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Effectiveness of Improving Groundnut Productivity Using PGPR and Foliar Spraying with Some Micronutrients

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ABSTRACT

One of the main obstacles to the decline in groundnut production is related to micronutrient deficiency, the deficiency of which leads to significant disruption of various physiological and metabolic processes within the plant. This study aimed to investigate the response of the *Bradyrhizobium*-groundnut symbiosis system to inoculation either individually or combined with some rhizobacteria (a mixture of Ps. *fluorescens*, B. *polymyxa*, B. *megaterium* and B. *circulans*), foliar spraying of some micronutrients and their interactions on the nodulation pattern, growth productivity, and some chemical traits of groundnut seeds. Two factorial experiments were conducted during two successive summertime of 2021 and 2022 at Kom-Ombo Agricultural Research Station, Aswan Governorate, Upper Egypt. Where, the treatments were allocated to experimental units in a split-plot design. The results showed that uninoculated groundnut had the least nodulation features, lowest values for vegetative growth and yield parameters, and lowest shelling percentages. However, inoculation with *Bradyrhizobium* significantly enhanced all previous groundnut parameters. The co-inoculation strategy treatment (*Bradyrhizobium* and a mixture of PGPRs) showed a promotive impression in all measurements. Foliar spraying with two levels of tested micronutrients (M_1 and M_2) significantly affected nodule traits, growth aspects, groundnut yield, shelling percentage, seed quality characteristics, and nutrient uptake compared to the unamended treatment (M_0). In most cases, the foliar spray treatment (M_1) was superior. Co-inoculation with *Bradyrhizobium* and PGPRs combined with any level of micronutrients was superior over all treatments and caused remarkable increases in all previous groundnut parameters. The synergistic effects of bacterial co-inoculation along with micronutrient application as foliar spray (M_1 level) registered the highest values of all above tested groundnut parameters. Excess spray of micronutrients foliar nutrition (M_2 level) led to an insignificant decrease compared to (M_1 level), but still higher than other tested combinations and came in second rank.

Keywords Groundnut (*Arachis hypogaea* L.), *Bradyrhizobium* spp., Plant growth promoting rhizobacteria, Micronutrients, Sandy clay loam soil, Groundnut yield and its components

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most important and economical oilseeds and legume crops used as food in tropical and subtropical climates. It is the world's third-most significant source of protein and the fourth-most significant source of edible oil (Panhwar, 2005). On average, groundnut seeds contain 45–50% oil, 25–30% protein, 20–30% carbohydrate, 5–10% fiber, and ash.

Additionally, it contains a lot of calcium, iron, and the vitamins A, B, E, and K, all of which are extremely important for human nutrition (Fageria *et al.,* 1997 and Sathya *et al.,* 2009).

Biological nitrogen fixation (BNF) is a substantial source of N in cropping systems since atmospheric N_2 is a renewable resource (Jensen and Hauggaard, 2003). Groundnuts, similar to other legumes, can fix atmospheric nitrogen thanks to symbiotic bacteria that fix nitrogen

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in their root nodules, which means groundnut plants require less N containing fertilizers. Additionally, it increases soil fertility, which makes them useful for crop rotation. *Rhizobium* inoculation boosts legume productivity and provides 50–70% of the nitrogen needed for crops. However, our soil lacks the right kind and quantity of nodule-forming bacteria necessary to support healthy legume growth, which may be due to the absence of effective strains in the soil. Thus, it is recommended to apply a groundnut-specific inoculant at planting in order to satisfy the plant N requirements and optimize yield and income. (Badawi *et al.,* 2011a; El-Shouny *et al.,* 2011 and Mokgehle *et al.,* 2014).

Plant growth-promoting rhizobacteria (PGPR) can increase plant productivity and growth in a number of ways, including directly through the synthesis of phytohormones, N_2-fixation, and siderophores that sequester iron, and the solubilization of unavailable mineral nutrients or indirectly, through the biological control of pathogens or the induction of host defense mechanisms (Van-Loon and Bakker, 2003 & Santoyo *et al.,* 2016). Phytohormones inducing stimulation of root growth, to provide more sites for rhizobial infection and nodulation, are the most frequently suggested ways to stimulate legume-Rhizobium symbiosis (Vessey, 2003). Numerous scientists have reported that combining rhizobacteria and rhizobia may improve nodulation, plant growth, and legume yield (Verma *et al.,* 2010; Badawi *et al.,* 2011a and Mathivanan *et al.,* 2014).

