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RESEARCH ARTICLE

Effect of adding alginate -restricted bacterial inoculants to sandy soil as a partial substitute for mineral fertilization on growth, quality and yield of tomato plants.

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Abstract

Two experiments were conducted over the 2022 and 2023 seasons at the Agricultural Research Station in El-Arish, North Sinai Governorate, Egypt. The aim was to assess the impact of two bacterial strains, *Azotobacter chroococcum* (AZ.) and *Bacillus subtilis* (Bac.), in encapsulated or liquid forms, alongside varying levels of N/P mineral fertilization, on tomato plant traits. Results indicate significant effects of bio-inoculation treatments on vegetative growth, physical fruit and yield characteristics, as well as chemical properties of fruits (Vitamin C, TSS, firmness, and Dry Matter%). The combination of *Bacillus* and *Azotobacter* encapsulated in calcium alginate showed superior performance, followed by the same mixed treatment in liquid form across all studied traits in both seasons, with some traits showing no significant differences between them. Under N/P stresses of 75% or 50%, bacterial treatments in combination with both application methods (liquid or encapsulated alginate) exhibited statistically equivalent or increased values in most traits compared to corresponding control treatments. Notably, alginate-encapsulated bacterial mix [(Bac.+AZ.)-Caps.] with 75% N/P showed significant maximum effects compared to untreated plants, with increases of up to 66.5% for vegetative traits, 32.4% for physical fruit and yield traits, 16.1% for chemical fruit traits, 11.8% for leaf N, P, and K, and 11.3% for fruit N, P, and K, followed by the liquid form of bacterial mix combined with 75% N/P. Additionally, a highly significant positive correlation between total microbial activity and dehydrogenase activity was observed at day 30. However, this correlation was no longer statistically significant at days 60 and 90.

Keywords: Alginate encapsulated; *Azotobacter chroococcum*; *Bacillus subtilis*; Biofertilizer; Immobilization; Tomat; Growth; Yield.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is widely recognized as one of the most important vegetables globally, prized for its edible fruits consumed in various diets around the world. Following potatoes, tomato is the second most important vegetable crop globally. Egypt ranks fifth in world tomato production, behind China, India, Turkey, and the USA, with an annual production of approximately 6,275,443 tons cultivated on 143,618 hectares (FAO, 2022). This translates to an average yield of about 41.6 tons per hectare (FAO, 2022). Tomatoes are renowned for their significant nutritional and medicinal benefits, particularly when considering their diverse array of essential nutrients. In a single cup of tomatoes, one can acquire 11.4% of the daily recommended intake for potassium, 5.6% for niacin, 7.0% for vitamin B6, and 6.8% for folic acid. Moreover, tomatoes are rich in essential

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vitamins such as A, C, E, and B complex vitamins (B1, B2, B3, B6, & B9), which work synergistically to promote heart health. Additionally, tomatoes contain vital minerals like nitrogen, phosphorus, calcium, and iron. Tomatoes are also rich in antioxidants, including carotenoids, and lycopene. These antioxidants play a crucial role in protecting against free radicals, supporting tissue growth, promoting neurological health, maintaining healthy skin, and reducing cholesterol levels (Collins *et al*., 2022). Lycopene, in particular, has been linked to the prevention of various cancers including prostate, cervical, colon, rectal, stomach, mouth, pharynx, and esophagus. Additionally, phytochemicals like polyphenols found in tomatoes may also contribute to a reduced risk of cancer (Ganesan *et al*., 2012).

Overuse of chemical fertilizers, especially those high in phosphorus and nitrogen, leads to significant contamination of soil, air, and water. This contamination can damage soil microorganisms, disrupt soil fertility, pollute the ecosystem, and even decrease crop productivity (Kumar *et al*., 2015; Ahmad *et al*., 2016). Nitrogen is crucial for plant growth. It plays a vital role in photosynthesis, cell division, assimilation of carbon dioxide, and chlorophyll production. Phosphorous (P) is most significant essential elements in nature for plants. It is involved in the formation of biological cell membranes and the activation of enzymes. (Vance *et al*., 2003). While the second most common metallic element in soil, after nitrogen, phosphorous can be found in both organic and inorganic forms. It is essential to several metabolic activities, including photosynthesis, energy transfer, and the quality of agricultural products.

Plant growth-promoting rhizobacteria (PGPR) have the ability to positively impact plant growth through a broad range of mechanisms, including the synthesis of phytohormones, siderophores, phosphate solubilization, biological nitrogen fixation, and antimicrobial activity (Benaissa 2019). studies by Adesemoye *et al*. (2009) and Dinesh *et al*. (2013) have shown that the presence of rhizobacteria and inorganic fertilizers can enhance plant growth by promoting increased nutrient uptake. Additionally, inorganic fertilizers may have an impact on the growth of rhizobacteria populations in the soil, which primarily produce phosphorus-solubilizing agents and indole acetic acid (IAA) (Martınez *et al*., 2011; Yuan *et al*. 2011). Notably, a number of studies have demonstrated a substantial correlation between enzyme activity and soil nutrient availability (Zheng *et al*., 2015; Guan *et al*., 2020; Bai *et al*., 2021). N fertilizers, for instance, have been shown to increase soil respiration and hydrolytic enzyme activity while suppressing soil oxidase activity (Li *et al*., 2018). Additionally, research on the stoichiometry of extracellular enzymes in soil can help clarify how the addition of N and P affects the demand for N and P resources by soil microbes, offering insights into the impact of microbial processes on nutrient cycling (Zhou *et al*., 2017).

Responses to N additions in a biological community of interacting organisms depend on the type and amount of chemical form(s) of N (Yang *et al*., 2014), the succession stage of soil microorganisms (Zhang *et al*., 2018), the composition of the soil enzymatic pool (Wang *et al*., 2013), the type of vegetation and the structure of plant communities (Schimel *et al*., 2007). It is difficult to identify and accurately forecast broad ecosystem response patterns in light of these varying effects of N% (Wang *et al*., 2013). Because of this, research on how nitrogen affects soil enzymes and the microbial community inside the soil needs to be contextualized within certain climatic and edaphic circumstances, and extrapolations to other biological communities need to be done carefully. According to Cramer *et al*. (2018), the biological communities of north Sinai (Mediterranean ecosystems) are extremely susceptible to climate change and factors linked to global environmental change, most notably N deposition (Ochoa-Hueso *et al*., 2011; Zuccarini

et al., 2021). Due to P-limitation and overall nutrient deficiency—both common characteristics of Mediterranean soils—this susceptibility to N deposition results from (Sardans *et al*., 2004; Sardans and Peñuelas, 2013). Because increased N intake and faster soil microorganism growth rates result in more P-mobilizing extracellular enzymes being produced, which enhances P acquisition from organic pools, N addition can exacerbate P-limitation (Vitousek *et al*., 2010; Zuccarini *et al*., 2021). Due to reduced rates of soil organic matter breakdown following N addition, soil C storage may rise. This process is detrimental to both carbon (C) mobilizing enzymes and N mobilizing enzymes (de Vries *et al*., 2009). (Yue *et al*., 2016; Peng *et al*., 2022). It is believed that intact cells and the dehydrogenase activities of the soil microflora contain active dehydrogenases in soils (Laad, 1978). Correlational data on the biological activity and microbial communities in soil is provided by dehydrogenase activity. Dehydrogenases carry out a variety of oxidative processes that lead to organic matter's breakdown, or dehydrogenation. One class of enzymes that provides information on the impact of natural environmental variables on soil microbial activity is represented by dehydrogenases (Schäffer, 1993). The objective of this study is to reduce the use of nitrogen and phosphate fertilizers as well as increase the yield and improve the quality characteristics by using the free-living nitrogen fixer bacterium, *Azotobacter chroococcum* and the phosphorous solubilizer bacterium *Bacillus subtilis* on tomato plants using the alginate encapsulation or liquid forms in the open field.

2. Materials and methods

Two experiments were carried out during the two successive seasons of 2022 and 2023 at Agric. Res. Station, El-Arish, North Sinai Governorate, Egypt to study the effect of two bacterial strains, i.e., *Azotobacter chroococcum* (Az.) and *Bacillus subtilis* (Bac.) under different levels of N/P mineral fertilization on vegetative growth, yield, and fruit characters of tomato (*Solanum lycopersicum* L.) *cv.* Lojain F_1, grown under open field conditions. The 35-old days seedlings were transplanted at the first May in both seasons in a split plot of a randomized complete block design with three replicates. The main plot treatment consisted of three levels of nitrogen (N) and phosphorus (P) fertilizer application (100%, 75%, and 50% of the recommended rate). The subplot treatment included seven bacterial treatments: a control (only NPK fertilizer), *Bacillus subtilis* alone, *Azotobacter chroococcum* alone, and a combination of both bacteria applied in either encapsulated or liquid form. The treatments consisted of three N/P levels (100%, 75%, 50% recommended) and this was the main plot treatment. In the sub-plot treatment, bacterial strains was used in in the two applying forms (encapsulate or liquid) under seven treatments in which the first was control (only NPK) and the other six treatments were included Bac., Az.) and mix of both Bac. plus Az. in the two applying abovementioned forms.

2.1. Bacterial strains, growth and culture conditions

In this work, the model "plant growth-promoting bacteria (PGPB)" were the free-living nitrogen fixer bacterium *Azotobacter chroococcum* and the phosphorous solubilizer bacterium *Bacillus subtilis*. The Department of Agricultural Microbiology at the National Research Center in Egypt graciously provided the previously stated microorganisms. Liquid N-free Ashby's Sucrose medium (g/L: K_2HPO_4 0.2, $MgSO_4$ 0.2, NaCl 0.2, Na_2MoO4 0.006, $CaCO_3$ 5.0, sucrose 20) was used to cultivate and maintain *A. chroococcum* (Bonartseva *et al*., 2017). The medium used to cultivate and sustain the *B. subtilis* culture was nutritional broth (Sigma-Aldrich, Germany).

2.2. Bacterial encapsulation in sodium alginate

Alginate beads were prepared for bacterial encapsulation in sodium alginate by following,

albeit slightly altered, the protocol outlined by Tirry *et al*. (2022). 500 mL Erlenmeyer flasks with 250 mL of liquid N-free Ashby's Sucrose medium (for Azotobacter) or nutrient broth (for *Bacillus*) were used to cultivate the bacteria. For *Bacillus* and *Azotobacter*, inoculated flasks were incubated for 24 hours and 4 days, respectively, at 28 °C on a rotary shaker spinning at 150 rpm. Following incubation, the bacteria were separated into individual cells using centrifugation (6000 g for 10 minutes) in 50 mL containers. The supernatant was then discarded, and the individual cells were twice cleaned using sterile distilled water. After being collected, the bacterial cells were again suspended in the proper volume of distilled water that was sterile. The isolates that were immobilized in alginate beads were prepared using these suspensions, either singly or in combination. In short, the bacterial suspension was combined with a 3% sodium alginate solution that had been continually steered. To achieve a bacterial concentration of 1 x 108 CFU mL^{-1}, sodium alginate and bacterial suspension were thoroughly combined (v, v) with gentle swirling for 5 minutes using a magnetic bar. To create beads in the sterile $CaCl_2$ 0.1 M solution, the mixture was put into a sterile 5 mL syringe. The $CaCl_2$ solution was added to the beads, which were then agitated for 15 minutes. After three rounds of sterile distilled water washing to remove any remaining debris and unpolymerized cells, the beads were returned to the $CaCl_2$ solution. The normal agricultural practices were done as needed and like those used in commercial tomato production according to the recommendation of the Egyptian Ministry of Agriculture and Land Reclamation with a drip irrigation system four times a week. The plot area was 25.2 m^2 (3 dripper lines, each measuring 6 m in length and 1.4 m in the width). Every plant was planted on a dripper line, with a 0.5 m spaced between each plant on the same line.

2.3. Experimental parameters

2.3.1. Vegetative growth:

A random sample of 5 plants from each plot was taken after 65 days from transplanting and the following data were recorded: Fresh weight of root, leaves and branches as well as the total plant dry weight.

2.3.2. NPK content in leaves

- Horneck and Miller's (1998) modified Kjeldahl technique was used to calculate total nitrogen.
- The Watanabe and Olsen (1965) method was used to determine phosphorus.
- According to Brown and Lilleland (1964), the Flame Photometer was used to determine the amount of potassium.

2.4. Chemical constituents of fruits

Random samples of ten fruits at ripe stage (from the third picking) were taken from each treatment to determine:

a. TSS (%), firmness (Kg/cm^2) and fruit dry matter % as well as Vitamin C (ascorbic acid) content in fruits tissues according to AOAC (1990).

b. Elemental Analysis, *i.e.,* Nitrogen, Phosphorous and Potassium content (%) in fruits tissues. Nitrogen was determined with the modified "Micro Kjeldahl" apparatus as described by Pregl (1945). Phosphorus was determined spectrophotometrically by using stannous chloride method according to (AOAC 1990). Potassium was measured with flame photometer according to the method described by Brown and Lilliland (1964).

2.5. Fruit yield

it was calculated as average fruit weight [in grades A (>100 g) & B (<100 g)], and total fruit yield ton/fed.

2.6. Soil's microbial enzyme activities:

2.6.1. Total microbial enzyme activities (TMA)

Based on the rate of fluorescein diacetate (FDA) hydrolytic activity, the total microbial enzyme activities of soils were determined using a

modified version of the Patle *et al*. (2018) approach. To put it briefly: 50 milliliter capped centrifuge tubes were filled with two grams of rhizosphere soil samples (in triplicate). The reaction was started with the addition of 0.2 mL of 0.1% FDA (in acetone) and 15 mL of potassium phosphate buffer (60 mM, pH 7.6). In a rotating shaker, tubes were incubated horizontally at 30°C for 20 minutes. Following incubation and color development, 15 mL of chloroform/methanol (2:1) was added, and the reaction was halted by vortexing for one minute. The tubes were centrifuged at 5000 rpm for 10 minutes in order to separate the chloroform layer and spin down the soil and turbidity. Using spectrophotometric measurement at 490 nm, the produced colored fluorescein in the chloroform layer was compared to fluorescein standards. An expression for the total amount of soil microbial activity was FDA hydrolysis values (µg of released fluorescein g-1soil).

2.6.2. Dehydrogenase activity (DHA)

With a few adjustments, the dehydrogenase activity in soil samples was measured using the procedure outlined by Navnage *et al*. (2018). In a nutshell, 0.2 ml of a 3% 2,3,5 triphenyltetrazolium chloride (TTC) solution is applied to one gram of soil in a 15 ml screw-capped tube. 0.5 ml of a 1% glucose solution was added to each tube, sealed with plastic stoppers, and incubated for 24 hours at 28 °C. Ten milliliters of methanol were used to extract the red-colored triphenyl tetrazolium formazan (TPF) that had developed after the sample was incubated, shaken for one minute, and left to stand in the dark for six hours. Each sample's supernatant is then filtered into a 50 ml conical flask, and the filtrates are quantified using a spectrophotometer at 485 nm.

2.7. Statistical analysis

Obtained data was subjected to statistical analysis of variance according to Snedecor and Cochran, 1980). Duncan's multiple range tests was used for comparison among means (Duncan, 1958).

3. Results

3.1. Vegetative growth parameters

3.1.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 1 indicate that all N/P levels had a significant effect on all vegetative growth characteristics. N/P positively affected the studied vegetative growth characteristics [Fresh weight of branches (BFW), leaves (LFW) and roots (RFW) as well as the dry weight of total plant (TPDW)] as 100% recommendations of nitrogen and phosphorus (N/P) recorded significantly the highest values for all vegetative traits followed by 75% of N/P and 50% of N/P, in descending order during the two study seasons with no significant differences between 100% N/P and 75% N/P in total plant dry weight in 2nd (2023). Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of TPDW, RFW, LFW and BFW by 27.23%, 30.29%, 42.41% and 59.55%, while exposure to low mineral applications of 75% N/P caused inhibition of the same traits by 10.77%, 18.19%, 25.11% and 31.92% in descending order as an average of both seasons (Fig. 1).

3.1.2. Effect of bio-inculcation

The results presented in Fig. 2 show that the vegetative growth characteristics (Fresh weight of branches, leaves and roots as well as the dry weight of total plant) were strongly influenced by treating with some bio-inoculation treatments. Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Azo..(L) without alginate] in all the studied traits during the two seasons of study with no significant differences between them in BFW and TPDW in both seasons and RFW in 2nd season. No significant differences between Bac. (Cap.), Azot. (Caps.) and Azot. (L.) for all vegetative growth traits in both seasons except, leaves fresh weight, while both the control (untreated treatment) and Bac. (L.) recorded the lowest values obtained in all the studied

vegetative growth traits with no significant differences between them in the two study seasons except, leaves fresh weight.

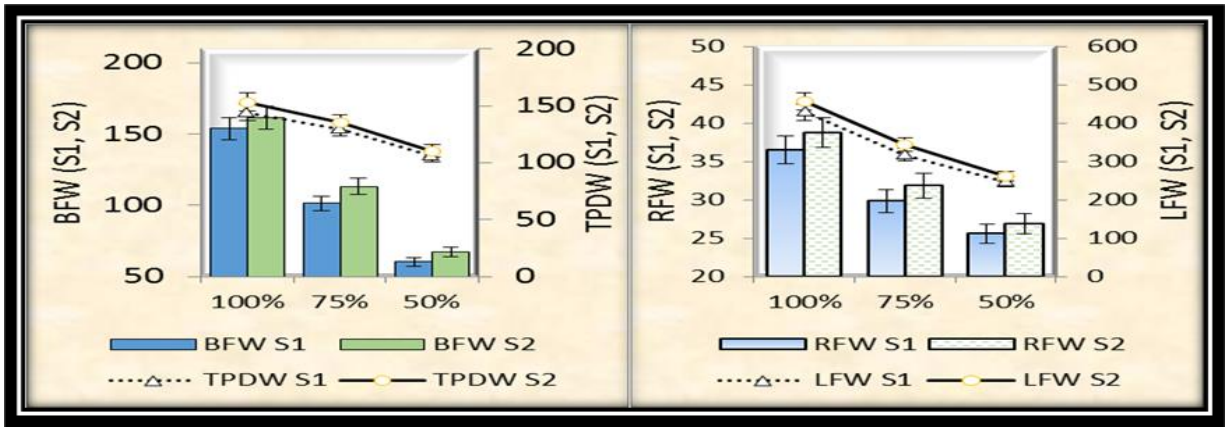


Figure 1. illustrates the vegetative growth characteristics, including the fresh weight of roots (RFW), branches (BFW), and leaves (LFW), as well as the total plant dry weight (TPDW) of tomato plants, in response to varying N/P levels during the 1st (S1) and 2nd (S2) seasons.

