Iron) | Fe | 12 | Fe EDTA (12%) |
| Manganese | Mn | 2 | Mn EDTA (12%) |
| Copper | Cu | 0.1 | $CuSO_4{\cdot}5H_2O$ |
| Zinc | Zn | 0.1 | $ZnSO_4{\cdot}7H_2O$ |
| Boron | B | 0.3 | $H_3BO_4$ |
| Molybdenum | Mo | 0.2 | $(NH_4)_6Mo_2O_{24}{\cdot}4H_2O$ |
| Sulfur* | S | 69 | $H_2SO_4^*$ |

*Sulfur comes from $H_2SO_4$, $MgSO_4$, and $CuSO_4$.

germination, the pot was filled with 0.5 tuff (granite) stones to hold the seedlings,
- Tap water only was pumped into the system for one week for the seedlings to adapt to the new environment.
- Then taps water was drained from the system and prepared nutrient solution was pumped into the PVC pipes at a rate of three times daily for 1.5 to 2 h.
- The nutrient solution pumping rate was chosen to allow plants growth and prevent root rot.
- When 10% of the nutrient solution volume was spent due to transpiration and evaporation, the nutrient solution was refilled or replenished.
- With time, seedlings were supported with wood (bamboo) sticks to stay in a vertical position,
- Faba beans plants were observed and measured daily.

Fig. 6 is a picture of the hydroponic system in operation.

*2.7. Field and lab measurement and analysis*

The following field measurements and laboratory analyses were conducted:

- Faba bean plant growth measurements started when plants were transferred to the 4-inch plastic pots. The plant measurements had been taken every 10 d until the end of the planting season including the growth parameters, plant height (PH), no of leaves (NL), leaves area (LA), leaf fresh weight (LFW), leaf dry weight (LDW), stems fresh weight (SFW), stem dry weight (DW), root fresh weight (RFW) and root dry weight (RDW)of the seedlings were recorded using the methods of Roberts and Mackey and Neal [32,33]. The separated parts of each plant were finally oven-dried at 75°C for 12 h and kept in desiccators to constant weight until a stable dry weight was measured.
- The dry ashing of collecting plant parts of faba beans including roots, leaves, stems, and fruits was conducted according to referenced methods [34,35]. Equipment used in the laboratory analysis includes Agilent 7500s ICPMS for the determination of heavy metals, nitrate meter: HANNA Instrument, HI 93728-0, for nitrate analysis, and SSpectronic21D spectrophotometer for phosphate and sulfate determination. Na was analyzed by Flame Photometry, Cl by titration with silver nitrate, and S by Colorimetry (by Hydrochloric acid and Barium chloride. All chemical analysis (heavy metals, salinity, nutrients, plant parts solutions) was conducted according to Standard Methods for the examination of Water and Wastewater [36].

Fig. 6. Picture of the hydroponic system in operation.

*2.8. Data managements*

The data were statistically analyzed using the one-way analysis of variance (ANOVA) to compare the response of each variety to the five treatments. The means were compared by LSD at 5% using SPSS program version 21 [37].

## 3. Results and discussion

The obtained results on the average nutrient content in response to various nutrient and salt treatments and average nutrient distribution in plant parts are presented below separately for micro and macronutrient elements. Because of the large data size (72 plants, 3 varieties, 4 plant parts, and 13 nutrients), the average nutrient concentration for the four replicates was reported in all results for the 13 nutrients and the three faba bean varieties. There are no results presented for TRT 3 and TRT 5 (high nutrient and high salinity treatment as the plants died. For those interested in the detailed results for each part of the plant, detailed data is listed in Abahri [38].

*3.1. Macronutrients*

*3.1.1. Nitrate*

Results presented in Tables 4 and 5 indicate that the nitrate concentration of faba bean varieties differed among the components at maturity of the three faba bean varieties with the order of leaf > pod > shoot > root. However, no significant difference occurred between the three faba bean varieties. The nitrate concentration increased in line1, 2

Table 4
Average content of nitrate in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 51.46(a)* | 50.56(a)* | 54.38(a)* |
| TRT 1 | 28.84(b)* | 29.10(b)* | 30.39(b)* |
| TRT 2 | 18.27(b)* | 18.42(bc)* | 19.10(bc)* |
| TRT 4 | 14.81(b)* | 10.51(c)* | 11.50(c)* |

*Significant difference between varieties at different lines.