Plants use micronutrients, which are necessary elements, in small amounts. The application of micronutrients increased the yield and quality of agricultural products; consequently, feed enriched with plant materials protects the health of humans and animals. Every essential element can correctly carry out its function in plant nutrition, ensuring that other elements are available to plants in balanced ratios (Tavakoli *et al.,* 2014). Despite the recommended use of fertilizer (NPK), groundnut productivity is not up to the potential level because groundnut needs seven micronutrients, which are recognized as being vital to plants. Mekdad (2019) and Kheravat *et al.,* (2020) stated that a lack of micronutrients is one of the main reasons for the low groundnut yield.

Micronutrients such as Fe, Zn, Mn and B are essential in most physiological processes (Marschner, 1998). Many studies have researcher demonstrated the significance role of micronutrients foliar application on groundnut diversities and their effects on chemical composition (Abdel-Motagally *et al.,* 2016 & Gowthami and Ananda, 2017). Iron is vital for the conservation of chloroplast structure and function, and it plays a major role in basic biological functions like nitrogen fixation, respiration, photosynthesis, and chlorophyll production, and uptake mechanisms. Applying iron foliarly, whose availability is unaffected by the pH of the soil, ensures that groundnut yield attributes are higher (Kim and Rees, 1992; Weisany *et al.,* 2013 and Kheravat *et al.,* 2020). While, the primary roles of zinc are catalytic, enzyme-building, and activating due to its propensity to form tetragonal complexes with nitrogen, oxygen, and sulfur. As a result, zinc serves as the primary building block of certain enzymes and is required for the synthesis of plant enzymes. Zinc also activates a variety of enzymatic processes (Aboyeji *et al.,* 2019 and Yadav *et al.,* 2019). Reddy *et al.,* (2023) reported that zinc controls sugar consumption, escalations the energy source for chlorophyll production, and helps in auxin formation and protein production. On the other hand, manganese has an important role in activating many enzymes that include oxidation and carboxyl reactions, citric acid cycle, phosphorus reactions, and carbohydrate metabolism. Superoxide dismutase and protein-manganese in photosystem II are the two most significant of these enzymes (Mousavi *et al.,* 2011 and Sabra *et al.,* 2019). Numerous plant functions, such as protein synthesis, respiration, the translocation of sugars and nutrients, and the metabolism of plant hormones, depend on boron. Because it is immobile in plants, an ongoing supply is required for the duration of the growing season (Hirpara *et al.,* 2019). Sathya *et al.,* (2009) and Poonguzhali *et al.,* (2019) reported that boron impacts the growth of groundnut through arresting the flower drop and also share in the production of carbohydrates and fats. They added that boron becomes more popular in management because it is essential to groundnut quality. The first negative effects affect the crops' ability to flower and fruit, which in turn affects crop quality and yield. Furthermore, B is a crucial micronutrient for improved growth and preventing "hollow heart", which lowers the crop's value in groundnuts. Many researchers confirmed that the flowering period was extended in boron deficient plants (Liu, 2002; Der *et al.,* 2015 and Aboyeji *et al.,* 2019).

The present study aimed to identify the influence of plant growth promoting rhizobacteria (PGPR) and foliar application of some micronutrients on the groundnut-*Bradyrhizobium* symbiosis system, plant growth, productivity, and some chemical traits of groundnut seeds.

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2. Materials and Methods

2.1. Experimental site

Two field experiments were carried out during the two successive summer growing seasons of 2021 and 2022 at Kom-Ombo Agricultural Research Station, (latitude of 24º 28′ N and longitude of 32º 57′ E), Aswan Governorate, Upper Egypt. This study was conducted to identify the effect of *Bradyrhizobium* bacterial inoculation, either individually or combined with some rhizobacteria (a mixture of *Pseudomonas fluorescens*, *Bacillus polymyxa*, *Bacillus megaterium* and *Bacillus circulans*), foliar application of some micronutrients, and their interactions on the nodulation pattern, growth, productivity, and some chemical traits of groundnut seeds under sandy clay loam soil conditions.