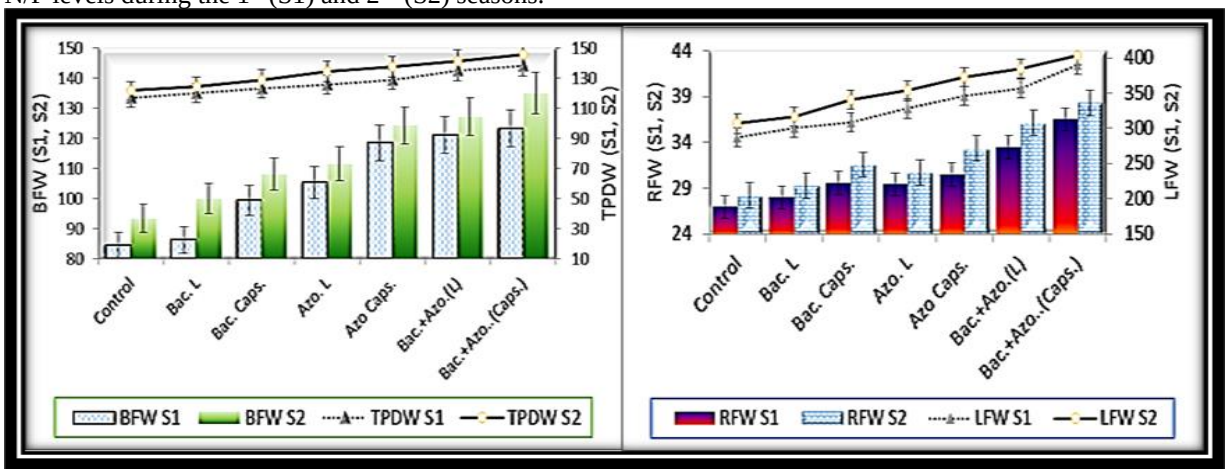


Figure 2. Vegetative growth characters of fresh weight for roots (RFW), branches (BFW), and leaves (LFW), along with the total plant dry weight (TPDW) of tomato plants as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

"Where Azotobacter chroococcum (Az.) and Bacillus subtilis (Bac.) are used, inoculation is carried out in two forms: liquid (L) and capsules (Caps)."

However, mixed treatment [(Bac.+Az.)/Caps] encapsulated in calcium alginate has significant maximum effects by 35.8%, 45.2%, 33.7% and 19.1% (Fig.3, in average of both seasons) for RFW, BFW, LFW and TPDW followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 26.3%, 39.5%, 25.0% and 16.0%, respectively over the control. The beneficial effect of bacterial inoculation is a result of many components that work synergistically at different concentrations.

3.1.3. Effect of the interaction

The results shown in Table 1 indicate that the vegetative growth characteristics were positively affected by the interaction of the N/P levels and bio-inculcation with bacterial strains in liquid or alginate capsulizes forms and this led to a positive interaction and significant differences between the treatments.

As for 100% N/P, many significant increases in all vegetative growth traits were observed in both seasons compared to corresponding control treatment of 100% recommended N/P.

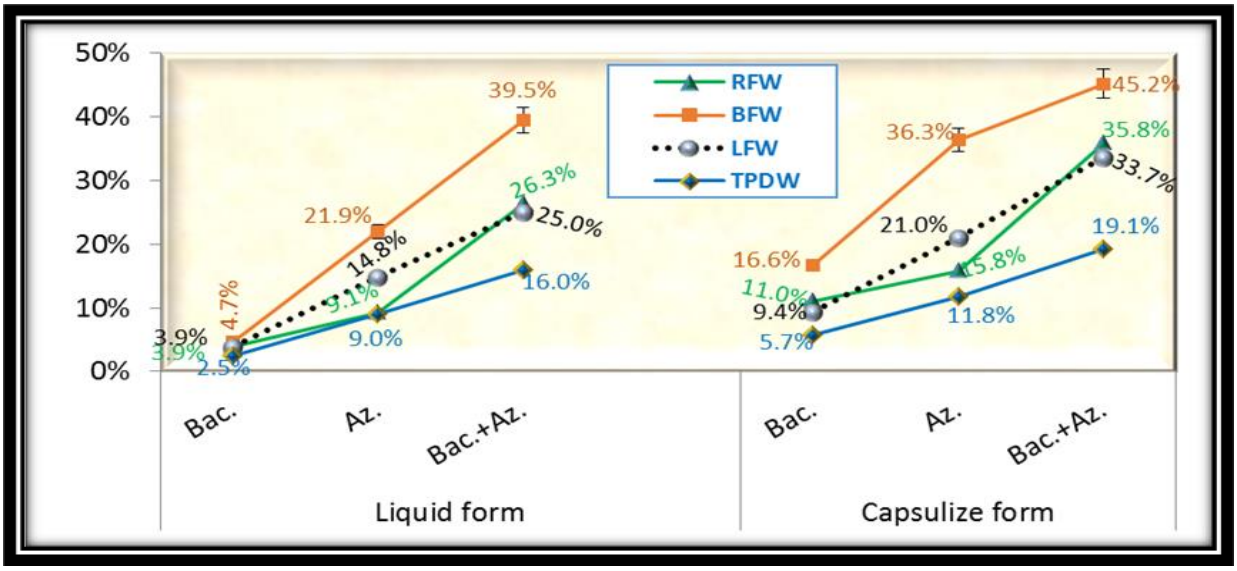


Figure 3. Changes % of vegetative growth characters of tomato plants over the control as affected by bacterial treatments in average of both seasons.
"Where Azotobacter chroococcum (Az.) and Bacillus subtilis (Bac.) are used, inoculation is carried out in two forms: liquid (L) and capsules (Caps)."

Table 1. Vegetative growth characters of tomato plants as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons.

		RFW		BFW		LFW		TPDW	
		S1	S2	S1	S2	S1	S2	S1	S2
100% N/P	Control	31.31^{c-h}	32.17^{b-d}	131.25^{bc}	140.53^{b-e}	335.40^{d-h}	385.86^{d-g}	134.31^{d-f}	138.70^{a-d}
	Bac. L	32.88^{c-f}	34.03^{bc}	133.36^{bc}	144.24^{a-d}	366.76^{c-f}	397.18^{d-f}	138.22^{c-e}	143.02^{a-d}
	Bac. Caps.	33.19^{c-e}	34.68^{bc}	152.73^{a-c}	154.55^{a-c}	379.50^{b-e}	424.39^{c-e}	140.15^{b-d}	149.20^{a-c}
	Azo. L	34.25^{cd}	35.51^{bc}	156.62^{ab}	162.40^{a-c}	427.09^{b-d}	434.36^{b-d}	142.11^{bc}	154.19^{ab}
	Azo Caps.	34.71^{c}	38.87^{b}	164.76^{a}	174.63^{ab}	469.05^{a-c}	490.72^{a-c}	145.01^{b}	158.15^{ab}
	Bac.+Azo.(L)	41.13^{b}	46.37^{a}	169.72^{a}	175.91^{ab}	481.17^{ab}	514.36^{ab}	152.40^{a}	163.81^{a}
	Bac.+Azo..(Caps.)	48.04^{a}	50.04^{a}	170.30^{a}	179.38^{a}	538.50^{a}	543.89^{a}	155.14^{a}	166.23^{a}
75% N/P	Control	27.84^{g-j}	29.85^{c-f}	73.21^{e-g}	85.55^{g-i}	296.98^{e-h}	299.56^{g-k}	122.01^{h}	128.67^{b-f}
	Bac. L	28.34^{f-j}	30.27^{c-f}	73.81^{e-g}	97.17^{f-h}	300.33^{e-h}	315.79^{f-k}	124.09^{gh}	129.40^{b-f}
	Bac. Caps.	29.54^{e-i}	31.75^{b-d}	88.53^{f}	106.85^{e-g}	308.68^{e-h}	338.50^{e-j}	128.91^{fg}	131.01^{b-f}
	Azo. L	29.22^{e-j}	31.17^{b-e}	97.29^{de}	109.11^{d-g}	314.94^{e-h}	355.12^{d-i}	129.79^{fg}	136.96^{a-e}
	Azo Caps.	29.93^{d-i}	32.32^{b-d}	126.76^{bc}	129.91^{c-f}	317.08^{e-h}	353.26^{d-i}	130.53^{f}	138.70^{a-d}
	Bac.+Azo.(L)	31.45^{c-h}	32.82^{b-d}	123.42^{cd}	129.02^{c-f}	329.92^{d-h}	362.56^{d-h}	133.63^{ef}	140.48^{a-d}
	Bac.+Azo..(Caps.)	32.29^{c-g}	34.45^{bc}	128.14^{bc}	136.12^{c-e}	355.84^{d-g}	385.79^{d-g}	138.51^{c-e}	143.93^{a-d}
50% N/P	Control	21.63^{l}	22.54^{fg}	48.90^{g}	53.95^{i}	228.48^{h}	234.56^{k}	93.00^{k}	96.67^{gh}
	Bac. L	22.77^{kl}	23.51^{f-g}	51.26^{g}	58.41^{i}	233.90^{h}	235.79^{k}	96.97^{k}	99.40^{f-h}
	Bac. Caps.	26.04^{i-k}	28.33^{c-f}	56.60^{fg}	62.79^{hi}	238.37^{h}	258.50^{jk}	98.91^{j}	106.01^{e-h}
	Azo. L	24.76j^{-l}	25.52^{d-g}	61.84^{fg}	63.01^{hi}	242.61^{h}	271.11^{i-k}	103.55^{j}	111.30^{d-h}
	Azo Caps.	26.81^{h-k}	28.84^{c-f}	63.45^{fg}	67.71^{hi}	251.03^{gh}	274.50^{h-k}	110.53^{i}	114.80^{d-g}
	Bac.+Azo.(L)	27.92^{g-j}	29.12^{c-f}	69.62^{e-g}	76.24^{g-i}	258.32^{f-h}	279.21^{h-k}	117.87^{h}	119.20^{c-g}
	Bac.+Azo..(Caps.)	29.28^{e-j}	30.48^{g}	53.26^{g}	89.19^{g-i}	276.41^{e-h}	280.69^{h-k}	120.55^{h}	125.42^{b-f}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

Upon treatment of 75% N/P stressed plants with bacteria strains treatments, many insignificant decreasing or increases in all vegetative growth traits were observed compared to the control treatment of 100% recommended NP. Oppositely, under N/P stresses of 75 or 50%, It is clearly noted that all bacterial treatments combined with the two adding program (liquid or capsulize of alginate) gave statistically equivalent or increase values in all vegetative growth traits

compared to the corresponding control treatments (50 or 75% recommended N/P treatments), indicating the efficient role of the studied bacterial strains adding by both forms to promote vegetative plant organs.

Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K has significant maximum effects by (15.7% & 5.1%), (66.5% & -2.8%), (24.3% & 2.8%) and (12.7% & 3.5%) in average of both seasons for fresh weight of roots (RFW), branches (BFW) and leaves (LFW), as well as total plant dry weight (TPDW) compare to the untreated plants of 75% and 100% N/P, respectively (Fig.4) followed by the liquid form of bacterial mixed [(Bac.+Az.)-L.] plus 75% N/P with 100% K (Bac.+Az.)-L.

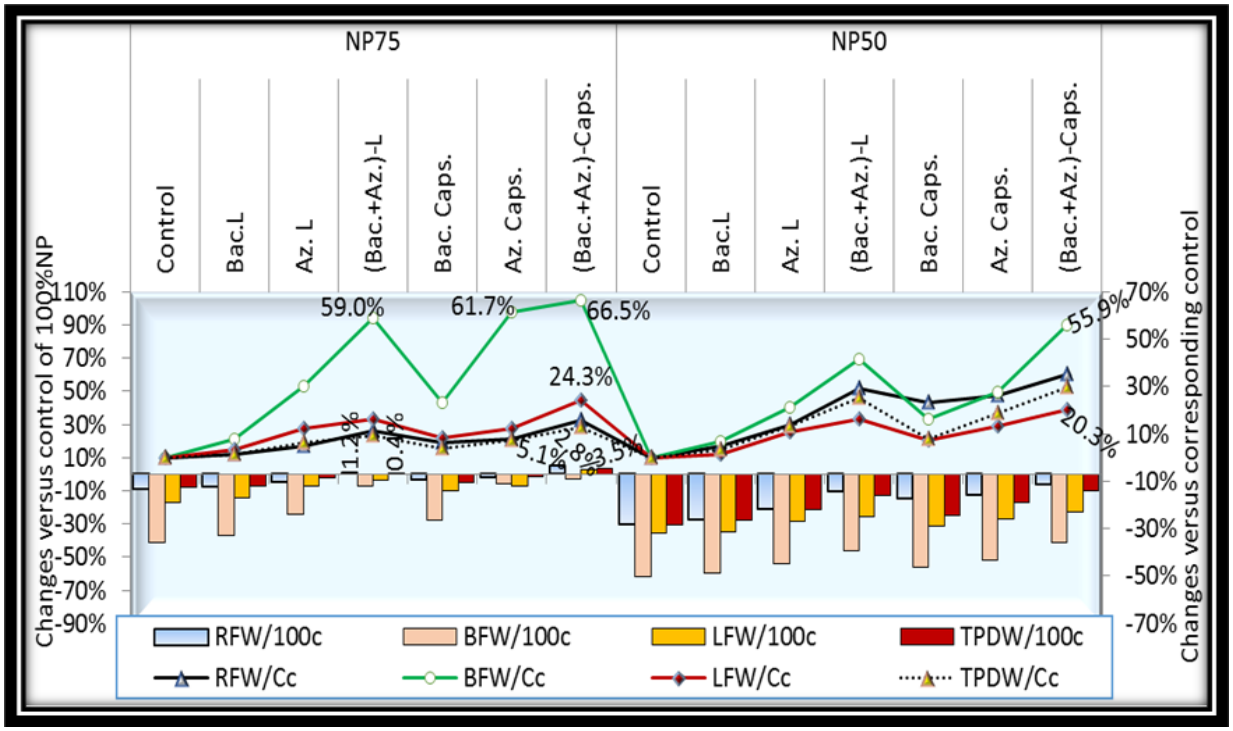


Figure 4. Changes % of Vegetative growth characters of tomato plants as affected by the interaction of N/P levels and bacterial treatments compared to the control treatment of 100% recommended N/P (100c) or to the corresponding control treatments (50 or 75% recommended N/P treatments, Cc) in average of both seasons.

Where: fresh weight for roots (RFW/100), branches (BFW/100), and leaves (LFW/100), along with the total plant dry weight (TPDW/100) denote comparisons of all treatments relative to the treatment receiving 100% of the recommended fertilization. Whereas fresh weight for roots (RFW/C), branches (BFW/C), and leaves (LFW/C), along with the total plant dry weight (TPDW/C) signify 75% and 50%, respectively, comparing all treatments with the control treatment, which receives 50% and 75% of the recommended mineral fertilization (corresponding to the control treatment).

3.2. Physical fruit and Yield traits

3.2.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 5 indicate that all N/P levels significantly affected all characteristics except AFW-B in both seasons. N/P positively affected the studied Physical fruit characteristics [Average fruit weight grade A (AFW-A), Average fruit weight grade B (AFW-B)] as well as total yield per fed. (TY), where 100% N/P recorded significantly the highest values for all traits followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between 100% N/P and 75% N/P in average fruit weight in both seasons.

Exposure of untreated plants (control) to low mineral applications of 50% N/P caused obvious inhibition of AFW-B, AFW-A and TY by 5.6%, 17.3% and 33.1%, while exposure to low mineral applications of 75% N/P caused inhibition of the same traits by 3.5%, 4.2% and 23.0% in descending order as an average of both seasons (Fig. 5).

3.2.2. Effect of bio-inculcation

The results presented in Fig. 6 show that the fruit and yield characteristics (AFW-A, AFW-B and TY) were strongly influenced by treating with some bio-inoculation treatments.