Table 5
Overall average content of nitrate in all parts of faba beans

| Plant parts | Faba bean Variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 26.70 | 23.33 | 25.27 |
| Leaves | 39.15 | 32.98 | 27.60 |
| Shoots | 23.46 | 20.58 | 30.20 |
| Roots | 24.05 | 31.89 | 32.28 |

and 3 compared to TRT 5, where the order of increase was line1 > line2 > line3 > line5. Interesting that the control line (TRT 0) had the highest nitrate content among the three varieties (Table 2) while the salinity treatment line (TRT 5) was the lowest in all three varieties with Isbani the lowest. This might be attributed to the salinity effect on nitrogen fixation and cell division and biomass reduction (leaves and flower-pods formation), and the decline in dry weight and nitrogen content in the shoot.

As nutrient concentration in the feed lines increases, the nitrate concentration in the three varieties of plants decreases (Table 4). The nitrate content of leaves was among faba bean varieties in the order of Artasi > Baladi > Isbani (Table 4). The obtained result revealed that nitrate increases in the leaves and roots but decreased in shoots and pods. This can be explained by the plant's roots successfully absorbing nitrogen and water from the nutrient solution and passing it (transporting it) to shoots, leaves, and pods. The foliar absorption of nitrogen (nitrogen transport and metabolism) might be related to nitrogen transport genes which are responsible for regulating plant metabolism. Also, the plant increased vegetative growth resulting in nitrogen consumption could lead to or a reason for nitrogen decrease in shoots and pods. This result and explanation agree with Cordovilla et al. [14] and Hawkesford et al. [15].

#### 3.1.2. Sulfate

Results presented in Tables 6 and 7 indicate that sulfate concentration of faba bean varieties differed among the components at maturity of the three faba bean varieties with the order of root > shoot > leaf > pod. The sulfated content of the roots for the three varieties was more than double that in the other three parts and decreased as we move from roots to shoots, leaves, and the pods. This indicates that the easy sulfate availability in the hydroponic feed water helped in sulfate absorption. No significant difference was found in sulfate content between Artasi and Baladi varieties while the sulfate content in the Isbani variety showed a different and lesser extent trend. The sulfate content in the Isbani variety was the highest in the 25% nutrient treatment (TRT 1) while sulfate content in the control line (TRT 0) was the Baladi highest among all varieties (Table 6). The sulfate content was the lowest in the salinity addition (TRT 5) and equally among the three varieties (Table 6). This agrees with the results obtained by Mansour [40], the increase in salinity content in feed water will increase sulfate in plant parts.

Sulfates in the control line (TRT 0) had the highest sulfate content among the Artasi and Baladi varieties (Table 6). As nutrient concentration in the nutrient feed lines increases, the sulfate concentration in the three varieties of plants decreases (Table 6). This might be attributed to the availability of copper in the feed solution which may inhibit sulfate absorption.

Table 6
Average content of sulfate in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| Line number | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 51.30(a)* | 55.80(a)* | 33.56(ab)* |
| TRT 1 | 25.96(ab)* | 30.04(ab)* | 37.06(a)* |
| TRT 2 | 17.10(ab)* | 16.75(b)* | 21.75(ab)* |
| TRT 4 | 13.46(b)* | 13.25(b)* | 13.81(b)* |

*Significant difference between varieties at different lines.

Table 7
The overall average content of sulfates in all parts of faba beans

| Plants parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 17.09 | 19.74 | 22.54 |
| Leaves | 21.04 | 22.75 | 23.58 |
| Shoots | 24.07 | 28.78 | 25.03 |
| Roots | 45.61 | 44.57 | 35.06 |

#### 3.1.3. Phosphate

The result in Table 8 shows a significant increase in the average content of phosphate in lines 1 and 2, compared to the control line (TRT 5). However, there is no significant difference observed between the three varieties. Phosphate content decreased in treatment lines where line1 > line2 > line3 > line5. Results obtained agree with those reported by Strogonov [42] and Ravikovitch and Yoles [43].