A representative sample of soil was collected from the top 20 cm layer of the experimental fields, air-dried, and sieved through a 2-medm screen. The main physical and chemical properties of the experimental soil were determined according to the methods described by Black *et al.* (1965) and Page *et al.* (1982), and the obtained data are presented in Table (1).

Table 1: Some physical and chemical properties of the experimental soil

Properties	Particle size distribution								
	Sand %	Silt %	Clay %	Texture class	O.M %	$CaCO_3$ %	S.P	pH	EC dS m^{-1}
Values	59.16	17.20	23.64	Sandy clay loam	0.48	3.98	27.5	7.87	1.9

	Soluble cations and anions (meq 100 g^{-1} soil)								Available Nutrients (mg kg^{-1})		
Properties	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	N	P	K
Values	3.19	2.65	3.63	0.95	-	2.52	4.16	3.74	40	8	250

2.2. Microbial cultures

Bradyrhizobium spp. (strain USDA 3456) and four tested rhizobacteria, namely *Pseudomonas fluorescens* (strain IFO.2034), *Bacillus polymyxa*, *Bacillus megaterium* and *Bacillus circulans* (local isolates), were kindly obtained from the Biofertilizers Production Unit, Agric. Microbiology. Dept., Soils, Water and Environ. Res. Inst. (SWERI), Agric. Res. Center (ARC), Giza, Egypt. *Bradyrhizobium* was cultured in a yeast extract mannitol (YEM) broth medium (Vincent, 1970). *Ps. fluorescens* was grown in King's medium B, while the nutrient broth medium was used for the activation and culture of *B. polymyxa*, *B. megaterium* and *B. circulans* (Atlas, 2005). Cultures were incubated at 28ºC for 3-5 days on a rotary shaker until early log phase to ensure a population density of 10^9 cfu/ml culture.

2.3. Bio-inoculant preparation

Neutral-powdered vermiculite supplemented with 10% Irish peat was packed into polyethylene bags (300g carrier per bag), then sealed and sterilized with gamma irradiation (5.0×10^6 rads). Each bacterial culture (120 ml of log phase growing culture) was injected into a sterilized carrier to satisfy 60% of the maximal water holding capacity, then mixed thoroughly and left for a week for curing.

2.4. Experimental design

The experiments were laid out in a split plot design with three replicates. Each experiment included 9 treatments, and the plot area was 10.5 m^2 consisting of five rows (3.5 m long and 60 cm between rows). The main plots were occupied by inoculation treatments, while the sub-plots contained the foliar application of micronutrients treatments.

I- Main plots (inoculation)

- Uninoculated.
- Inoculation with *Bradyrhizobium* spp.
- Inoculation with *Bradyrhizobium* + PGPRs (mixture of *Ps. fluorescens*, *B. polymyxa*, *B. megaterium* and *B. circulans*).

II- Sub-plots (foliar application of micronutrients)

- Without micronutrients addition (M_0), spraying with tap water.
- Spraying of Fe, Mn and Zn in the form of sulphate and B as boric acid (98%) in solution consisted of 300g $FeSO_4.7H_2O$ + 150g $MnSO_4.1H_2O$ + 100g $ZnSO_4.7H_2O$ + 60g H_3BO_3/600 L water/fed (M_1). Feddan (fed) = 4200 m^2
- Spraying of Fe, Mn and Zn in the form of sulphate and B as boric acid (98%) in solution consisted of 600g $FeSO_4.7H_2O$ + 300g $MnSO_4.1H_2O$ + 200g $ZnSO_4.7H_2O$ + 120g H_3BO_3/600 L water/fed (M_2).

Foliar spraying with M_1 and M_2 solutions at a volume of 600 liters/fed, divided into three equal doses, added at the vegetative and pod formation stages after 30, 45 and 60 days from sowing.

2.5. Inoculation

Groundnut seeds (*Arachis hypogaea* L., cv. Giza 6) were supplied by the Oil Crops Research Department, Field Crops Research Institute, ARC, Giza, Egypt. Seeds were inoculated with gamma irradiated vermiculite-based inoculants at a rate of 400g inoculum/40kg seeds (a mixture of equal portions from solid inoculants); just before sowing, using Arabic gum solution (16%) as an adhesive agent.