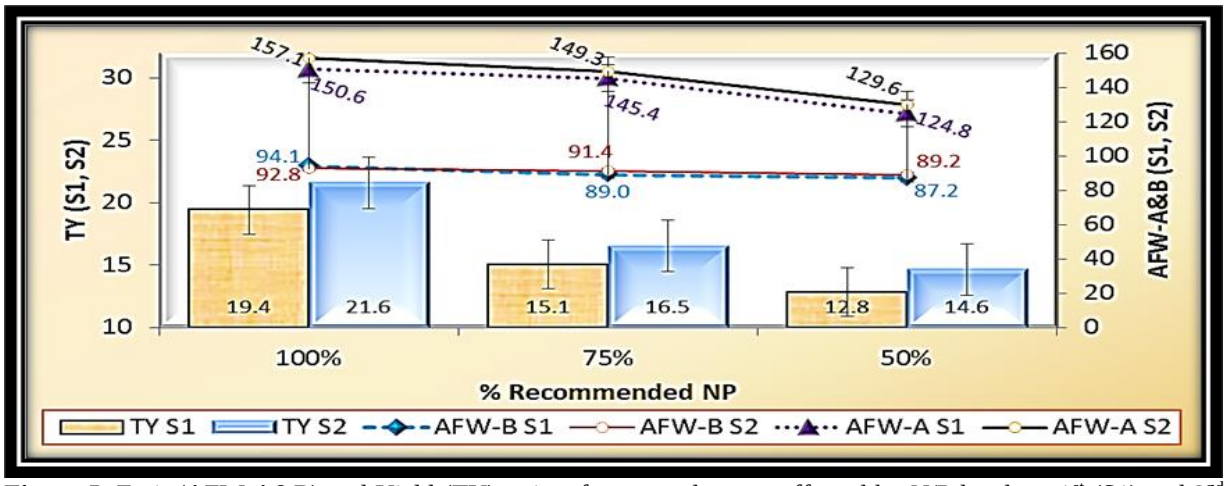


Figure 5. Fruit (AFW-A&B) and Yield (TY) traits of tomato plants as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

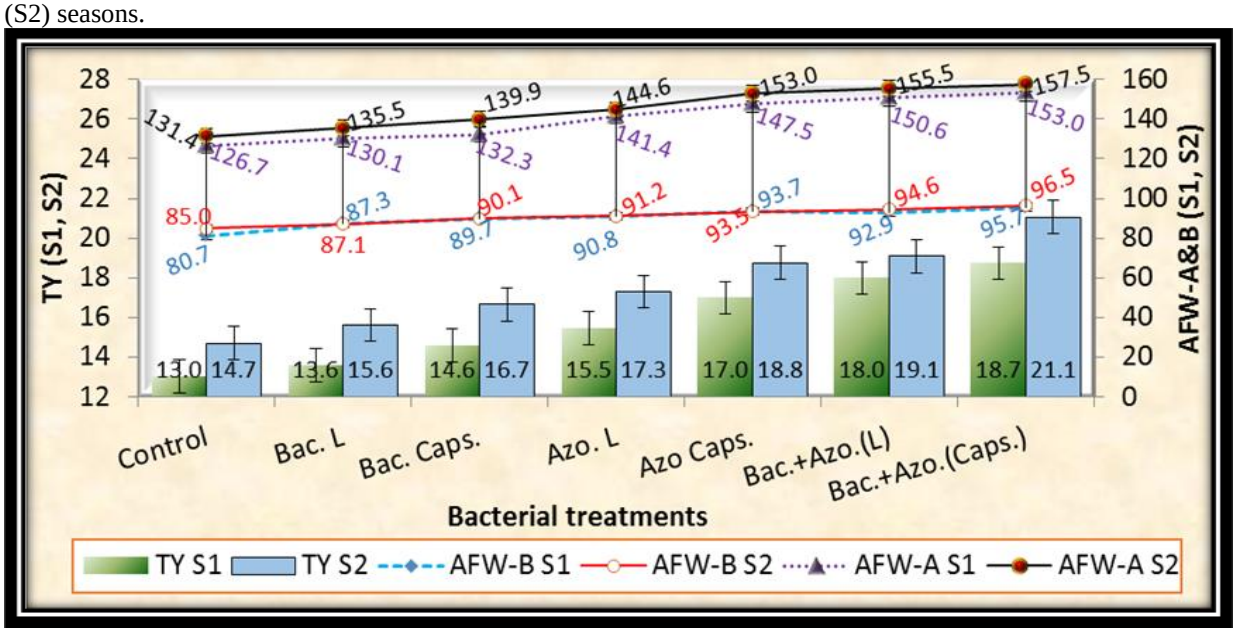


Figure 6. Fruit (AFW-A&B) and Yield (TY) traits of tomato plants as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Azo..(L) without alginate] and then the treatment of *Azotobacter*, alone encapsulated in calcium alginate (Azo Caps) in the three studied traits (AFW-A, AFW-B and TY) with no significant differences between them in the two seasons of study. Moreover, it was observed that

no significant differences between Bac. (Cap.), Azot. (Caps.) and Azot. (L.), while both the control (untreated treatment) and Bac. (L.) recorded the lowest values obtained for AFW-A, AFW-B and TY traits with no significant differences between them in the two study seasons. However, mixed treatment [(Bac.+Az.)/Caps] encapsulated in calcium alginate has significant maximum effects by 20.31%, 15.93% and 43.35% (Fig.7, in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 18.56%, 13.17% and 33.62% and *Azotobacter*, alone encapsulated in calcium alginate (Azo Caps), respectively for AFW-A, AFW-B and TY comparing to the control.

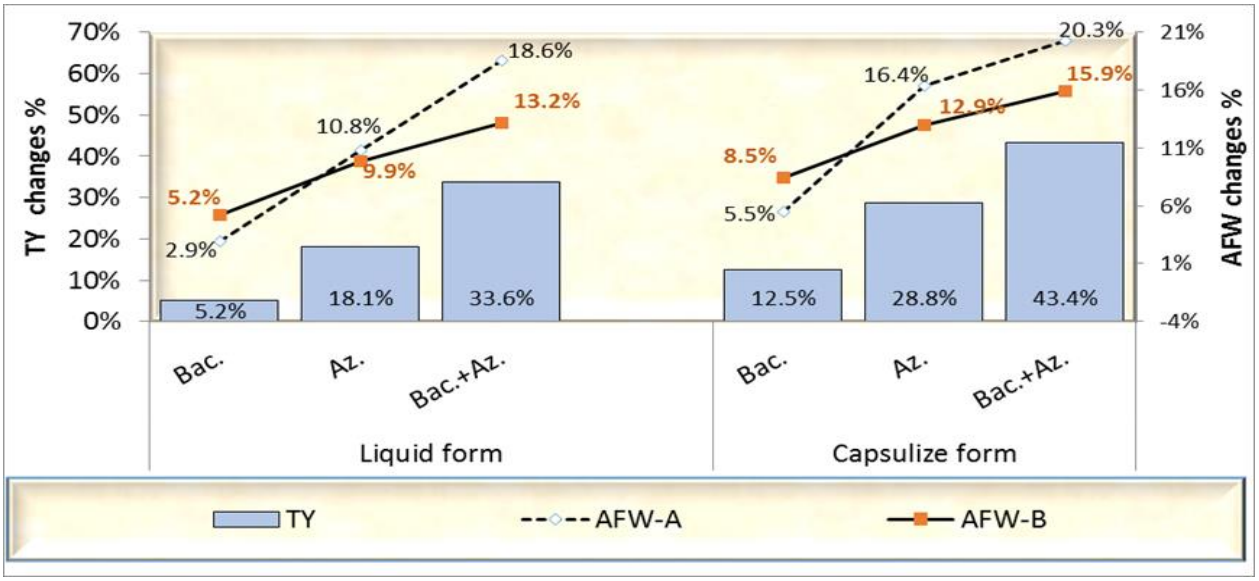


Figure 7. Changes % of Average fruit weight (AFW-A, AFW-B) and total yield (TY) as well as fruit quality (fruit firmness "Firm", dry matter" DM", vitamin C "V.C", and total soluble solids "TSS") of tomato plants over the control as affected by bacterial treatments in an average of both seasons.

3.2.3. Effect of the interaction

The results shown in Table 2 indicate that the average fruit weight in grade A (AFW-A) and grade B (AFW-B) as well as total yield (ton/fed.) traits of tomato were positively affected by the interaction of the N/P levels and *bio-inculcation* with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the treatments. As for 100% N/P, many significant increases in all fruit and yield traits were observed in both seasons compared to corresponding control treatment of 100% recommended NP.

Under N/P stresses of 75 or 50%, It is clearly noted that all bacterial treatments combined with the two adding program (liquide or capsulize of alginate) gave statistically equivalent or increase values in all the three fruit and yield traits compared to the control treatment of 100% recommended N/P and the corresponding control treatments (50 or 75% recommended N/P treatments) except Bac.L for AFW-A and both Bac.L and Caps. for TY compared to the control treatment of 100% recommended NP. These results indicated that the efficient role of the studied bacterial strains adding by both forms to promote these traits.

Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K has significant maximum effects by (15.1% & 19.8%), (11.1% & 20.4%) and (13.3% & 32.4%) in average of both seasons for average fruit weight grade A (AFW-A),

Table 2. Average fruit weight in grade A (AFW-A) and grade B (AFW-B) as well as total yield (ton/fed.) traits of tomato as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons

		AFW-A		AFW-B		TY	
		S1	S2	S1	S2	S1	S2
100% N/P	Control	134.20^{b-e}	141.63^{a-e}	87.09^{d-f}	86.35^{d-g}	15.09^{d-g}	17.05^{f-i}
	Bac. L	136.23^{b-e}	142.80^{a-e}	92.80^{a-d}	88.14^{b-g}	15.61^{d-f}	18.50^{d-g}
	Bac. Caps.	136.79^{b-e}	144.74^{a-e}	94.68^{a-c}	93.01^{a-e}	17.34^{cd}	20.60^{c-e}
	Azo. L	155.79^{a-c}	156.90^{a-e}	94.63^{a-c}	93.90^{a-c}	18.51^{c}	20.99^{cd}
	Azo Caps.	162.23^{ab}	169.01^{ab}	95.33^{ab}	95.38^{ab}	21.16^{b}	23.37^{bc}
	Bac.+Azo.(L)	162.70^{ab}	170.95^{ab}	96.54^{a}	95.98^{a}	23.72^{a}	24.26^{ab}
	Bac.+Azo..(Caps.)	166.04^{a}	173.93^{a}	97.61^{a}	96.98^{a}	24.63^{a}	26.51^{a}
75% N/P	Control	131.01^{c-e}	133.81^{b-e}	74.62^{g}	85.42^{fg}	13.15^{g-i}	14.36^{i-k}
	Bac. L	135.80^{b-e}	144.08^{a-e}	85.92^{d-f}	87.62^{c-g}	13.66^{f-h}	15.15^{h-k}
	Bac. Caps.	140.50^{a-e}	149.36^{a-e}	87.91^{c-e}	90.23^{a-g}	14.05^{f-h}	15.42^{h-k}
	Azo. L	142.45^{a-e}	146.45^{a-e}	90.71^{a-d}	92.50^{a-f}	15.06^{d-g}	16.20^{g-j}
	Azo Caps.	153.12^{a-d}	155.18^{a-e}	96.63^{a}	92.95^{a-e}	15.84^{d-f}	17.46^{f-i}
	Bac.+Azo.(L)	156.18^{a-c}	157.46^{a-d}	91.25^{a-d}	94.31^{a-c}	16.46^{c-e}	17.85^{e-h}
	Bac.+Azo..(Caps.)	158.74^{a-c}	158.64^{a-c}	96.25^{ab}	96.46^{a}	17.12^{cd}	19.30^{d-f}
50% N/P	Control	114.93e	118.87^{e}	80.47^{fg}	83.14^{g}	10.86^{j}	12.71^{k}
	Bac. L	118.40^{e}	119.57^{de}	83.04^{ef}	85.61^{e-g}	11.44^{i-j}	13.19^{jk}
	Bac. Caps.	119.68^{e}	125.56^{c-e}	86.42^{d-f}	86.92^{c-g}	12.35^{h-j}	13.93^{jk}
	Azo. L	126.07^{de}	130.51^{c-e}	87.04^{d-f}	87.32^{c-g}	12.85^{g-j}	14.68^{i-k}
	Azo Caps.	127.21^{de}	134.83^{b-e}	89.08^{b-e}	92.02^{a-f}	13.98^{f-h}	15.43^{h-k}
	Bac.+Azo.(L)	132.85^{c-e}	138.13^{a-e}	90.93^{a-d}	93.54^{a-d}	13.80^{f-h}	15.16^{h-k}
	Bac.+Azo..(Caps.)	134.31^{b-e}	140.01^{a-e}	93.10^{a-d}	95.90^{a}	14.41^{e-h}	17.37^{f-i}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

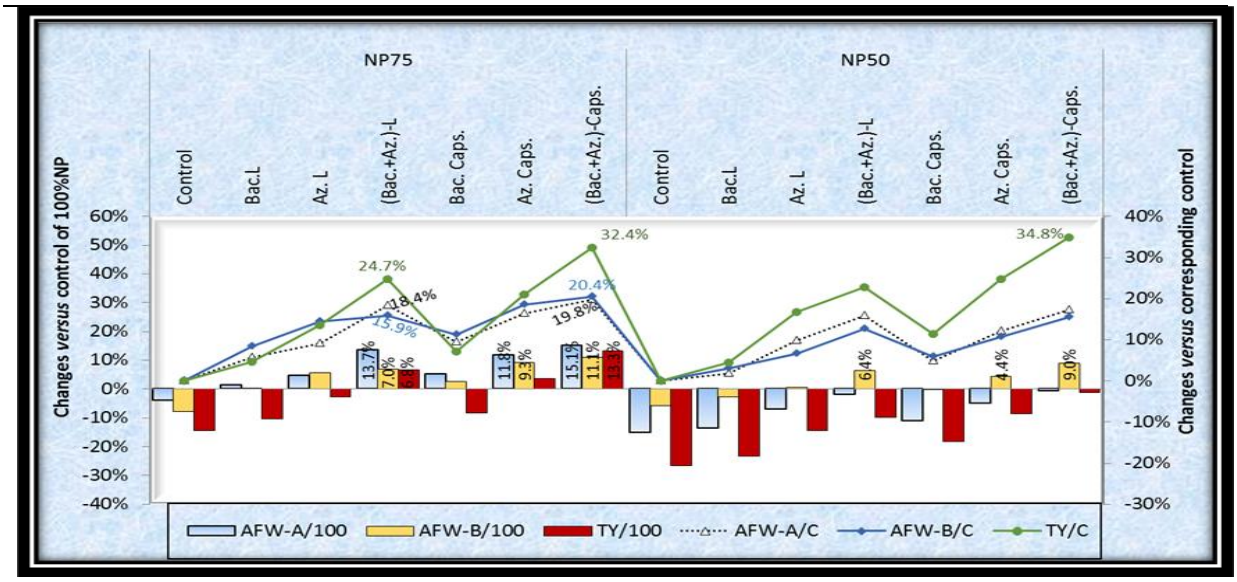


Figure 8. Changes % of average fruit weight (AFW-A, AFW-B) and total yield (TY) as affected by the interaction of N/P levels and bacterial treatments compared to the control treatment of 100% recommended N/P (100c) or to the corresponding control treatments (50 or 75% recommended N/P treatments, Cc) in average of both seasons.

Where: (AFW-A/100, AFW-B/100), and total yield (TY/100 denote comparisons of all treatments relative to the treatment receiving 100% of the recommended fertilization., while (AFW-A/C, AFW-B/C), and total yield (TY/C) signify 75% and 50%, respectively, comparing all treatments with the control treatment, which receives 50% and 75% of the recommended mineral fertilization (corresponding to the control treatment).

average fruit weight grade B (AFW-B) and total yield (TY) compare to the untreated plants of 100% and 75% N/P, respectively followed by the liquid form of bacterial mixed [(Bac.+Az.)-L.] plus 75% N/P with 100% K (Bac.+Az.)-L. for AFW-A and TY as well as Az.-Caps (*Azotobacter* alone encapsulated in calcium alginate) and both forms of bacterial mixed [(Bac.+Az.)-Caps. and -L] plus 50% N/P with 100% K in descending order for AFW-B with no significant effects on AFW-A or TY.

3.3. Chemical quality of fruit

3.3.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 9 indicate that all N/P levels had a significant effect on all characteristics except TSS in both seasons. N/P positively affected the studied chemical fruit characteristics [Firmness (Firm.), dry matter (DM %), vitamin C (VC) and TSS] as 100% N/P recorded significantly the highest values for all traits followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between them for TSS in both seasons.

Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of VC, TSS, Firm. and DM % by 11.55%, 12.79%, 15.67% and 24.46%, while exposure to low mineral applications of 75% N/P caused inhibition of the same traits by 5.24%, 5.77%, 9.83% and 13.31% in descending order as an average of both seasons (Fig. 9).

3.3.2. Effect of bio-inculcation

The results presented in Fig. 10 show that the chemical fruit characteristics (VC, TSS, Firm. and DM %) were strongly influenced by treating with some bio-inoculation treatments.