It is noticeable that as phosphate content increased in nutrient solution (lines 2 and 3) phosphate content in plants of the three varieties decreased which means it was absorbed by the roots and certainly helped in pod formation (this showed in the increased phosphate content of pods in the three varieties).

It was observed that there is no significant difference in phosphate content between plant parts in the three varieties and the concentrations were in general moderate indicating that the roots absorbed phosphates from nutrients solution and plants used them in the metabolism and growth of various plant parts (Table 9).

#### 3.1.4. Potassium

The result in Table 10 shows that the average content of potassium in the control line (TRT 0) of the three varieties

Table 8
Average content of phosphate in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| Line | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 29.08(a)* | 30.77(a)* | 32.44(a)* |
| TRT 1 | 9.85(b)* | 10.87(b)* | 11.24(b)* |
| TRT 2 | 4.92(bc)* | 4.78(bc)* | 5.59(bc)* |
| TRT 4 | 1.54(b)* | 1.28(c)* | 1.25(c)* |

*Significant difference between varieties at different lines.

tested was the highest and double that in the salinity treatment line (TRT 5) [40,41]. In response to increased content of nutrient solution (TRT 1 and 3) potassium content in plants of the three varieties decreased (Table 10) which means that potassium was absorbed by the roots and certainly helped in protein and plant synthesis and growth (this is shown in Table 11, the increased potassium content in plant parts of the three varieties).

However, there is no significant difference observed in potassium content in comparison between the three varieties (Table 11). The relatively high potassium content in plant parts in response to salinity addition is noticeable and might mean that the faba bean can absorb nutrients in moderately saline nutrient solution [14,42,43]. The Baladi variety absorbed more potassium than Artasi and Isbani (Table 10).

The relatively high amount of average potassium content in various parts of the faba bean as well as in parts of the plants in the three varieties (Tables 10 and 11) is due to potassium being required for the growth of all parts of the plants. Although, the potassium-sodium competitivity impacts potassium absorption [44,45].

Table 9
Overall average content of phosphate in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi | Baladi | Isbani |
| Pods | 12.50 | 12.37 | 15.33 |
| Leaves | 8.67 | 10.06 | 9.73 |
| Shoots | 9.85 | 11.21 | 11.07 |
| Roots | 14.37 | 14.08 | 14.39 |

Table 10
Average content of potassium in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 84.61(a)* | 102.05(a)* | 89.17(a)* |
| TRT 1 | 56.04(ab)* | 62.04(ab)* | 59.60(ab)* |
| TRT 2 | 26.47(b)* | 24.32(b)* | 36.90(b)* |
| TRT 4 | 54.08(ab)* | 52.88(b)* | 52.13(b)* |

*Significant difference between varieties at different lines.

Table 11
Overall average content of potassium in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 60.86 | 41.77 | 63.93 |
| Leaves | 59.77 | 68.88 | 63.17 |
| Shoots | 47.93 | 61.64 | 55.34 |
| Roots | 52.64 | 69.02 | 55.72 |

*3.1.5. Sodium*

Results in Table 12 show that the average content of sodium in TRT 2 (100% Cooper addition) has significantly increased compared to other lines (line3 >> line5 > line2 > l ine1). This is due to the competition of $Na^+$ with $K^+$ and other ions with similar physicochemical properties [46]. This is supported by data in Table 9, where the potassium content in TRT 2 is the lowest among other lines. However, there is no significant difference between the three varieties in the average sodium concentration within the same treatment line. Result also shows an increase in the sodium concentration in the Isbani variety compared to Baladi and Artasi.

Results show that average sodium concentration in roots, shoot, and leave are relatively close for the three varieties and all are much higher than that in pods. This indicates the need for faba bean for sodium in its growth. The average concentration of sodium in roots was the highest among all parts and the highest in Isbani followed by Baladi and Artasi (Table 13).

Results in Table 13 show the average content of sodium in whole plants, the result revealed that there is no significant difference between plants parts and between varieties, the lowest sodium content was in the pods, where the sodium content was in this order Isbani > Baladi > Artasi, while the highest sodium content was in the root where Isbani > Baladi > Artasi.