Groundnut seeds were sown into hills, at 50 cm between ridges and 10 cm between hills, on 26th and 29th of April in the first and second growing seasons, respectively, and then irrigation took place immediately. The growing groundnut plants were thinned to specify the plant density, and the crop was kept clean by hand weeding two and three weeks after sowing. The uniform agricultural practices were done according to the Egyptian Ministry of Agriculture and Land Reclamation (EMALR) recommendations for cultivating groundnut, taking in mind the stated treatments.

2.6. Fertilization

All tested treatments received 20 kg N fed^{-1} in the form of ammonium sulphate (20.5% N) at sowing as an activator dose for *Bradyrhizobium*, while phosphorus as calcium superphosphate (15% P_2O_5) was incorporated into the soil before sowing at a rate of 200 kg fed^{-1}. Potassium as potassium sulphate (48 % K_2O) was applied at a rate of 50 kg fed^{-1}, at two equal doses (21 and 45 days of sowing).

2.7. Sampling

After 75 days of sowing, five plants were uprooted at random from the second row of each plot to evaluate the root nodulation status (number, fresh and dry weights of nodules) and plant height, as well as the number of branches and dry weight of shoots. At harvest, ten guarded plants were randomly taken from the second inner two rows of each experimental unit to determine yield components, namely the number of pods $plant^{-1}$, the weight of pods and seeds $plant^{-1}$ (g) and shelling percentage. Seed crude protein, seed oil contents and oil yield (kg fed^{-1}) were also assayed. Plants in the middle three ridges of each plot (3 m^2) were harvested and their pods and straw were air dried to calculate pod yield (kg fed^{-1}), seed yield (kg fed^{-1}) and straw yield (kg fed^{-1}).

2.8. Analyses

2.8.1. Plant materials

- The oven dried seeds and straw materials were wet digested using a mixture of pure $HClO_4$ and H_2SO_4 at a ratio of 1:1. Total nitrogen was determined using the micro-Kjeldahel method, phosphorus was determined Spectro-photometrically using ammonium molybdate and stannus chloride reagents, while potassium was determined Flamephotometeri cally (Page *et al.* 1982).
- The crude protein percentage of groundnut seeds was calculated by multiplying N% by 6.25, according to Mariotti *et al.* (2008).
- Oil percentage (%) in dry groundnut seeds was determined by using Soxhelt apparatus and petroleum ether as organic solvent, according to A.O.A.C. (2005).
- Seed oil yield (kg fed^{-1}) was estimated by multiplying of seed oil percentage by the seed yield in kg fed^{-1}.
- Shelling percentage (%) was estimated from seeds of 100 pods /100 pods weight (g) multiplying by 100.

2.9. Statistical analysis

The experimental data obtained were subjected to analysis of variance (ANOVA) according to the procedures outlined by Snedecor and Cochran (1980), treatment means were compared on the basis of L.S.D test at 5% level of probability.

3. Results and Discussions

3.1. Root nodulation status

The nodulation features of the groundnut roots, namely the nodules number (plant^{-1}), fresh weight of nodules (mg plant^{-1}) and dry weight of nodules (mg plant^{-1}) as affected by bacterial inoculation, foliar application of some micronutrient and their interactions after 75 days from sowing are shown in Table (2). Data reveals that the uninoculated plants had the least number of nodules (26.8 and 30.1 plant^{-1}) and recorded the least nodules fresh weight (62.7 and 66.8 mg plant^{-1}) and nodules dry weights (53.6 and 57.6 mg plant^{-1}) in both growing seasons. The findings imply that the native groundnut rhizobia in the experimental soil are insufficient in number and have low nitrogen fixation efficiency. This observation was also stated by Mekhemar *et al.* (2007) and Badawi *et al.* (2011a). The nodulation process initiated on the groundnut roots was extremely enhanced due to inoculation with *Bradyrhizobium* rather than native rhizobia (uninoculated treatment), which caused the number of nodules to rise noticeably (90.3 and 94.7 plant^{-1}), nodules fresh weight (169.7 and 174.9 mg plant^{-1}) and nodules dry weight (145.1 and 150.0 mg plant^{-1}). The pronounced variations between the inoculated and uninoculated treatments demonstrated this, underscoring the critical need of continuously inoculating legume seeds with rhizobial strains that are both effective and efficient to achieve good nodulation (El-Shouny *et al.,* 2011; Ravichandra *et al.,* 2015 & Siczek and Lipiec, 2016).