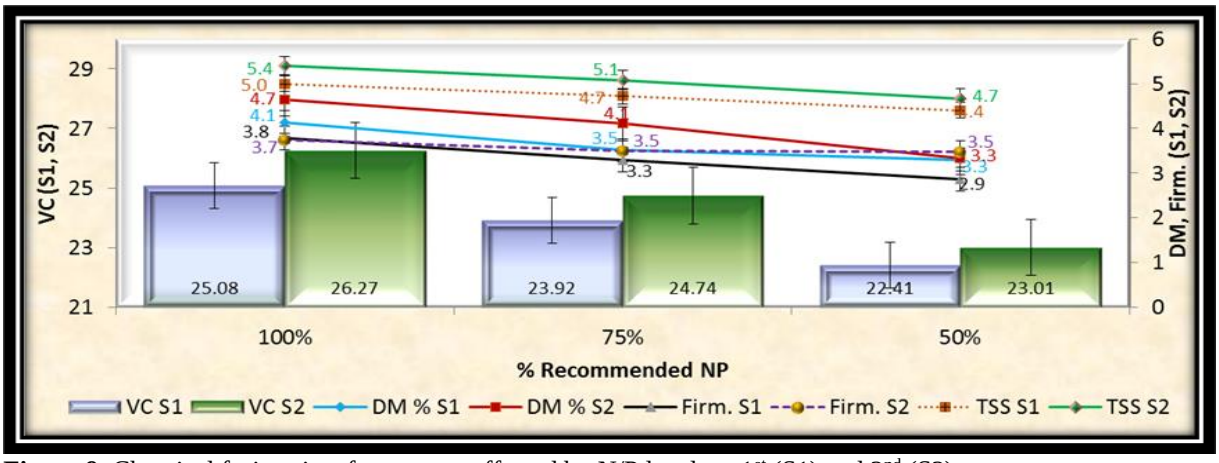


Figure 9. Chemical fruit traits of tomato as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

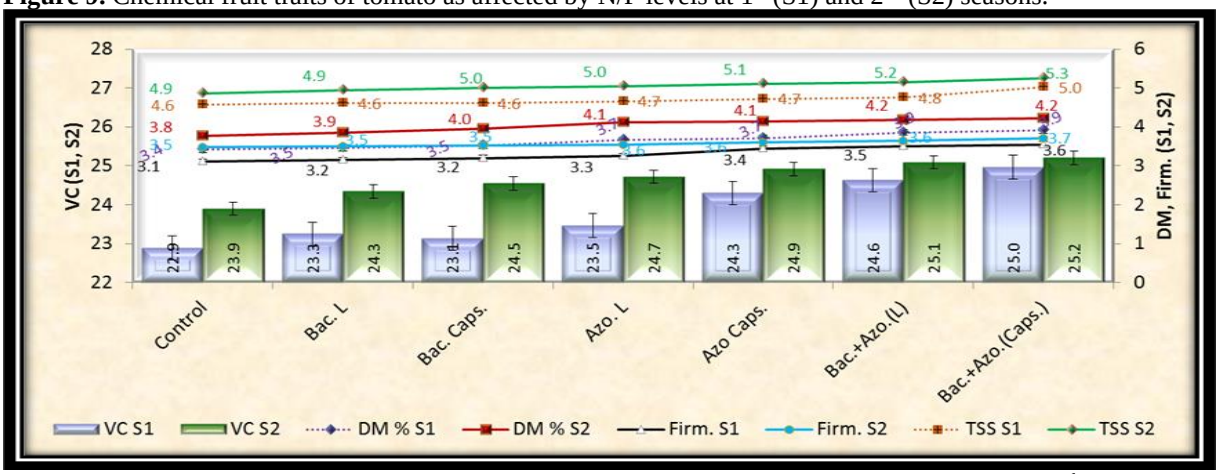


Figure 10. Fruit and Yield traits of tomato plants as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Azo..(L) without alginate] and then the treatment of *Azotobacter*, alone encapsulated in calcium alginate (Azo Caps) in the studied traits (VC, TSS, Firm. and DM %) with no significant differences between them in the two seasons of study except Firmness in 1st season and TSS in both seasons in which alone encapsulated in calcium alginate (Azo Caps) and Mixed of [Bac+Azot. (L.)] treatments were not observed any significant differences. Moreover, it was observed that the control (untreated treatment) followed by Bac. (L.) recorded the lowest values obtained with no significant differences between them in the two study seasons. However, mixed treatment [(Bac.+Az.)/Caps] encapsulated in calcium alginate has significant maximum effects by 10.0%, 12.9%, 7.2% and 8.8% (abovementioned Fig.11, in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 8.2%, 11.7%, 6.3% and 4.9% and then *Azotobacter*, alone encapsulated in calcium alginate (Azo Caps), respectively for Firm., DM %, VC and TSS comparing to the control.

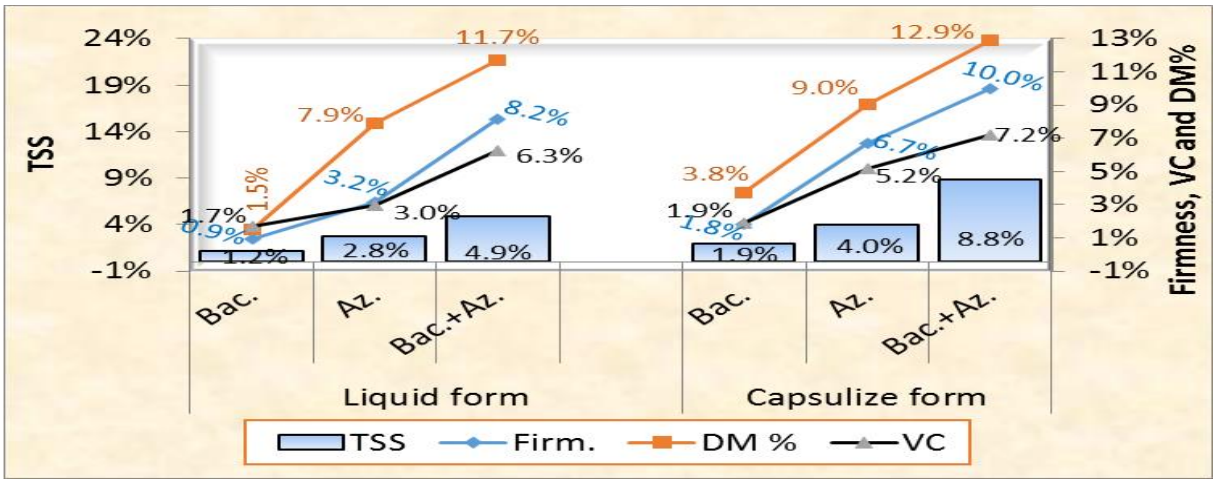


Figure 11. Change % of average fruit quality (fruit firmness "Firm", dry matter " DM", vitamin C "V.C" , and total soluble solids "TSS") of tomato plants over the control as affected by bacterial treatments in an average of both seasons.

3.3.3. Effect of the interaction

The results shown in Table 3 indicate that the Firmness (Firm.), dry matter (DM %), vitamin C (VC) and TSS traits of tomato were positively affected by the interaction of the N/P levels and *bio-inculcation* with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the treatments. As for 100% N/P, many significant increases in all chemical fruit traits were observed in both seasons compared to corresponding control treatment of 100% recommended NP. Under N/P stresses of 75 or 50%, It is clearly noted that all bacterial treatments combined with the two adding program (liquide or capsulize of alginate) gave statistically equivalent or increase values in all the four chemical fruit traits compared to the control treatment of 100% recommended N/P and the corresponding control treatments (50 or 75% recommended N/P treatments) except Bac. in liquid (L) or capsulize (Caps.) forms for DM trait under 75% N/P and for the four chemical fruit traits under 50% N/P compared to the control treatment of 100% recommended NP. These results indicated that the efficient role of the studied bacterial strains adding by both forms to promote these traits.

Table 3. Firmness (Firm.), dry matter (DM %), vitamin C (VC) and TSS traits of tomato as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons.

		Firm.		DM %		VC		TSS	
		S1	S2	S1	S2	S1	S2	S1	S2
100% N/P	Control	3.49^{c-e}	3.62^{bc}	3.70^{c-e}	4.46^{bc}	23.77^{e-g}	25.26^{b-e}	4.87^{a-e}	5.24^{a-e}
	Bac. L	3.57^{b-d}	3.66^{a-c}	3.74^{c-e}	4.47^{bc}	24.26^{d-f}	25.88^{a-d}	4.89^{a-d}	5.29^{a-d}
	Bac. Caps.	3.64^{bc}	3.67^{a-c}	3.85^{b-d}	4.54^{b}	24.36^{c-e}	26.24^{a-c}	4.89^{a-d}	5.29a^{-d}
	Azo. L	3.72^{b}	3.69^{a-c}	4.17^{a-c}	4.73^{a}	25.25^{b-d}	26.39^{b}	4.95^{a-c}	5.34^{a-d}
	Azo Caps.	3.95^{a}	3.73^{a-c}	4.27^{ab}	4.74^{a}	25.39^{a-c}	26.60^{a}	5.01^{ab}	5.46a^{-c}
	Bac.+Azo.(L)	4.03^{a}	3.82^{ab}	4.60^{a}	4.74^{a}	26.17^{ab}	26.62^{a}	5.05^{a}	5.56^{ab}
	Bac.+Azo..(Caps.)	4.13^{a}	3.98^{a}	4.65^{a}	4.84^{a}	26.38^{a}	26.92^{a}	5.34^{b-e}	5.66^{a}
75% N/P	Control	3.16^{g-i}	3.44^{c}	3.36^{de}	3.62^{g}	23.96^{g}	24.26^{e-i}	4.59^{b-e}	4.92^{a-d}
	Bac. L	3.17^{f-i}	3.45^{c}	3.41^{de}	3.81^{f}	23.85^{e-g}	24.53^{e-g}	4.67^{b-e}	5.00^{a-d}
	Bac. Caps.	3.23^{f-i}	3.45^{c}	3.43^{de}	4.00^{e}	23.20^{fg}	24.46^{e-h}	4.67^{b-e}	5.09^{a-d}
	Azo. L	3.30^{e-h}	3.51^{bc}	3.50^{de}	4.28^{d}	23.20^{fg}	24.68^{d-f}	4.70^{a-e}	5.09^{a-d}
	Azo Caps.	3.33^{e-g}	3.53^{bc}	3.52^{de}	4.30^{d}	24.43^{c-e}	24.88^{d-f}	4.77^{a-e}	5.11^{a-d}
	Bac.+Azo.(L)	3.37^{d-f}	3.55^{bc}	3.62^{de}	4.38^{cd}	24.63^{c-e}	25.31^{b-e}	4.79^{a-e}	5.14^{a-d}
	Bac.+Azo..(Caps.)	3.44^{c-e}	3.57^{bc}	3.70^{c-e}	4.40^{cd}	24.95^{cd}	25.03^{c-e}	4.86^{e}	5.22^{a-d}
50% N/P	Control	2.69^{j}	3.41^{c}	3.21^{e}	3.26^{i}	21.69^{h}	22.20^{k}	4.26^{e}	4.44^{e}
	Bac. L	2.71^{j}	3.41^{c}	3.24^{e}	3.26^{i}	21.65^{h}	22.61^{jh}	4.28^{e}	4.53^{de}
	Bac. Caps.	2.73^{j}	3.42^{c}	3.28^{e}	3.31^{hi}	21.85^{h}	22.91^{jk}	4.27^{de}	4.65^{c-e}
	Azo. L	2.76^{j}	3.44^{c}	3.31^{d-e}	3.32^{hi}	21.95^{h}	23.10^{i-k}	4.32^{c-e}	4.70^{c-e}
	Azo Caps.	3.04^{i}	3.53^{bc}	3.32d^{e}	3.37^{hi}	23.08^{g}	23.23^{h-k}	4.37^{c-e}	4.74^{b-e}
	Bac.+Azo.(L)	3.10^{hi}	3.55^{bc}	3.35d^{e}	3.41^{h}	23.10^{g}	23.33^{g-k}	4.40^{c-e}	4.75^{b-e}
	Bac.+Azo..(Caps.)	3.08^{i}	3.56^{bc}	3.38d^{e}	3.43^{h}	23.56^{e-g}	23.67^{f-j}	4.86^{b-e}	4.86^{a-e}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

As shown in Fig. 12 Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K (T7) has significant maximum effects by (6.2% & -1.4%), (16.1% & -0.7%), (3.7% & 1.2%), (6% & -0.3%) in average of both seasons for Firmness (Firm.), dry matter (DM %), vitamin C (VC) and TSS traits compare to the untreated plants of 75% and 100% N/P, respectively followed by the liquid form of bacterial mixed [(Bac.+Az.)-L.] plus 75% N/P with 100% K (T4). as well as Az.-Caps (*Azotobacter* alone encapsulated in calcium alginate, (T6) and both forms of bacterial mixed [(Bac.+Az.)-Caps. and -L] plus 50% N/P with 100% K (T14, T11) compare to corresponding controls in descending order.

3.4. Leaves elemental analysis:

3.4.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 13 indicate that N/P significantly affected nitrogen and phosphorus contents of leaves in the two seasons and 2nd one, respectively with no significant affected in K% in both seasons. 100% N/P recorded significantly the highest values followed by 75% N/P and 50% N/P, in descending order during the two study seasons.

Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of K, N and P % by 5.12%, 20.43% and 31.86%, while exposure to low mineral applications of 75% N/P caused inhibition of the same traits by 5.24%, 5.77%, 9.83% and 13.31% in descending order as an average of both seasons (Fig. 9).

3.4.2. Effect of bio-inculcation

The results presented in Fig. 14 show that the leaves elemental traits (N, P and K %) were strongly influenced by treating with some bio-inoculation treatments.

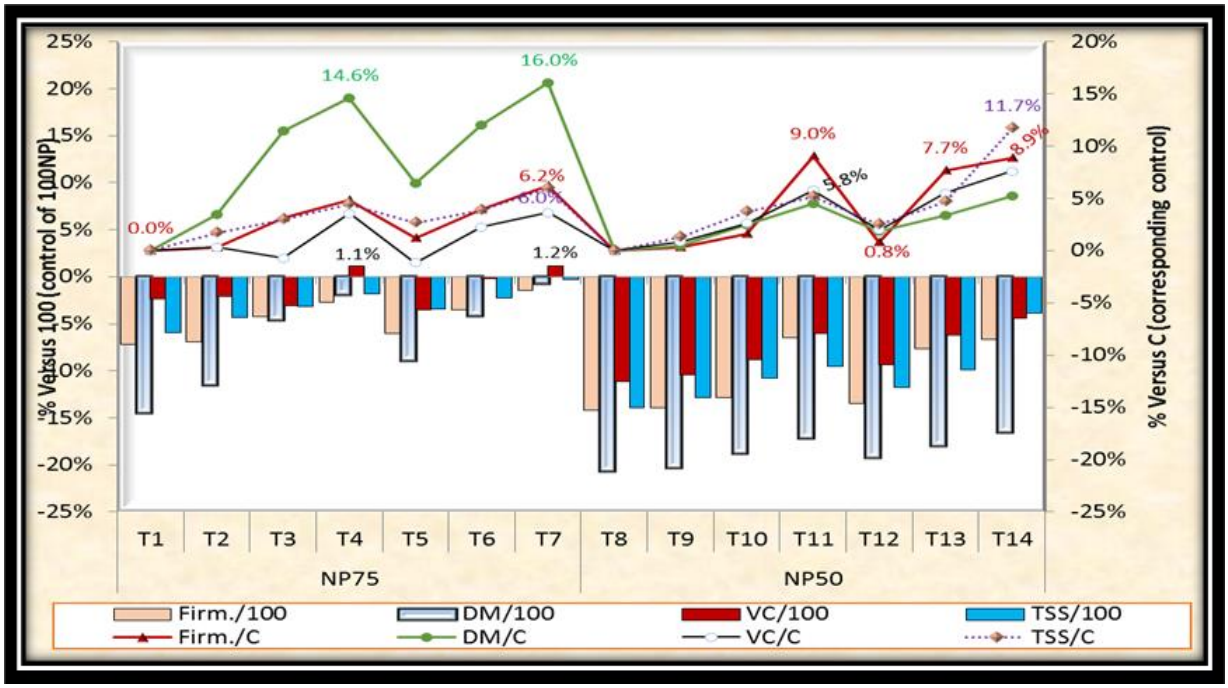


Figure 12. Changes % of fruit quality of tomato plants as affected by the interaction of N/P levels and bacterial treatments compared to the control treatment of 100% recommended N/P (100c) or to the corresponding control treatments (50 or 75% recommended N/P treatments, Cc) in average of both seasons.

Where: (fruit firmness "Firm/100", dry matter "DM/100", vitamin C "V.C/100", and total soluble solids "TSS/100") denote comparisons of all treatments relative to the treatment receiving 100% of the recommended fertilization. Whereas (fruit firmness "Firm/C", dry matter "DM/C", vitamin C "V.C/C", and total soluble solids "TSS/C") signify 75% and 50%, respectively, comparing all treatments with the control treatment, which receives 50% and 75% of the recommended mineral fertilization (corresponding to the control treatment).

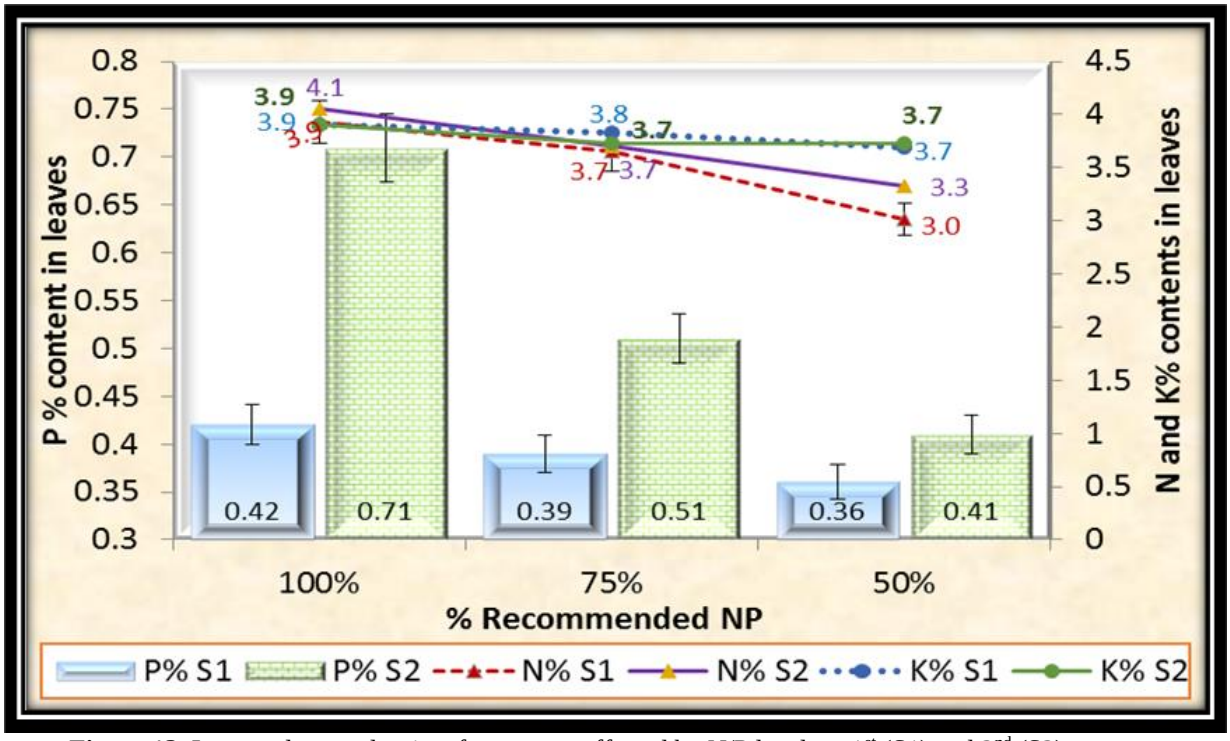


Figure 13. Leaves elemental traits of tomato as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