*3.1.6. Magnesium*

The results in Table 14 show that the average content of magnesium in parts of the Baladi variety and in response to all treatments are higher than those in the other two varieties. Leaves showed higher magnesium content than roots,

Table 12
Average content of sodium in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi | Baladi | Isbani |
| TRT 0 | 7.67(b)* | 12.51(b)* | 9.51(b)* |
| TRT 1 | 17.90(b)* | 21.22(b)* | 16.37(b)* |
| TRT 2 | 91.26(a)* | 96.67(a)* | 112.10(a)* |
| TRT 4 | 43.69(ab)* | 42.92(ab)* | 41.88(b)* |

*Significant difference between varieties at different lines.

Table 13
Overall average content of sodium in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 12.24 | 14.16 | 20.97 |
| Leaves | 46.35 | 51.60 | 46.02 |
| Shoots | 56.66 | 53.62 | 53.47 |
| Roots | 45.28 | 53.95 | 59.42 |

shoots, and pods (Table 15). This is logical as magnesium is involved in the activation of enzymes in respiration and photosynthesis (Chlorophyll formation). The magnesium content in Artasi and Isbani variety and in response to all treatments was almost equal (Table 14).

It is noted from the result listed in Table 15 that statistically there is no significant difference between treatment lines, and between varieties (very few differences between magnesium content values for the three varieties). The reason for the insignificance may be due to the competition of Mg with other ions such as sodium [42], or it may be due to the precipitation of Mg in the bottom of nutrient solution feed lines. There is a slight increase in TRT 0 and 2, compared to the control line, because Cooper solution (lines 2 and 3) contain Mg, and control line 1 does not.

#### 3.1.7. Calcium

The result in Tables 16 and 17 indicate the very high calcium concentration in both plant parts and the plants as a whole and in the three varieties indicating the importance of calcium as a macronutrient for the faba bean plants either in nitrates metabolism, cell division, and pod development and formation. However, within each plant part and for the three varieties there was no difference in calcium concentration (Table 16).

The calcium concentration in plants of the control line (TRT 0) was the lowest among all treatments. There is very little calcium in the control feed contrary to other treatments. Plants in the salinity treatment line (TRT 5) were having the highest calcium concentration (Table 16). This is evidence that salinity increases calcium content in plants, this finding agrees with Epstein and Bloom [47] who reported that calcium plays a major role in salt tolerance. Also, according to Marschner [46] most researchers have observed a depressive effect of $Na^+$ on $Ca^{2+}$ uptake. According to Xiong and Zhu [48], calcium is an important determinant for homeostasis particularly relevant to sodium and potassium for plants' salt tolerance.

Calcium concentration in the Baladi variety parts was the highest (Table 17) followed by the Artasi and then the Isbani.

### 3.2. Micronutrients

#### 3.2.1. Copper

The results in Table 18 show the traces of average content of copper in all parts of faba beans at different treatment lines. There is no statistically significant difference between treatment lines 1, 2, and 3. Copper concentration in plants in response to salinity addition (Treatment TRT 5) was very reduced in concentration (more than ten times less than other lines). Copper reduction in plants (TRT 5) might be caused by the salinity stress in plants. Average copper concentration in the roots was the highest and in the order: roots >> leaves > pods > shoot.

As copper helps in the uptake and utilization of calcium, functioning of the membrane, pollen germination, cell elongation, germination, etc., roots absorbed copper and distributed it to other parts, and in order: root to shoot to leaves and pods for seed production (Table 19). Noticeable that the copper concentration for the control line (TRT 0) was the highest among all treatments (line1 > lines 2 and 3 > TRT 5).

Copper concentration in plants (Table 18) was almost equal between lines and within lines for the three varieties in response to nutrient addition (lines 2 and 3). For copper concentration in plant parts, copper concentration roots of Baladi variety was higher than Isbani and the Artasi.