Table 2: Nodulation pattern formed on the groundnut roots as affected by bacterial inoculation, foliar application of some micronutrients, and their interactions after 75 days from sowing

Treatments		**Number of nodules plant^{-1}**		**Nodules fresh weight (mg plant^{-1})**		**Nodules dry weight (mg plant^{-1})**	
		2021	**2022**	**2021**	**2022**	**2021**	**2022**
		Overall means of inoculation (I)					
Uninoculated		26.8	30.1	62.7	66.8	53.6	57.6
***Bradyrhizobium* spp.**		90.3	94.7	169.7	174.9	145.1	150.0
***Bradyrhizobium* spp. + PGPRs**		119.6	124.3	271.2	276.8	231.9	237.2
LSD 0.05		8.5	9.8	18.5	18.6	15.8	15.9
		Overall means of micronutrients treatments (M)					
M_0		61.3	65.3	128.4	133.1	109.8	114.3
M_1		84.0	88.1	177.2	182.2	151.5	156.3
M_2		91.5	95.8	198.1	203.2	169.3	174.2
LSD 0.05		10.0	4.6	8.72	9.3	7.5	8.1
		Interaction Effect (I x M)					
Uninoculated	**M_0**	21.0	24.0	49.5	53.4	42.3	46.1
	M_1	26.6	30.0	60.7	64.8	51.9	55.8
	M_2	33.0	36.3	77.9	82.3	66.6	70.8
***Bradyrhizobium* spp.**	**M_0**	70.3	74.6	135.3	140.2	115.7	120.4
	M_1	95.3	99.6	173.8	179.0	148.6	153.5
	M_2	105.3	110.0	200.1	205.4	171.0	176.1
***Bradyrhizobium*+ PGPRs**	**M_0**	92.6	97.3	200.4	205.7	171.3	176.4
	M_1	130.0	134.6	297.1	302.8	254.0	259.5
	M_2	136.3	141.0	316.2	322.0	270.3	275.8
LSD 0.05		6.9	8.0	15.1	16.1	12.9	14.0

PGPRs: Inoculation with mixture of *Pseudomonas fluorescens, Bacillus polymyxa, Bacillus megaterium* and *Bacillus circulans*

M_0: Without micronutrients addition (M_0), spraying with tap water.

M_1: Spraying of Fe, Mn, Zn and B in solution consisted of 300g $FeSO_4.7H_2O$ + 150g $MnSO_4.1H_2O$ + 100g $ZnSO_4.7H_2O$ + 60g H_3BO_3 /600L water/fed.

M_2: Spraying of Fe, Mn, Zn and B in solution consisted of 600g $FeSO_4.7H_2O$ + 300g $MnSO_4.1H_2O$ + 200g $ZnSO_4.7H_2O$ + 120g H_3BO_3 /600L water/fed.

Co-inoculation of groundnut with *Bradyrhizobium* and the mixture of rhizobacteria revealed significant predictable improvement in symbiotic parameters such as nodules number (119.6 and 124.3 plant^{-1}), nodules fresh weight (271.2 and 273.8 mg plant^{-1}) and nodules dry weight (231.9 and 237.2 mg plant^{-1} in comparison to plants that have either not been inoculated or have received a *Bradyrhizobium* inoculation. The multiple mechanisms provided by combining more than efficient rhizobacteria, which facilitate root proliferation and increase the number of rhizobia-occupied infection sites, may be integrated to produce the promoting effects on nodulation. Numerous researchers have documented the processes that account for the enhanced rhizobia-legume association by other PGPR (Saharan and Nehra, 2011; Miransari, 2013 & Mohamad and Mohammed, 2020).