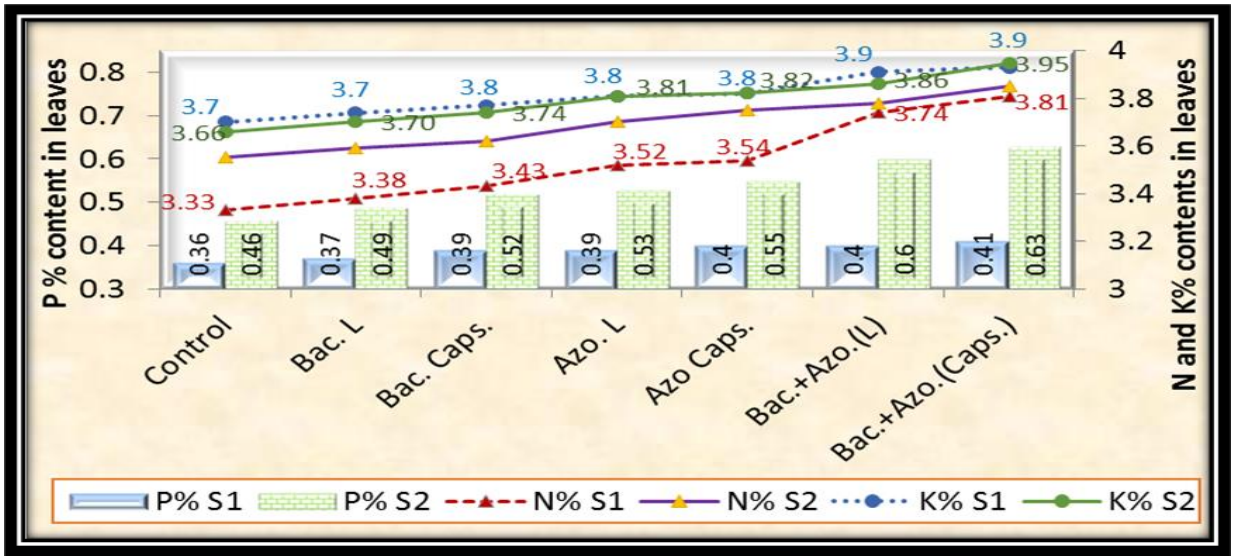


Figure 14. Leaves elemental traits of tomato plants as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Az.(L) without alginate] and then the treatment of *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in these traits with no significant differences between them for N and P in 2nd and 1st season, respectively. Moreover, it was observed that no significant differences between the two application forms of *Azotobacter* treatments (Azot. L or Caps.) in all elementals. The control (untreated treatment) followed by Bac. (L.) recorded the lowest values obtained with no significant differences between them in the two study seasons. However, mixed treatment [(Bac.+Az.)/Caps] encapsulated in calcium alginate has significant maximum effects by 11.3%, 26.8% and 7.1% (Fig.15, in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 9.3%, 22.0% and 5.6% and then *Azotobacter*, alone encapsulated in calcium alginate (Az.Caps), respectively for N%, P% and K% comparing to the control.

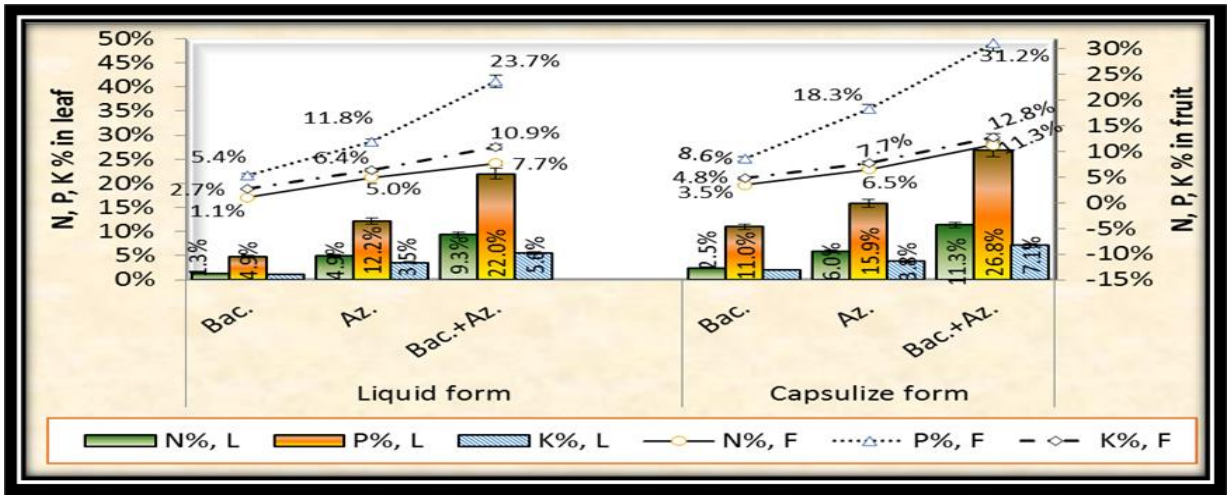


Figure 15. Changes % of Leaves and fruit elemental traits of tomato plants over the control as affected by bacterial treatments in an average of both seasons.

3.4.3. Effect of the interaction

The results shown in Table 4 indicate that the nitrogen (N%.), phosphorus (P%) and potassium (K%) of leaves elemental traits of tomato were positively affected by the interaction of the N/P levels and *bio-inculcation* with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the treatments. As for 100% N/P, many significant increases in all chemical fruit traits were observed in both seasons compared to corresponding control treatment of 100% recommended NP.

Under N/P stresses of 75%, it is clearly noted that mixed and signal *Azotobacter* bacterial treatments in liquid (L) or capsulize (Caps.) gave statistically equivalent values in all the leaves elemental traits compared to the control treatment of 100% recommended N/P and the corresponding control treatments of 50% recommended N/P treatments).

As shown in Fig. 16 Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K (T7) has maximum effects by (8.94% & -0.39%), (11.8% & -1.04%), (7.41% & 1.82%) in average of both seasons for N, P and K % traits compare to the untreated plants of 75% and 100% N/P, respectively.

Table 4. Leaves contents of nitrogen (N%.), phosphorus (P%) and potassium (K%) in tomato plants as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons.

		N%		P%		K%	
		S1	S2	S1	S2	S1	S2
100% N/P	Control	3.81^{a-e}	3.90^{c-e}	0.40^{b-d}	0.56^{ef}	3.83^{ef}	3.86^{b}
	Bac. L	3.82^{a-e}	3.95^{b-e}	0.40^{bc}	0.61^{de}	3.88^{c-e}	3.86^{b}
	Bac. Caps.	3.87^{a-e}	4.00^{b-d}	0.40^{b}	0.65^{cd}	3.92^{a-c}	3.85^{bc}
	Azo. L	3.92^{a-d}	4.06^{a-c}	0.41^{b}	0.69^{bc}	3.93^{a-c}	3.94^{a}
	Azo Caps.	3.97^{a-c}	4.11^{ab}	0.43^{a}	0.71^{b}	3.94^{a-c}	3.95^{a}
	Bac.+Azo.(L)	4.05^{ab}	4.11^{ab}	0.43^{a}	0.84^{a}	3.94^{ab}	3.96^{a}
	Bac.+Azo..(Caps.)	4.08^{a}	4.18^{a}	0.44^{a}	0.88^{a}	3.96^{a}	3.98^{a}
75% N/P	Control	3.47^{de}	3.58^{h-j}	0.39^{b-f}	0.46^{h-k}	3.74^{g}	3.55^{j}
	Bac. L	3.53^{c-e}	3.61^{g-j}	0.39^{b-f}	0.50^{g-j}	3.77^{fg}	3.61^{i}
	Bac. Caps.	3.61^{b-e}	3.64^{g-i}	0.39^{b-f}	0.50^{f-i}	3.79^{fg}	3.70^{fg}
	Azo. L	3.73^{a-e}	3.67^{g-i}	0.39^{b-f}	0.51^{f-h}	3.82^{ef}	3.77^{de}
	Azo Caps.	3.67^{a-e}	3.72^{f-h}	0.40^{b-e}	0.51^{f-h}	3.86^{de}	3.77^{de}
	Bac.+Azo.(L)	3.77^{a-e}	3.78^{e-g}	0.40^{b-e}	0.53^{fg}	3.90^{a-d}	3.80^{cd}
	Bac.+Azo..(Caps.)	3.80^{a-e}	3.88^{d-f}	0.40^{b-d}	0.55^{fg}	3.91^{a-d}	3.92^{a}
50% N/P	Control	2.72^{f}	3.17^{m}	0.29^{h}	0.35^{n}	3.52^{j}	3.57^{ij}
	Bac. L	2.79^{f}	$3.20l^{m}$	0.33^{g}	0.38^{mn}	3.57^{ij}	3.62^{hi}
	Bac. Caps.	2.82^{f}	$3.21l^{m}$	0.38^{ef}	0.40^{k-n}	3.60^{i}	3.67^{gh}
	Azo. L	2.90^{f}	$3.36k^{l}$	0.38^{ef}	0.40^{l-n}	3.66^{h}	3.73^{ef}
	Azo Caps.	2.99^{f}	3.41^{k}	0.38^{e-f}	0.42^{j-l}	3.68^{h}	3.75^{d-f}
	Bac.+Azo.(L)	3.41^{e}	3.45^{jk}	0.38^{e-f}	0.44^{j-l}	3.89^{b-d}	3.83^{bc}
	Bac.+Azo..(Caps.)	3.54^{c-e}	3.51^{i-k}	0.39^{b-f}	0.45^{i-l}	3.93a-c	3.95^{a}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

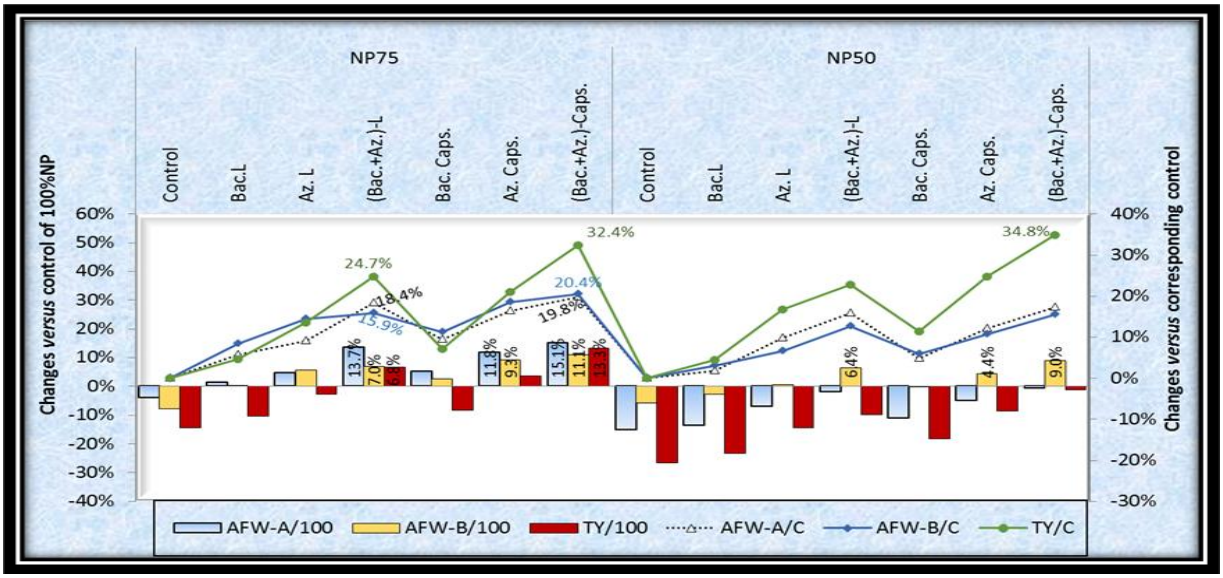


Figure 16. Elemental content of leaves (N, P, and K %) as affected by the interaction of N/P levels and bacterial treatments compared to the control treatment of 100% recommended N/P (100c) or to the corresponding control treatments (50 or 75% recommended N/P treatments, Cc) in average of both seasons.
Where: the elemental content of leaves (N/100, P/100/100, and K %) denote comparisons of all treatments relative to the treatment receiving 100% of the recommended fertilization. the elemental content of leaves (N/C, P/C, and K/C %) signify 75% and 50%, respectively, comparing all treatments with the control treatment, which receives 50% and 75% of the recommended mineral fertilization (corresponding to the control treatment).

3.5. Fruit elemental analysis

3.5.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 17 indicate that all N/P levels had a significant effect on all Fruit elemental characteristics. N/P positively affected the studied Fruit elemental characteristics [N%, P% and K%. 100% N/P recorded significantly the highest values for traits followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between 75% and 50% N/P in N% and P% in 1st (2022) and both seasons, respectively.

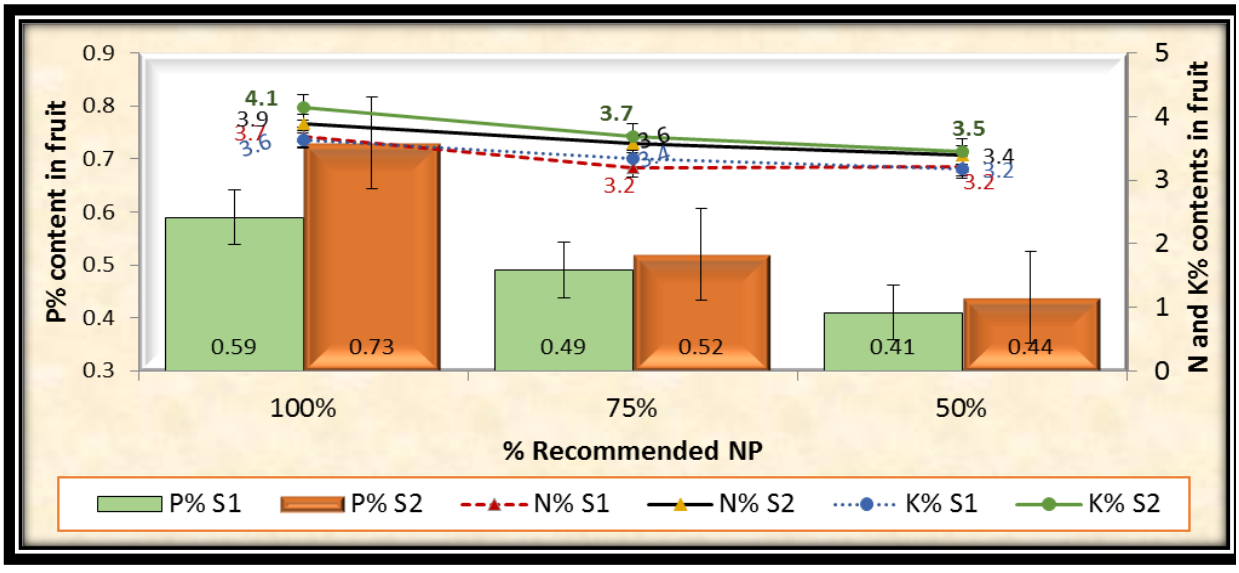


Figure 17. Fruit elemental traits of tomato as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of N, K and P % by 12.68%, 14.91% and 35.61%, while exposure to low mineral applications of 75% N/P caused inhibition of the same traits by 10.57%, 9.64% and 23.48% in descending order as an average of both seasons (Fig. 17).

3.5.2. Effect of bio-inculcation

The results presented in Table 5 and Fig. 18 show that the fruit elemental traits (N, P and K %) were strongly influenced by treating with some bio-inoculation treatments. Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Az.(L) without alginate] and then the treatment of Azotobacter, alone encapsulated in calcium alginate (Az. Caps) in these traits with no significant differences between them for P in 1st season. Moreover, it was observed that no significant differences between mixed treatment in liquid form [(Bac.+Az.(L) without alginate] and *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in all elementals in both seasons except n% in 1st season. The control (untreated treatment) followed by Bac. (L.) recorded the lowest values obtained with no significant differences between them in the two study seasons except P and K% in 1st season.

However, mixed [(Bac.+Az.)/Caps] encapsulated in calcium alginate treatment has significant maximum effects by 11.3%, 31.2% and 12.8% (abovementioned Fig.15, in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 7.7%, 23.7% and 10.9% and then *Azotobacter*, alone encapsulated in calcium alginate (Az.Caps), respectively for N%, P% and K% comparing to the control.

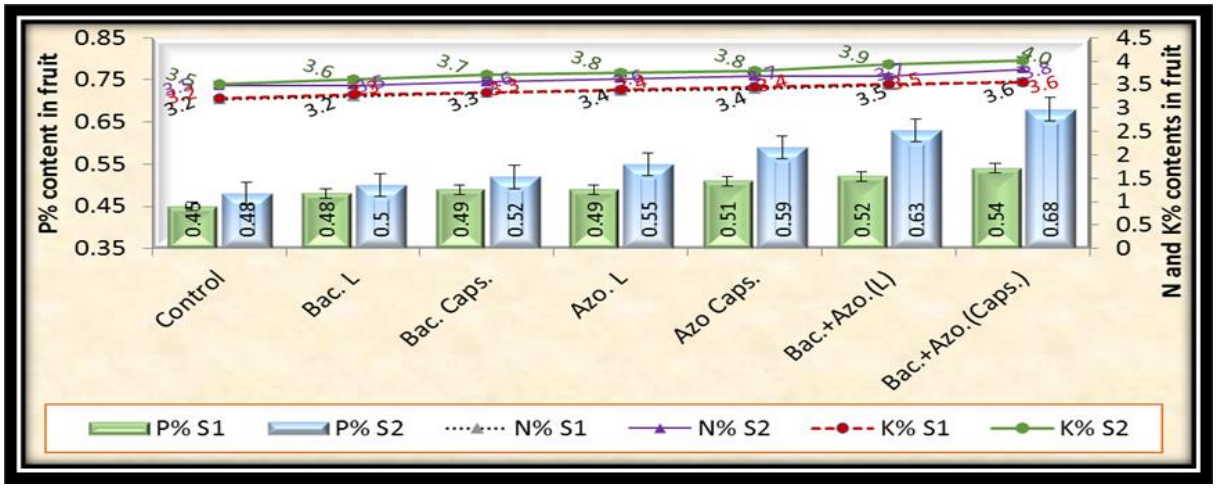


Figure 18. Fruit elemental traits (N, P, and K%) of tomato plants as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

Under N/P stresses of 75%, it is clearly noted that mixed treatments in the two forms and signal *Azotobacter* bacterial treatments in capsulize (Caps.) form gave statistically equivalent values in all the fruit elemental traits compared to the control treatment of 100% recommended N/P and showed significantly increases compared to the corresponding control treatments of 50% recommended N/P treatments). As shown in Fig. 19 Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K (T7) has maximum effects by (11.2% & -1.1%), (11.3% & 0.00%) and (6.8% & -0.9%) in average of both seasons for N, P and K % traits, respectively compare to the untreated plants of 75% and 100% N/P, respectively.