Table 14
Average content of magnesium in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 13.65 | 26.56 | 13.32 |
| TRT 1 | 11.23 | 12.90 | 13.22 |
| TRT 2 | 8.68 | 11.37 | 9.47 |
| TRT 4 | 10.16 | 16.30 | 13.23 |

Table 15
Overall average content of magnesium in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 5.40(c)* | 14.12 | 6.59(b)* |
| Leaves | 16.21(a)* | 22.96 | 21.50(a)* |
| Shoots | 12.24(ab)* | 14.92 | 4.80(b)* |
| Roots | 9.87(bc)* | 15.13 | 16.35(a)* |

*Significant difference between plants part in each variety.

Table 16
Average content of calcium in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 49.77 | 50.65 | 33.94 |
| TRT 1 | 106.77 | 61.76 | 55.91 |
| TRT 2 | 88.66 | 131.48 | 148.83 |
| TRT 4 | 222.24 | 173.30 | 127.89 |

Table 17
Overall average content of calcium in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 21.28(b)* | 20.51(b)* | 28.95(b)* |
| Leaves | 189.62(a)* | 203.41(a)* | 136.68(a)* |
| Shoots | 132.44(ab)* | 62.97(ab)* | 86.66(ab)* |
| Roots | 124.10(ab)* | 130.29(ab)* | 114.27(ab)* |

*Significant difference between plants part in each variety.

Table 18
Average content of copper in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 0.068 | 0.090 | 0.089 |
| TRT 1 | 0.053 | 0.063 | 0.065 |
| TRT 2 | 0.066 | 0.063 | 0.066 |
| TRT 4 | 0.0025 | 0.0077 | 0.0031 |

Table 19
Overall average content of copper in all parts of faba beans

| Plant parts | Faba bean Variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 0.021(b)* | 0.013(b)* | 0.021(b)* |
| Leaves | 0.047(ab)* | 0.041(ab)* | 0.038(ab)* |
| Shoots | 0.010(b)* | 0.033(ab)* | 0.036(ab)* |
| Roots | 0.112(a)* | 0.137(a)* | 0.126(a)* |

*Significant difference between plants part in each variety.

*3.2.2. Chloride*

Similar to the sodium results (Table 12), Table 20 shows the average content of chloride in TRT 2 (100% Cooper addition) has significantly increased compared to other lines (line3 >> line5 > line2 > line1). This is due to the competition of Cl with $Na^+$, $K^+$, and other ions with similar physicochemical properties [48]. This is supported by data in Table 9, where the potassium content in TRT 2 is the lowest among other lines. However, there is no significant difference between the three varieties within the same line.

It was noticed that when Cooper solution increased (treatment TRT 1 and 3) chloride content in plants decreased (Table 20), this happened because nitrate where competes with chloride and this agree with what was reported by White and Broadley [49], and Bernal et al. [50] which also explains the competition in line (3).

There is an increase in chloride concentration in the Isbani variety compared to Baladi and Artasi (Isbani > Baladi > Artasi). Results show a significant decrease in lines (1) and (2) when compared to line (3). The concentration of chloride increased slightly in Baladi in lines (1) and (2) compared to Artasi and Isbani.

The chloride concentration in plant parts (Table 21), indicates that the three varieties have the same trend (roots > shoots > leaves > pods) with small differences.

*3.2.3. Iron*

The results listed in Table 22 show an increase in iron concentration in the control line (TRT 0) for all varieties compared to other lines. In TRT 1 (25% Cooper addition), there is a decrease observed in iron concentration compared to TRT 0, and in TRT 2 (100% Cooper addition). The decrease in iron concentration in TRT 1 might be due to the inappropriate iron dose in the 25% nutrient feed solution. There is a slight variation in the response of faba varieties to various treatments: iron concentration in the Isbani variety for lines 2, 3, and 5 was the highest among the three varieties while the response to various treatments by the Artasi and Baladi varieties is not clear. Also, there is a decrease in iron concentration in TRT 2 compared to the salinity treatment line (TRT 5). However, there is no statistically significant difference between treatment lines. The increased levels of iron resulting from salinity treatments have been reported for tomatoes, squash, and soybean. This increase may be due to interactions between iron and phosphate or interactions between (Fe and Zn, Mn and Cu) [48,51–53].