Table 5. Fruit contents of nitrogen (N%.), phosphorus (P%) and potassium (K%) in tomato plants as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons.

		N%		P%		K%	
		S1	S2	S1	S2	S1	S2
100% N/P	Control	3.44^{f}	3.81^{a-d}	0.51^{cd}	0.57^{e-g}	3.50^{c-f}	3.81^{d-f}
	Bac. L	3.56^{d}	3.81^{a-d}	0.56^{bc}	0.59^{e-f}	3.52^{c-f}	3.88^{de}
	Bac. Caps.	3.66^{c}	3.86^{a-c}	0.56^{bc}	0.61^{de}	3.55^{c-e}	4.01^{cd}
	Azo. L	3.72^{b}	3.89^{a-c}	0.58^{a-c}	0.69^{cd}	3.61^{cd}	4.12^{c}
	Azo Caps.	3.79^{a}	3.93^{ab}	0.60^{ab}	0.78^{bc}	3.65^{bc}	4.17^{bc}
	Bac.+Azo.(L)	3.77^{a}	3.94^{ab}	0.64^{ab}	0.86^{b}	3.78^{ab}	4.39^{ab}
	Bac.+Azo..(Caps.)	3.81^{a}	3.98^{a}	0.65^{a}	0.98^{a}	3.84^{a}	4.60^{a}
75% N/P	Control	3.05^{kl}	3.40^{hi}	0.48^{de}	0.49^{g-j}	3.25^{i-k}	3.53^{g-k}
	Bac. L	3.09^{k}	3.42^{g-i}	0.48^{de}	0.51^{f-j}	3.26^{h-k}	3.61^{f-j}
	Bac. Caps.	3.16^{j}	3.50^{f-h}	0.49^{c-e}	0.51^{e-j}	3.30^{g-k}	3.68^{e-i}
	Azo. L	3.16^{j}	3.59^{e-h}	0.49^{c-e}	0.52^{e-j}	3.36^{f-j}	3.69^{e-i}
	Azo Caps.	3.22^{i}	3.63^{d-f}	0.50^{c-e}	0.52^{e-j}	3.40^{e-j}	3.71^{f-h}
	Bac.+Azo.(L)	3.30^{h}	3.67^{d-f}	0.50^{c-e}	0.56^{e-h}	3.43^{e-h}	3.77^{d-g}
	Bac.+Azo..(Caps.)	3.39^{fg}	3.78^{b-d}	0.51^{cd}	0.57^{e-h}	3.46^{d-g}	3.78^{d-g}
50% N/P	Control	3.03^{l}	3.21^{j}	0.35^{g}	0.37^{k}	2.88^{m}	3.17^{l}
	Bac. L	3.06^{kl}	3.22^{j}	0.39^{fg}	0.42^{jk}	3.08^{l}	3.30^{kl}
	Bac. Caps.	3.16^{j}	3.28^{ij}	0.41^{e-g}	0.43^{i-k}	3.13^{kl}	3.40^{j-l}
	Azo. L	3.21^{ij}	3.37^{h-j}	0.41^{e-g}	0.44^{i-k}	3.20^{j-l}	3.45^{i-k}
	Azo Caps.	3.21^{ij}	3.44^{g-i}	0.42^{e-g}	0.46^{h-k}	3.27^{h-k}	3.49^{h-k}
	Bac.+Azo.(L)	3.36^{g}	3.45^{g-i}	0.42^{e-g}	0.46^{i-k}	3.31^{g-j}	3.64^{e-j}
	Bac.+Azo..(Caps.)	3.51^{e}	3.73^{c-e}	0.45^{d-f}	0.48^{g-j}	3.33^{g-j}	3.67^{e-i}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

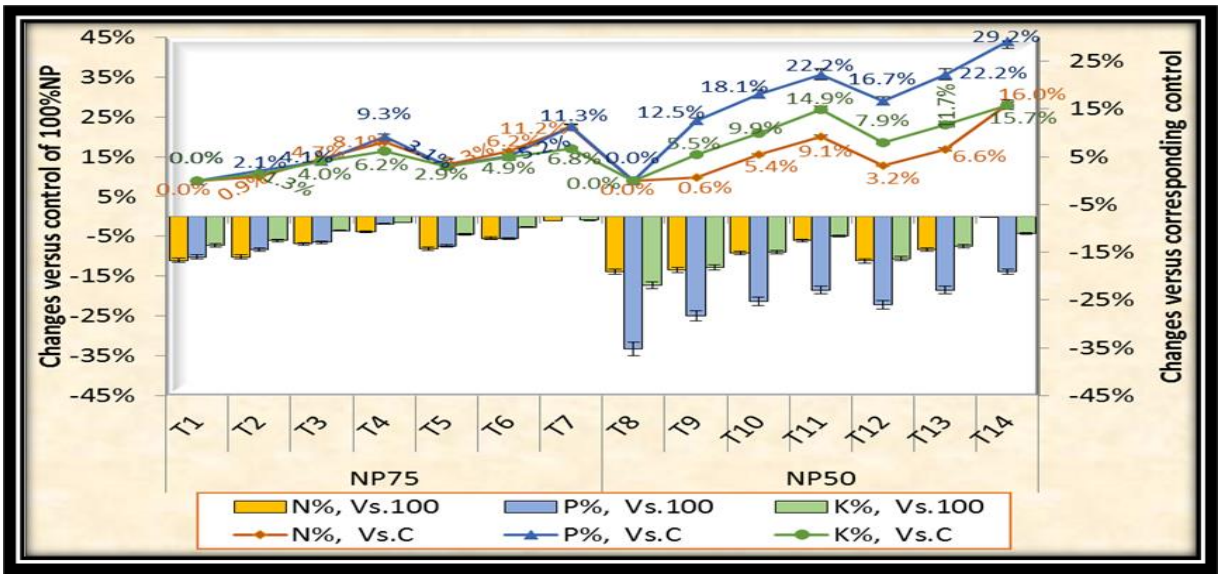


Figure 19. Elemental content of fruits (N, P, and K %) as affected by the interaction of N/P levels and bacterial treatments compared to the control treatment of 100% recommended N/P (100c) or to the corresponding control treatments (50 or 75% recommended N/P treatments, Cc) in average of both seasons.

Where: the elemental content of fruits (N/100, P/100/100, and K/100 %) denote comparisons of all treatments relative to the treatment receiving 100% of the recommended fertilization. the elemental content of fruits (N/C, P/C, and K/C %) signify 75% and 50%, respectively, comparing all treatments with the control treatment, which receives 50% and 75% of the recommended mineral fertilization (corresponding to the control treatment).

Moreover, T14 (Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 50% N/P with 100% K) has maximum effects by (16.0% & -0.1%), (29.2% & -13.9%) and (15.7% & -4.2%) in average of both seasons for N, P and K % traits, respectively compare to the untreated plants of 50% and 100% N/P, respectively.

3.6. Soil's microbial enzyme activities
3.6.1. Total Microbial Activity of soil
3.6.1.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 20 indicate that all N/P levels had a significant effect on Total Microbial Activity of soil (TMA) in all sampling times (t1, t2 and t3). 100% N/P recorded significantly the highest activities (µg Fluorescein/g soil) for TMA followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between 75% and 50% N/P in the third sampling time (t3) in both seasons.

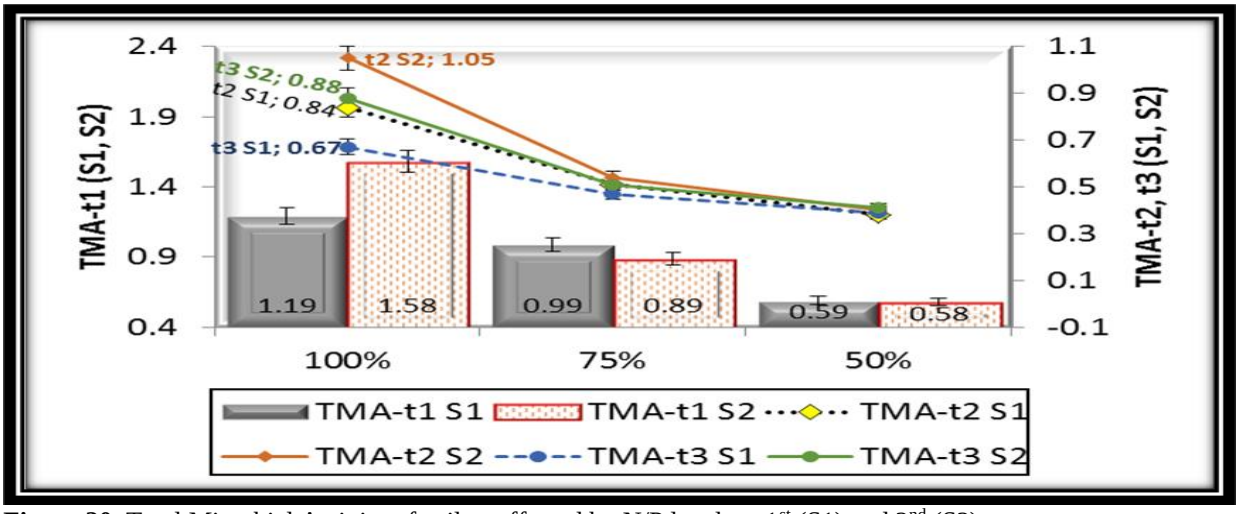


Figure 20. Total Microbial Activity of soil as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of TMA by 57.76% (t1), 58.73% (t2) and 48.39% (t3), while exposure to low mineral applications of 75% N/P caused inhibition by 32.13% (t1), 44.44% (t2) and 36.77% (t3) in average of both seasons (Fig. 20).

3.6.1.2. Effect of bio-inculcation

The results presented in Fig. 21 show that the Total Microbial Activity of soil at different times (t1, t2 and t3) were strongly influenced by treating with some bio-inoculation treatments. Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Az.(L)] and then the treatment of *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in the three TMA sampling times. However, it was observed that no significant differences between mixed treatment in liquid form [(Bac.+Az.(L)] and *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in all times in both seasons except t1 in 1st season. The control (untreated treatment) followed by Bac. (L.) recorded the lowest values obtained with no significant differences between them in the two study seasons except t1 in 2nd season.

However, mixed [(Bac.+Az.)/Caps] encapsulated in calcium alginate treatment has significant maximum effects by 97.1%, 55.0% and 38.95% (Fig.22), in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 64.3%, 40.0% and 28.4% and then *Azotobacter*, alone encapsulated in calcium alginate (Az.Caps), respectively for t1, t2 and t3 comparing to the control.

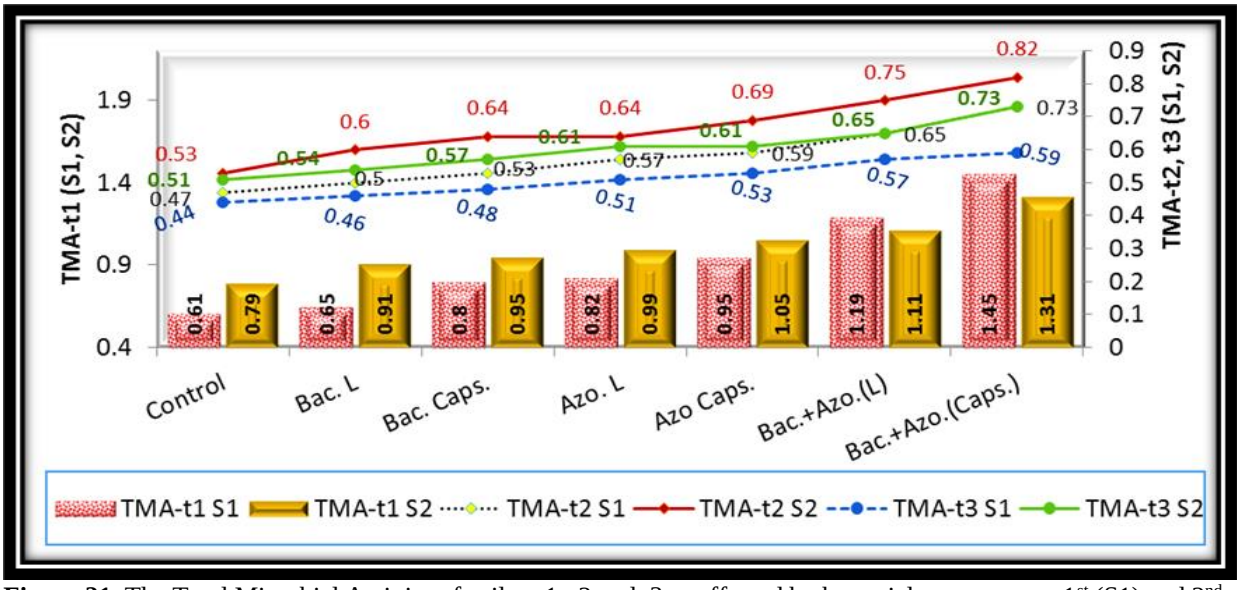


Figure 21. The Total Microbial Activity of soil at t1, t2 and t3 as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

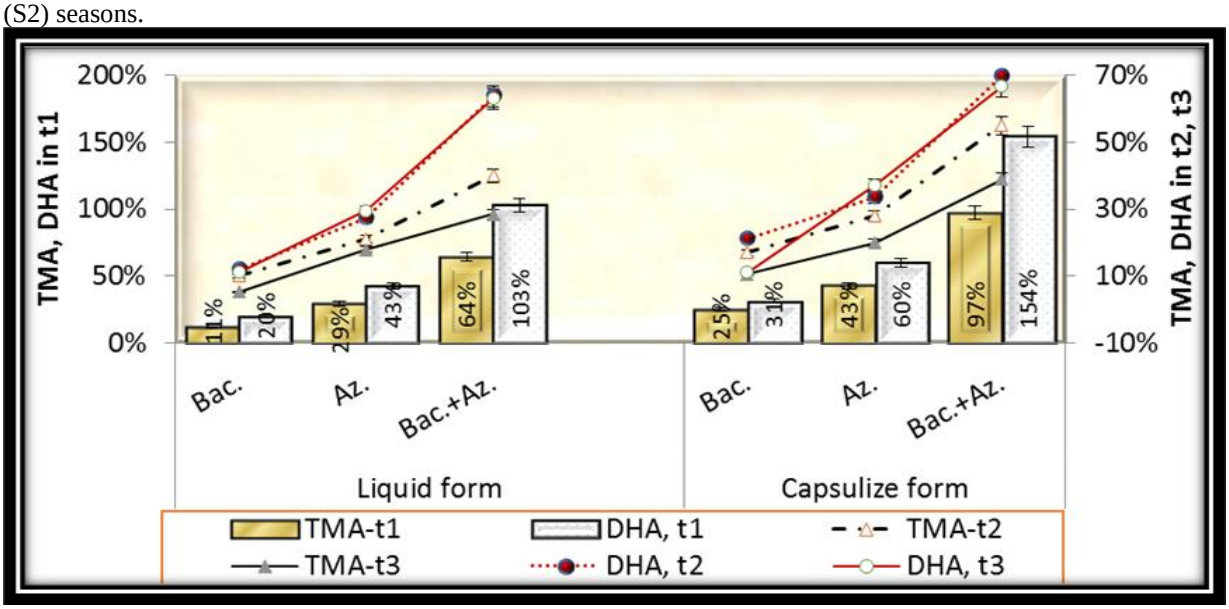


Figure 22. Changes percentage of Total Microbial (TMA) and dehydrogenase (DHA) Activities of soil in three different times (t1, t2, t3) as affected by bacterial treatments comparing to the corresponding control in average of both seasons.

2.6.1.3. Effect of the interaction

The results shown in Table 6 indicate that the TMA in soils of tomato plants were affected at t1, t2 and t3 by the interaction of the N/P levels and *bio-inculcation* with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the treatments in some cases under the recommended NPK.

As for 100% N/P, many significant increases in all sampling times were observed in both seasons compared to corresponding control treatment of 100% recommended NP.

Table 6. Total Microbial Activity (TMA) of soil in three different times (t1, t2, t3) as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons.