Iron in plant parts (Table 23), is in the order: root > leaves > shoot > pod. Iron in the plant roots is high in the three varieties and this proves the high requirement of iron in faba beans (it is an important part of protein and activates enzymes in plant parts). Also, results indicated that iron accumulated in leaves. There is no significant difference in iron concentration between faba varieties in each plant part, while there is a significant difference between plant parts in each variety (Table 23).

Table 20
Average content of chloride in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 8.07(b)* | 13.08(b)* | 10.93(b)* |
| TRT 1 | 19.00(b)* | 19.67(b)* | 18.23(b)* |
| TRT 2 | 92.13(a)* | 99.15(a)* | 114.12(a)* |
| TRT 4 | 45.03(ab)* | 45.32(ab)* | 44.08(b)* |

*Significant difference between varieties at different lines.

Table 21
Overall average content of chloride in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 12.04 | 15.01 | 21.84 |
| Leaves | 48.08 | 54.46 | 48.33 |
| Shoots | 57.76 | 55.44 | 56.06 |
| Roots | 46.36 | 52.32 | 61.13 |

Table 22
Average content of iron in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 1.78 | 2.62 | 2.41 |
| TRT 1 | 1.07 | 1. 74 | 1.47 |
| TRT 2 | 1.34 | 1.19 | 1.77 |
| TRT 4 | 1.37 | 1.26 | 1.55 |

Small differences in iron concentration between various treatments may be attributed to heterogeneous iron precipitation in the feed lines or feed tanks. Also, iron is regularly added to nutrient solutions in chelated form. Many researchers have shown that chelates reduce the plant uptake of metals from nutrient solutions [54,55].

*3.2.4. Zinc*

The results in Table 24 show that the average content of zinc in all three plant varieties in the control line (TRT 0), is greater than all treatments. However, zinc concentration in the Baladi variety was greater than that in Artasi and Isbani. As a nutrient solution in the feed lines increased (lines 2 and 3), zinc concentration in plants increased for the Artasi variety and decreased for Baladi and Isbani. This increase in zinc is due to Cooper nutrient solution containing zinc, so plants' absorbance is zinc-dependent on zinc concentration in the solutions. The zinc concentration in plants in response to salinity was lowest in the Artasi variety and highest in Baladi. However, zinc plays an important role in activating enzymes [56], so its increase in salinity treatment may be to cope with salinity stress.

The response of the three faba bean varieties and their parts content to zinc addition in the nutrient solution was inconsistent and variable (Table 24). The zinc content of the three faba bean varieties and their parts in response to salinity treatment (TRT 5) indicates a small decrease (Table 24). As zinc presence in nutrient solution increased zinc concentration in plants of the three varieties increased. The zinc content of plant parts of the three varieties was relatively high (Table 24) This result confirms that zinc enhances plant growth (chlorophyll production) and pod production [57,58]. There was no significant difference found in zinc concentration within the roots for the various varieties, indicating the high absorbance of zinc by the roots of the three varieties.

*3.2.5. Manganese*

The results listed in Table 26 show the average content of manganese in all three varieties in response to salinity was the highest among all treatments. Similar results were reported by Maas et al for several plants [48,51–53]. The response of the three varieties to nutrient addition (lines 2 and 3) was insignificant and had the lowest manganese concentration among all treatments (line1 > line2 > line3 > line5 – Table 25). Manganese concentration in the Baladi variety was more than double that in Artasi and Isbani for the control as well as nutrient addition treatments (Table 26).

Manganese concentration in the roots of the three varieties was the highest among all plant parts (Table 27). However, the manganese in the roots of the Baladi was more than double that in Artasi and Isbani. This is due to that the manganese presence helping in the splitting of water during photosynthesis and enhancing root elongation and consequently metal absorbance.

*3.2.6. Molybdenum*

Molybdenum content in plants of the three varieties in response to salinity addition was the lowest among all treatments indicating the sensitivity of faba beans to salinity. The response of the three varieties to nutrient treatment (lines 2 and 3 – Tables 28 and 29) was profound and in the order: Isbani > Baladi > Artasi. Isbani variety had four-time molybdenum content than Artasi and more than two times more than Baladi.