		TMA-t1		TMA-t2		TMA-t3	
		S1	S2	S1	S2	S1	S2
100% N/P	Control	0.81^{h-j}	1.13^{e}	0.64^{ef}	0.81^{e}	0.59^{d-f}	0.73^{d}
	Bac. L	0.84^{g-j}	1.42^{d}	0.69^{de}	0.97^{d}	0.60^{de}	0.81^{c}
	Bac. Caps.	1.05^{f}	1.51^{cd}	0.74^{d}	1.03^{cd}	0.62^{cd}	0.82^{c}
	Azo. L	1.08^{ef}	1.58^{bc}	0.82^{c}	1.03^{cd}	0.66^{cd}	0.91^{b}
	Azo Caps.	1.15^{e}	1.65^{b}	0.86^{c}	1.08^{c}	0.69^{bc}	0.91^{b}
	Bac.+Azo.(L)	1.46^{c}	1.68^{b}	0.96^{b}	1.17^{b}	0.75^{ab}	0.94^{b}
	Bac.+Azo..(Caps.)	1.96^{a}	2.07^{a}	1.17^{a}	1.28^{a}	0.80^{a}	1.06^{a}
75% N/P	Control	0.59^{l}	0.79^{hi}	0.42^{i-m}	0.44^{h-j}	0.43^{h-j}	0.45^{gh}
	Bac. L	0.70^{k}	0.81^{g-i}	0.46^{h-k}	0.47^{gh}	0.45^{g-j}	0.46^{gh}
	Bac. Caps.	0.89^{g-i}	0.85^{f-h}	0.48^{h-j}	0.52^{gh}	0.45^{g-j}	0.49^{fg}
	Azo. L	0.90^{gh}	0.86^{f-h}	0.50^{hi}	0.52^{gh}	0.47^{g-i}	0.49^{fg}
	Azo Caps.	0.92^{g}	0.91^{fg}	0.51^{gh}	0.54^{g}	0.48^{g-i}	0.50^{fg}
	Bac.+Azo.(L)	1.36^{d}	0.93^{f}	0.59^{fg}	0.62^{f}	0.52^{e-g}	0.55^{f}
	Bac.+Azo..(Caps.)	1.58^{b}	1.08^{e}	0.60^{f}	0.68^{f}	0.52^{f-h}	0.62^{e}
50% N/P	Control	0.42^{m}	0.46^{k}	0.34^{m}	0.33^{k}	0.30^{k}	0.33^{i}
	Bac. L	0.43^{m}	0.48^{k}	0.36^{lm}	0.34^{k}	0.33^{k}	0.34^{i}
	Bac. Caps.	0.45^{m}	0.50^{k}	0.36^{lm}	0.37^{jk}	0.37^{jk}	0.40^{hi}
	Azo. L	0.49^{m}	0.52^{jk}	0.38^{k-m}	0.38^{i-k}	0.41^{ij}	0.43^{gh}
	Azo Caps.	0.79^{i-k}	0.60^{j}	0.38^{k-m}	0.45^{g-i}	0.42^{ij}	0.44^{gh}
	Bac.+Azo.(L)	0.75^{jk}	0.72^{i}	0.40^{j-m}	0.46^{gh}	0.45^{g-j}	0.44^{gh}
	Bac.+Azo..(Caps.)	0.80^{h-j}	0.78^{hi}	0.43^{i-l}	0.49^{gh}	0.46^{g-i}	0.50^{fg}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

Under N/P stresses of 75%, it is clearly noted that mixed treatments in the capsulized (Caps.) form gave statistically equivalent values in all the three times compared to the control treatment of 100% recommended N/P and showed significantly increases compared to the corresponding control treatments of 75 or 50% recommended N/P treatments). As shown in Fig. 23 Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K (T7) has maximum effects by (92.8% & 37.1%), (48.8% & -11.7%) and (29.6% & -13.6%) in average of both seasons for t1, t2 and t3 % sampling times, respectively compare to the untreated plants of 75% and 100% N/P, respectively. Moreover, T14 (Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 50% N/P with 100% K) has maximum effects by (79.6% & -18.6%), (37.3% & -36.6%) and (52.4% & -27.3%) in average of both seasons for t1, t2 and t3 % sampling times, respectively compare to the untreated plants of 50% and 100% N/P, respectively.

3.6.2. Dehydrogenase activity in soil samples

3.6.2.1. Effect of N/P fertilizer levels

The results illustrated in Fig. 24 indicate that all N/P levels had a significant effect on dehydrogenase activity in soil samples (DHA) in all sampling times (t1, t2 and t3). 100% N/P recorded significantly the highest activities (µ mol of formazan / g soil) for DMA followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between 75% and 50% N/P in the third sampling time (t3) in both seasons.

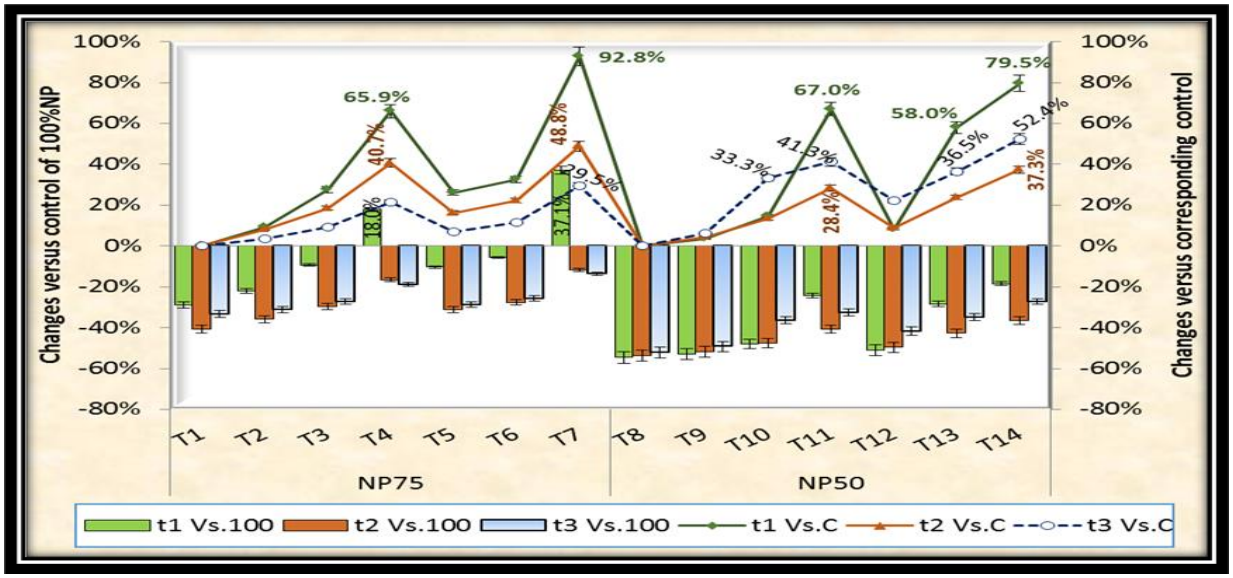


Figure 23. Changes percentage of Total Microbial Activity of soil in three different times (t1, t2, t3) as affected by the interaction of N/P levels and bacterial treatments versus the control treatment of 100% recommended N/P (*Vs.*100) or the corresponding control (*Vs.*C) of each N/P treatment at 1st (S1) and 2nd (S2) seasons.

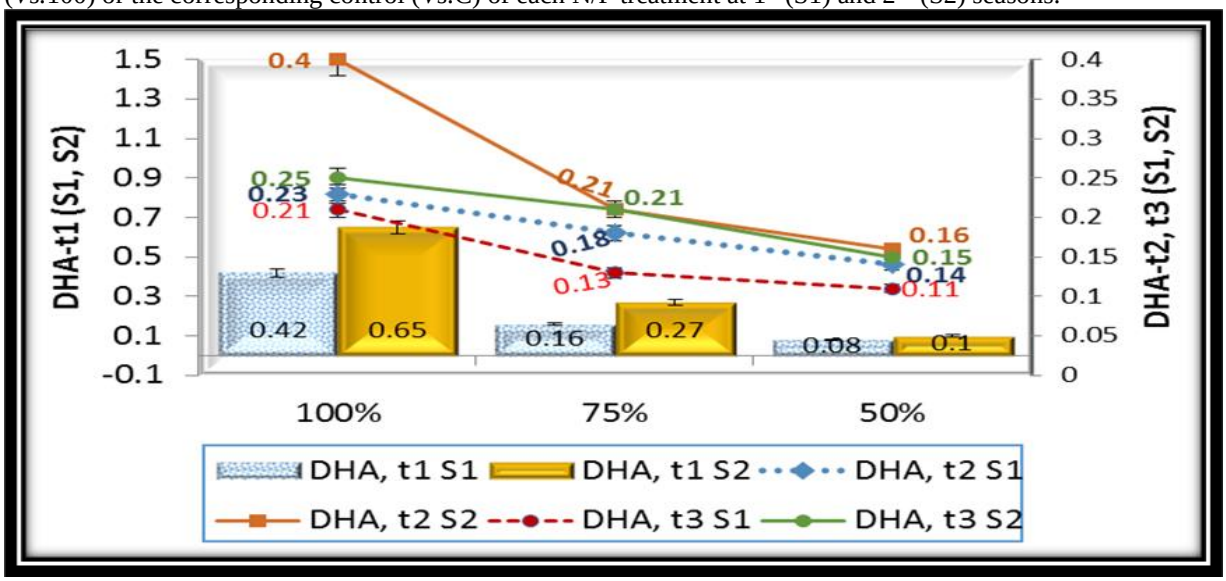


Figure 24. Dehydrogenase activity in soil samples as affected by N/P levels at 1st (S1) and 2nd (S2) seasons.

Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of DHA by 83.18% (t1), 52.38% (t2) and 43.48% (t3), while exposure to low mineral applications of 75% N/P caused inhibition by 59.81% (t1), 38.10% (t2) and 26.09% (t3) in average of both seasons (Fig. 24).

3.6.2.2. Effect of bio-inculcation

The results presented in Fig. 25 show that the Dehydrogenase activity in soil samples at different times (t1, t2 and t3) were strongly influenced by treating with some bio-inoculation treatments.

Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Az.(L)] and then the treatment of *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in the three TMA sampling times. However, it was observed that no significant differences between mixed treatment

in liquid form [(Bac.+Az.(L)] and *Azotobacter*, alone encapsulated in calcium alginate (Az. Caps) in all times in both seasons except t1 in 1st season. The control (untreated treatment) followed by Bac. (L.) recorded the lowest values obtained with no significant differences between them in the two study seasons except t1 in 2nd season. However, mixed [(Bac.+Az.)/Caps] encapsulated in calcium alginate treatment has significant maximum effects by 154.29%, 69.70% and 66.67% (abovementioned Fig.22), in average of both seasons) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form by 102.86%, 63.64% and 62.96% and then *Azotobacter*, alone encapsulated in calcium alginate (Az.Caps), respectively for t1, t2 and t3 comparing to the control.

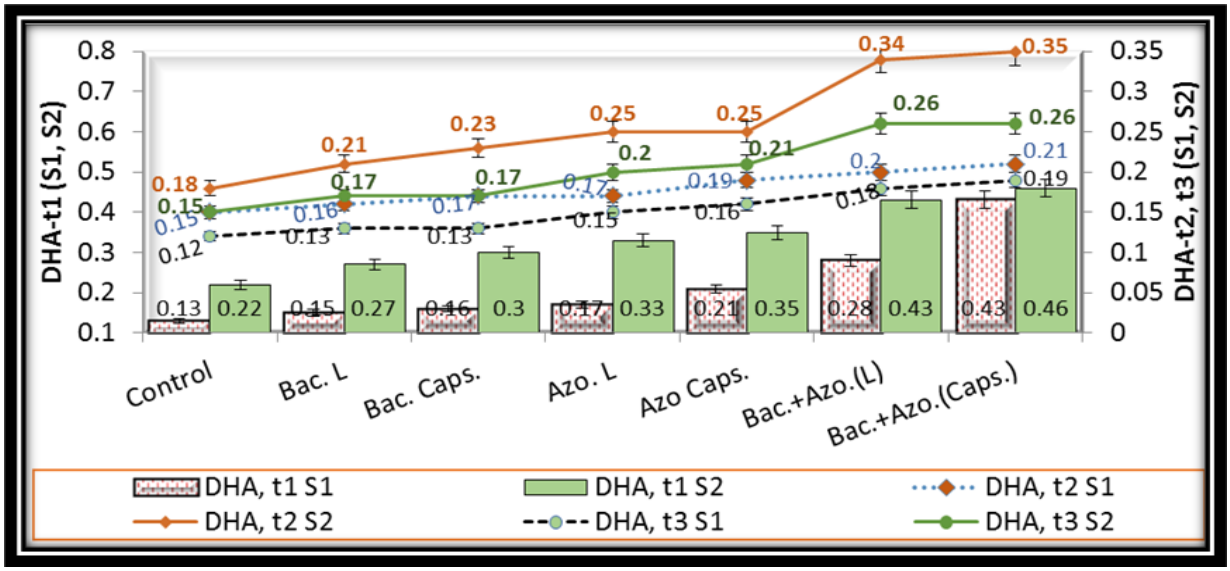


Figure 25. Dehydrogenase activity in soil samples at t1, t2 and t3 as affected by bacterial treatments at 1st (S1) and 2nd (S2) seasons.

3.6.2.3. Effect of the interaction

The results shown in Table 7 indicate that the DHA in soils of tomato plants were affected at t1, t2 and t3 by the interaction of the N/P levels and *bio-inculcation* with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the treatments in some cases under the recommended NPK.

As for 100% N/P, many significant increases in all sampling times were observed in both seasons compared to corresponding control treatment of 100% recommended NP.

Under N/P stresses of 75%, it is clearly noted that mixed treatments in the capsulized (Caps.) form gave statistically significant increase (t3) or equivalent (others) values in all the three times compared to the control treatment of 100% recommended N/P and showed significantly increases compared to the corresponding control treatments of 75 or 50% recommended N/P treatments). As shown in Fig. 26 Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K (T7) has maximum effects by (72.7% & -9.5%), (20% & -4.6%) and (64.3% & 48.4%) in average of both seasons for t1, t2 and t3 % sampling times, respectively compare to the untreated plants of 75% and 100% N/P, respectively. Moreover, T14 (Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 50% N/P with 100% K) has maximum effects by (136.4% & -58.7%), (63.6% & -18.2%) and (45% & -6.5%) in average of both seasons for t1, t2 and t3 % sampling times, respectively compare to the untreated plants of 50% and 100% N/P, respectively.

Table 7. Dehydrogenase activity (DHA) in soil samples in three different times (t1, t2, t3) as affected by the interaction of N/P levels and bacterial treatments at 1st (S1) and 2nd (S2) seasons

		DHA, t1		DHA, t2		DHA, t3	
		S1	S2	S1	S2	S1	S2
100% N/P	Control	0.23^{e-g}	0.40^{e}	0.20^{c-e}	0.24^{de}	$0.14d^{e}$	0.17^{c-e}
	Bac. L	0.26^{d-f}	0.52^{d}	0.20^{b-e}	0.26^{d}	0.17^{cd}	0.19^{b-d}
	Bac. Caps.	0.27^{de}	0.59^{c}	0.21^{b-e}	0.32^{c}	0.17^{cd}	0.21^{bc}
	Azo. L	0.29^{d}	0.65^{b}	0.22^{b-d}	0.38^{b}	0.21^{bc}	0.23^{b}
	Azo Caps.	0.37^{c}	0.66^{b}	0.24^{a-c}	0.38^{b}	0.24^{ab}	0.26^{a}
	Bac.+Azo.(L)	0.55^{b}	0.84^{a}	0.26^{ab}	0.60^{a}	0.26^{ab}	0.33^{a}
	Bac.+Azo..(Caps.)	0.96^{a}	0.89^{a}	0.28^{a}	0.63^{a}	0.29^{a}	0.33^{a}
75% N/P	Control	0.12^{j-m}	0.21^{h}	0.16^{d-h}	0.19^{e-h}	0.12^{de}	0.16^{c-e}
	Bac. L	0.13^{j-l}	0.22^{h}	0.16^{d-h}	0.21^{d-g}	0.12^{de}	0.17^{b-d}
	Bac. Caps.	0.14^{i-k}	0.23^{h}	0.17^{d-g}	0.21^{d-h}	0.12^{de}	0.17^{c-e}
	Azo. L	0.15^{h-k}	0.25^{gh}	0.18^{d-g}	0.21^{d-g}	0.13^{de}	0.20^{bc}
	Azo Caps.	0.17^{h-j}	0.27^{gh}	0.18^{c-f}	0.22^{d-f}	0.13^{de}	0.21^{bc}
	Bac.+Azo.(L)	0.19^{g-i}	0.31^{fg}	0.19^{c-e}	0.23^{de}	0.14^{de}	0.29^{a}
	Bac.+Azo..(Caps.)	0.21^{f-h}	0.36^{ef}	0.19^{c-e}	0.23^{de}	0.17^{cd}	0.29^{a}
50% N/P	Control	0.05^{o}	0.06^{k}	0.10^{h}	0.12^{i}	0.90^{e}	0.11^{e}
	Bac. L	0.06^{no}	0.07^{k}	0.12^{gh}	0.14^{hi}	0.10^{e}	0.13^{de}
	Bac. Caps.	0.06^{m-o}	0.07^{k}	0.12^{f-h}	0.15^{g-i}	0.10^{e}	0.13^{de}
	Azo. L	0.07^{l-o}	0.08^{jk}	0.13^{f-h}	0.15^{g-i}	0.10^{e}	0.15^{c-e}
	Azo Caps.	0.09^{k-o}	0.11^{i-k}	0.15^{e-h}	0.16^{f-i}	0.11^{de}	0.15^{c-e}
	Bac.+Azo.(L)	0.10^{k-o}	0.13^{ij}	0.16^{d-h}	0.18^{e-h}	0.12^{de}	0.17^{c-e}
	Bac.+Azo..(Caps.)	0.11^{j-n}	0.15^{i}	0.17^{d-g}	0.19^{e-h}	0.12^{de}	0.17^{c-e}

Values having the same alphabetical letter(s) did not significantly differ at 0.05 levels of significance, according to Duncan's multiple range test

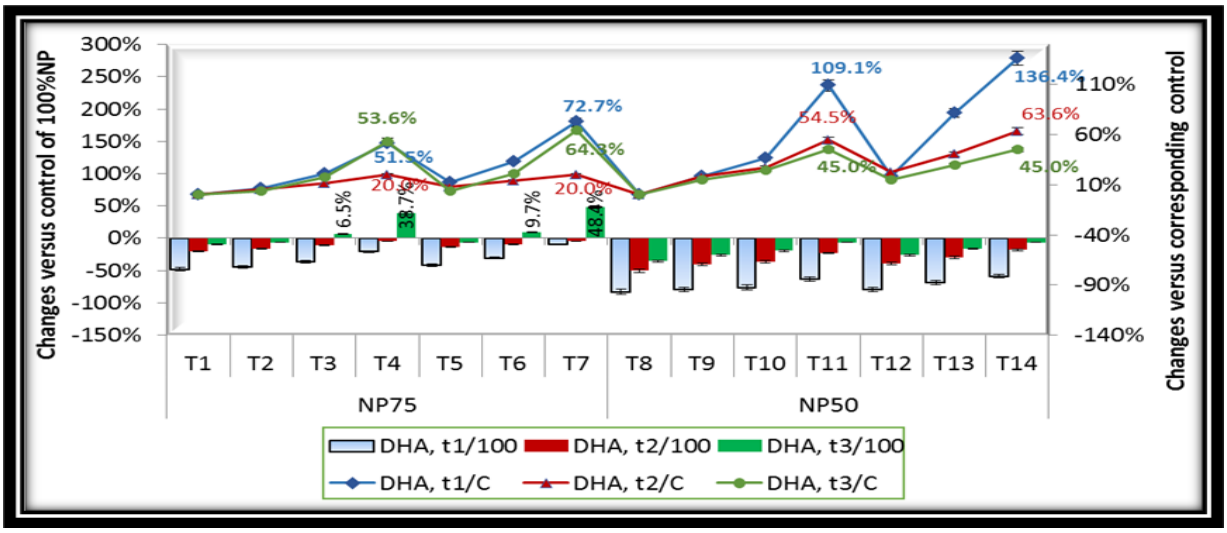


Figure 26. Changes percentage of Dehydrogenase activity in soil samples in three different times (t1, t2, t3) as affected by the interaction of N/P levels and bacterial treatments versus the control treatment of 100% recommended N/P (*Vs.*100) or the corresponding control (*Vs.*C) of each N/P treatment at 1st (S1) and 2nd (S2) seasons.