Roots of the three varieties had the highest molybdenum content among all other parts. This is an indication

Table 23
Overall average content of iron in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 0.18(b)* | 0.15(b)* | 0.22(b)* |
| Leaves | 1.07(b)* | 1.20(b)* | 1.43(b)* |
| Shoots | 0.74(b)* | 0.86(b)* | 0.80(b)* |
| Roots | 3.59(a)* | 4.60(a)* | 4.75(a)* |

*Significant difference between plants part in each variety.

Table 24
Average content of zinc in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 0.166(a)* | 0.198(a)* | 0.169(a)* |
| TRT 1 | 0.071(b)* | 0.051(b)* | 0.092(b)* |
| TRT 2 | 0.125(ab)* | 0.039(b)* | 0.076(b)* |
| TRT 4 | 0.049(b)* | 0.074(ab)* | 0.066(b)* |

*Significant difference between varieties at different lines.

Table 25
Overall average content of zinc in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 0.058 | 0.088 | 0.105 |
| Leaves | 0.167 | 0.074 | 0.099 |
| Shoots | 0.080 | 0.099 | 0.089 |
| Roots | 0.106 | 0.101 | 0.111 |

Table 26
Average content of manganese in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 0.41(a)* | 0.87(a)* | 0.44(a)* |
| TRT 1 | 0.14(b)* | 0.30(b)* | 0.14(b)* |
| TRT 2 | 0.12(b)* | 0.27(b)* | 0.12(b)* |
| TRT 4 | 0.064(b)* | 0.063(b)* | 0.066(b)* |

*Significant difference between varieties at different lines.

Table 27
Overall average content of manganese in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 0.04(b)* | 0.12(b)* | 0.033(b)* |
| Leaves | 0.14(b)* | 0.14(b)* | 0.13(b)* |
| Shoots | 0.025(b)* | 0.022(b)* | 0.027(b)* |
| Roots | 0.54(a)* | 1.20(a)* | 0.57(a)* |

*Significant difference between plants part in each variety.

Table 28
Average content of molybdenum in all parts of faba beans at different lines

| Treatment line number | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| TRT 0 | 0.070(a)* | 0.131(a)* | 0.0978(ab)* |
| TRT 1 | 0.047(ab)* | 0.070(ab)* | 0.1721(a)* |
| TRT 2 | 0.046(ab)* | 0.070(ab)* | 0.1721(a)* |
| TRT 4 | 0.0025(b)* | 0.011(b)* | 0.0038(b)* |

*Significant difference between varieties at the lines.

Table 29
Overall average content of molybdenum in all parts of faba beans

| Plant parts | Faba bean variety | | |
|---|---|---|---|
| | Artasi (ppm) | Baladi (ppm) | Isbani (ppm) |
| Pods | 0.03(b)* | 0.10(b)* | 0.013(b)* |
| Leaves | 0.16(b)* | 0.13(b)* | 0.15(b)* |
| Shoots | 0.022(b)* | 0.024(b)* | 0.027(b)* |
| Roots | 0.60(a)* | 1.33(a)* | 0.61(a)* |

*Significant difference between plants part in each variety.

of the high dependence and absorbance of molybdenum by faba beans and its need for regulating enzyme activities and for growth [59,60].

## 4. Concluding remarks

Based on the results obtained the following concluding remarks were observed:

- The NFT hydroponic growing system was successful in faba bean growth and production.
- No systematic faba bean responses were observed neither for nutrient treatment nor for salinity treatment.
- Very high nutrient (300 Cooper) and very high salinity treatment (7.8 ds/m NaCl) resulted in the death of all faba bean plants at the flowering stage.
- Salinity of irrigation water affects nutrient distribution in faba beans, where some nutrients increase in plant parts such as Na, Ca, and Cl, while other nutrients decrease as K and $NO_3$.
- Nutrient treatment is a positive way to influence plant part's composition and quality.
- The hydroponic system provided easy access to faba bean varieties to nutrients and their absorbance.
- Ion competition such as that between Mg and Na, Cl with Na and K, Ca and Na, K and Na, caused depressive effect on nutrient absorption.
- There was a significant difference found between the three varieties of faba bean in response to salt and nutrient solution.

## Conflict of interest

The authors declare that they do not have any conflict of interest.

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