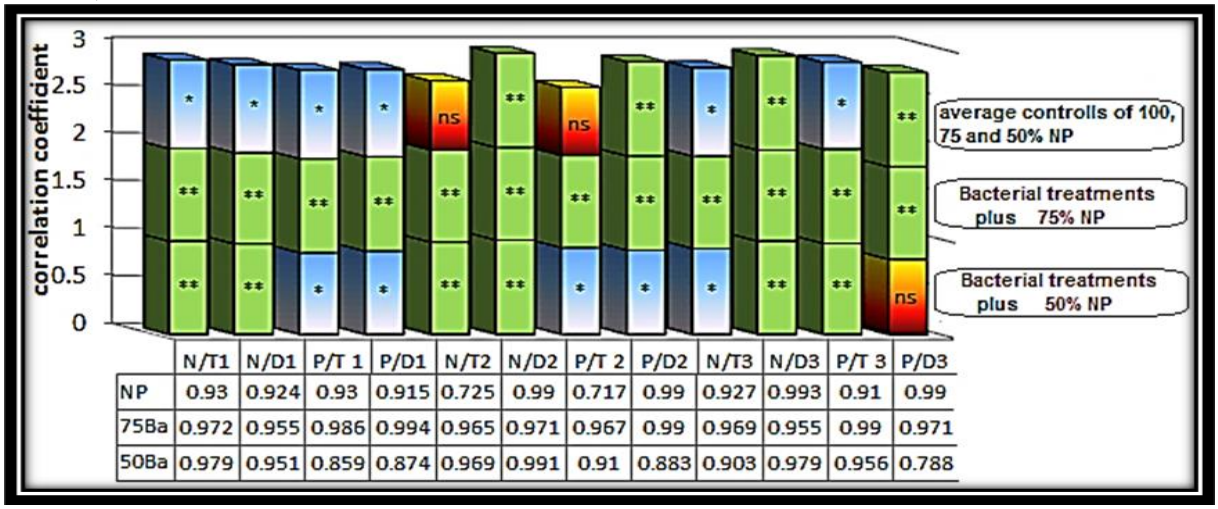
3.7. Relationships of N% and P% with TMA and DHA

Under N/P applications in Fig. 27 (without bacterial treatments), both N% and P% showed a

highly significant correlations ($P < 0.01$) with DHA2,3 (at 60 and 90 days) whereas only significant one ($P < 0.05$) at 30 days with DHA1 and TMA1 and at 90 days with TMA3. No significant correlations (ns) were observed related to TMA2 (at 60 days) with N or P%.

Upon treatment of 75% N/P stressed plants with bacteria strains treatments, there was a highly significant positive correlation between N% or P% with both TMA and DHA activities at the three sampling times ($p < 0.01$; Fig.28). As for 50% N/P treatments, adding the bacterial treatments changed the correlation pictures to significant ($P < 0.05$) or highly significant ($P < 0.01$) correlations between N% or P% with both TMA and DHA activities at the three sampling times ($P < 0.01$; fig. 28) except for P % with DHA3 (ns at 90 days) compared to N/P applications (no bacterial treatments).

On the other hand, the correlation between TMA and DHA, was highly significant at the first time (30 days), then the was absent at the last two times (60 and 90 days). Upon treatment of 75% and 50% N/P stressed plants with bacterial treatments, there was a highly significant positive correlation ($p < 0.01$; Fig.28) between TMA and DHA activities at the three sampling times except the third time of adding 50% N/P, in which the correlation was not significant.



	N/T1	N/D1	P/T 1	P/D1	N/T2	N/D2	P/T 2	P/D2	N/T3	N/D3	P/T 3	P/D3
NP	0.93	0.924	0.93	0.915	0.725	0.99	0.717	0.99	0.927	0.993	0.91	0.99
75Ba	0.972	0.955	0.986	0.994	0.965	0.971	0.967	0.99	0.969	0.955	0.99	0.971
50Ba	0.979	0.951	0.859	0.874	0.969	0.991	0.91	0.883	0.903	0.979	0.956	0.788

Figure 27. Relationships of N% or P% with total microbial (T1, T2 and T3) and dehydrogenase (D1, D2 and D3) activities at 30, 60 and 90 days under N/P applications (without bacterial treatments) as well as both 75% and 50% N/P stressed plants with bacteria strains treatments.

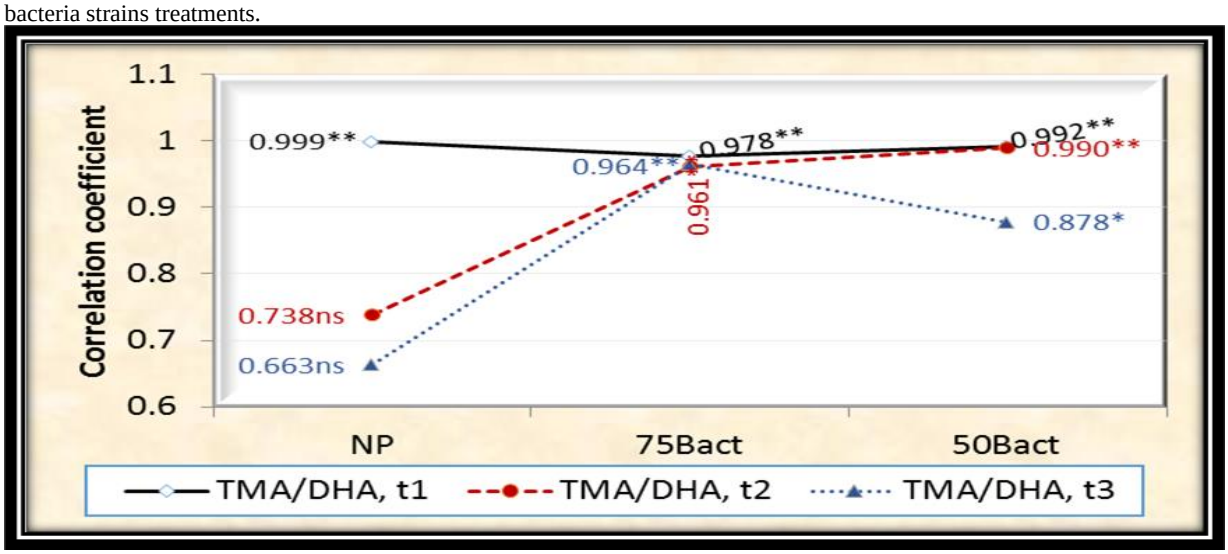


Figure 28. Relationships between total microbial (TMA) and dehydrogenase (DHA) activities at 30, 60 and 90 days under N/P applications (without bacterial treatments) as well as both 75% and 50% N/P stressed plants combined with bacterial treatments

4. Discussion

The results indicate that all N/P levels had a significant effect on all vegetative growth characteristics, AFW-A, TY, Chemical quality of fruit except TSS and Fruit elemental traits in both seasons. 100% N/P recorded significantly the highest values for all traits followed by 75% N/P and 50% N/P, in descending order during the two study seasons with no significant differences between 100% N/P and 75% N/P in total plant dry weight in 2nd (2023), average fruit weight, TSS (both seasons) N% in fruit (1st season) and P% in fruit (both seasons). Exposure of untreated plants (Control) to low mineral applications of 50% N/P caused obvious inhibition of Chemical quality of fruit (up to 24.46%), TY (33.1%), fruit elemental traits (up to 35.6) and vegetable growth (up to 59.6%) in descending order. On the other hand, exposure to low mineral applications of 75% N/P caused inhibition of the Chemical quality of fruit (up to 13.3%), TY (23.0%), fruit elemental traits (up to 23.5%) and vegetable growth (up to 31.92%) as an average of both seasons. In this regard, El-Tohamy *et al*. (2009), Abusetta (2020), Prado, (2021) and Magalhães *et al*., (2023) found that the growth of plants was negatively affected by the low chemical fertilization treatments, especially at 50% of N. Nutrient deficiencies are harmful to plants, as Nutrients act in different activities of plant metabolism, participating as integral elements of organic compounds (N) and in the acquisition and energy use and for the genome (P). Nutrient deficiencies are expressed in the morphological and productive characteristics of plants, causing significant damage (Prado, 2021). However, little is known about the symptoms and impacts of nutrient deficiency in peppercorns. Oppositely, the increase in plant growth by relatively high levels of nitrogen may be attributed to the beneficial effects of N on stimulating the meristematic activity, for producing more tissues and organs, and cell enlargement, since N plays major roles in the synthesis of structural proteins and other several macro-molecules, in addition to its vital contribution in several biochemical processes in the plant related to growth. P also plays a role in plant structure and is directly involved with energy transfer and storage (Aquino *et al*., 2019). Thus, P omission limits plant growth, reducing energy production and transport (Araújo *et al*., 2016).

The results of *bio-inculcation* effects in this work show that the vegetative growth characteristics (Fresh weight of branches, leaves and roots as well as the dry weight of total plant), physical fruit and yield characteristics (AFW-A, AFW-B and TY), chemical fruit characteristics (VC, TSS, Firm. and DM %) as well as leaves and fruit elemental traits (N, P and K %) were strongly influenced by treating with some bio-inoculation treatments. Mixed treatment of *Bacillus* and *Azotobacter* encapsulated in calcium alginate [(Bac.+Az.)/Caps] surpassed the other treatments followed by the same mixed treatment in liquid form [(Bac.+Azo..(L) without alginate] in all the studied traits during the two seasons of study with no significant differences between them in some traits. However, mixed treatment [(Bac.+Az.)/Caps] encapsulated in calcium alginate has significant maximum effects up to 45.2% (vegetative traits), 43.4% (TY), 31.2% (fruit elements) followed by the mixed treatment [(Bac.+Az.)/L] in liquid form up to 39.5% (vegetative traits), 33.62% (TY) and 23.7% (fruit elements) over the control. The beneficial effect of bacterial inoculation is a result of many components that work synergistically at different concentrations. These results are in agreement with those mentioned by Bacilio *et al*., (2017) and He *et al*. (2019). Additionally, applying bacteria in fertilizer may also significantly improve soil fertility and plant growth development (Muthusamy *et al*., 2023) by fixing nitrogen gas and releasing nutrients like iron, zinc, and Manganese as well as some phytohormones like auxins, cytokinins, and gibberellins—substances that may promote uptake and sufficient nutrients, thereby enhancing plant growth. PGPR's capacity to produce endospores, particularly *Bacillus* spp.,

makes it easier to create biofertilizer that is successful in various environmental situations (Francis *et al*., 2010; Perez-Garcia *et al*., 2011; Erturk *et al*., 2012).

The results of the interaction shown in Tables 3-9 indicate that all studied traits were affected by the interaction of the N/P levels and bio-inculcation with bacterial strains in liquid or alginate capsulize forms and this led to a positive interaction and significant differences between the most treatments. As for 100% N/P, many significant increases in most traits were observed in both seasons compared to corresponding control treatment of 100% recommended NP. Upon treatment of 100% N/P stressed plants with bacteria strains treatments, many insignificant decreasing or increases in all traits were observed compared to the control treatment of 100% recommended NP. Oppositely, under N/P stresses of 75 or 50%, it is clearly noted that all bacterial treatments combined with the two adding program (liquid or capsulize of alginate) gave statistically equivalent or increase values in most traits compared to the corresponding control treatments (50 or 75% recommended N/P treatments), indicating the efficient role of the studied bacterial strains adding by both forms to promote vegetative plant organs. Alginate capsulize of bacterial mixed [(Bac.+Az.)-Caps.] plus 75% N/P with 100% K has significant maximum effects up to 66.5% & 3.5% for vegetative traits, 32.4% & 15.1% (physical fruit and yield traits), 16.1% & 1.2% (chemical fruit traits), 11.8% & 1.8% (leaves N, P and K) and 11.3% & 0.0% (fruit N, P and K) compare to the untreated plants of 75% and 100% N/P, respectively followed by the liquid form of bacterial mixed [(Bac.+Az.)-L.] plus 75% N/P with 100% K (Bac.+Az.)-L. The beneficial effect of bacterial inoculation is a result of many components that work synergistically at different concentrations. These results are in agreement with those mentioned by Chiquito-Contreras *et al*. (2017) and Hernandez-Montiel *et al*. (2020). It is clearly noticed that all bio-fertilizer treatments applied along with 50% N/P gave statistically increase results as compared to the untreated plants of 50% recommended dose of N/P fertilizer, indicating the efficient role of the studied bacterial strains for substitution of nitrogen N/P up to 50% (Gholve *et al.*, 2004). The decline in the amount of nitrogen fertilization, without much reducing the trait leads to a lower cost of using nitrogen fertilizer and thus increases profit and also reduces pollution resulting from the use of nitrogen fertilizer (Abd El-Rheem *et al.*, 2015). Many investigators reported that applied Bacterial strains to tomato plant rhizosphere, which have ability to produce antifungal metabolites, phosphate solublization, HCN (Hydrocyanic Acid) and IAA (indole-3-acetic acid) as Omar *et al*. (2018). Moreover, using bacteria in fertilizer may be play a profound role in improving soil fertility and plant growth development via N2 fixation and releasing certain nutritive elements such Fe, Zn, and Mn, and some phytohormones such as gibberellins, auxins, and cytokinins- substances which may encourage up taking and sufficient nutrients, subsequently enhance plant growth. Additionally, with dual inoculation with biological nitrogen fixers in addition to the advised full dose of nitrogen fertilizer, there were enhanced levels of plant nitrogen, phosphate, and potash, leaf chlorophyll, and residually accessible soil nitrogen, phosphate, and potash (El-Komy, 2005).

The relationship that forms between N% or P% and both TMA and DHA activities, as well as between TMA and DHA activities themselves, were altered by the addition of bacterial treatments. These correlation coefficients show that N/P and soil microbial and enzyme activity are related, either directly or indirectly. Numerous investigations have demonstrated a relationship between changes in soil organic matter content across different terrestrial biological communities and soil enzyme activities (Debnath *et al*., 2015; Wang *et al*., 2016; Ngaba, Ma & Hu, 2020). This study found

that the application of biofertilizer significantly affected the activity of soil enzymes.

5. Conclusion

- The study had the chance to investigate possible applications for sodium alginate because it is inexpensive, renewable, environmentally benign, non-toxic, and naturally occurring. It found that there are numerous benefits to encasing microorganisms in alginate beads, specifically the free-living nitrogen fixer bacterium *Azotobacter chroococcum* and the phosphorous solubilizer bacterium *Bacillus subtilis*. It might contribute to the preservation of the physiological activity and, thus, a high rate of bacterial survival during storage. Furthermore, bacteria that are enclosed promote growth.
- The current study's findings support the hypothesis that sodium alginate gradually affects tomato plants' capacity to produce and withstand nitrogen deficit (50% & 75% N/P). According to the field testing, alginate combined (Bac.+Az.) bacterial treatment under 75% N/P resulted in an increase in productivity of about 13.32% (compared to 100% N/P control) and 32.4% (compared to 75% N/P control). Additionally, it was shown that additional alginate treatments and liquid forms improved productivity. In contrast, the treatments of Mix-Caps, Mix-L, and Az.Caps were determined to have the best overall results when nitrogen was deficient.
- It should be noted that while the experiment demonstrated a gradual influence on tomato plants, not all treatments yielded consistent outcomes. This discrepancy could be attributed to environmental or seasonal factors. The collective findings indicate that the encapsulation of bacteria into alginate beads holds significant promise for the development of a bio-inoculation technique that may be advantageous for sustainable agriculture.

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Institutional Review Board Statement
All Institutional Review Board Statements are confirmed and approved.
Data Availability Statement
Data presented in this study are available on fair request from the respective author.
Ethics Approval and Consent to Participate
Not applicable
Consent for Publication
Not applicable.
Conflicts of Interest
The authors disclosed no conflict of interest.

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