Irrespective of bacterial inoculation, nodulation originated on groundnut roots after 75 days of sowing as affected by the foliar application of some micronutrients, are given in Table (2). It is evident that the parameters of nodule traits of groundnut roots were better as a consequence of micronutrients foliar application in comparison to the unamended treatment (M_0). Foliar application of micronutrients treatments recorded the highest values of root nodules number (84.0 and 91.5 nodule plant^{-1}), nodules fresh weights (177.2 and 198.1 mg plant^{-1}) and nodules dry weights (159.5 and 169.3 mg plant^{-1}) for M_1 and M_2 treatments in the first season, respectively. The corresponding higher values recorded in the second season for M_1 and M_2 treatments were 88.1 and 95.8 nodule plant^{-1}, 182.2 and 203.2 mg plant^{-1} and 156.3 and 174.2 mg plant^{-1}, respectively. The beneficial effect of micronutrients on the initiation and development of nodular structure could be explained by their essential roles in the production of IAA, auxin metabolism, biological activity, and stimulation of enzyme activity and photosynthetic pigments. These results are quite in line with those of Badawi *et al.* (2011b), Der *et al.* (2015) and Kheravat *et al.* (2020). According to Radhika and Meena (2021) & Patel et al., (2022) who confirmed the important role of micronutrients in enzyme activities because they are essential parts of the complex of "nitrogenase" N_2 fixing enzymes, which raises leg hemoglobin levels and consequently nodulation and N_2-fixation. Data regarding nodulation status revealed a significant interaction between bacterial inoculation and foliar application of micronutrients at both seasons (Table 2). The uninoculated unamended treatment gave the least nodules number (21.0 and 24.0 plant^{-1}), the least nodules fresh weight (49.5 and 53.4 mg plant^{-1}) and recorded the least nodules dry weight (42.3 and 46.1 mg plant^{-1}) in both seasons, correspondingly. However, co-inoculation with *Bradyrhizobium* and rhizobacteria (PGPRs) combined with any level of micronutrients was superior to the rest of all treatments and caused remarkable increases in the number of nodules and their fresh and dry weights on groundnut roots. This significant superiority holds fairly true in both seasons. The associative action of micronutrients (M_1 and M_2) and such biofertilizers yielded the maximum values of nodules number (130.0 and 136.3 plant^{-1}), nodules fresh weight (297.1 and 316.2 mg plant^{-1}) and nodules dry weight (254.0 and 270.3mg plant^{-1}) in the first season, respectively. A similar trend was exhibited in the second season in nodules number (134.6 and 141.0 plant^{-1}), nodules fresh weight (302.8 and 322.0 mg plant^{-1}) and nodules dry weight (259.5 and 275.8 mg plant^{-1}), respectively. These results could be explained by foliar application of micronutrients with PGPRs inoculation may enhance the *Bradyrhizobium* bacteria to produce more nodules as a result of an increase in the amount of nutritional elements that are available and needed at trace amounts by the nodule system and the plant. Such promotion of the nodulation pattern is confirmed by many investigators (Abdel-Wahab *et al.,* 2009; El-Shouny *et al.,* 2011 & Badawi and Elsayed, 2015). They concluded that using inoculation with rhizobia and the addition of micronutrients gave better nodulation of soybean, faba bean and groundnut crops as compared with the control treatment.

3.2. Plant growth characters

Some growth aspects of groundnut plants, expressed by plant height (cm), number of branches (plant^{-1}) and plant shoot dry mass (g plant^{-1}) as affected by bacterial inoculation, foliar application of some micronutrient and their interactions after 75 days from sowing are shown in Table (3). Data exerted that the overall growth of groundnut plants, except the dry weight of shoots, was significantly affected by the various inoculation treatments. Irrespective of micronutrients application, the uninoculated plants had the lowest values of plant height (46.8 and 50.6 cm); number of branches (9.4 and 11.4 plant^{-1}) and dry weight of shoot (27.1 and 28.5 g plant^{-1}) in both tested seasons, respectively. Inoculation with *Bradyrhizobium* increased all growth parameters compared to uninoculated treatment.

The explicit role of *Bradyrhizobium* in furnishing a better rhizosphere for plant growth and the supply of nitrogen might be the reason for the observed increase in growth parameters of the groundnut plants as reported by Bambara and Ndakidemi (2010), Badawi *et al.* (2011a) and Ravichandra *et al.* (2015). However, data indicates that bacterization of groundnut seeds with *Bradyrhizobium* and a mixture of rhizobacteria recorded significant increases in growth parameters, relatively to the uninoculated plants or plants inoculated with *Bradyrhizobium* only. In both seasons, plant height increased by 14.3 and 13.4%, number of branches by 28.7% and 27.2%, while dry weight of shoot increased by 14.0 and 13.3% above the uninoculated plants, respectively. The promotion effect of such synergistic interaction on plant vigour may have resulted from co-inoculation with the mixture of PGPRs, which amplified the effect of *Bradyrhizobium's* critical role in promoting plant growth and N_2-fixation, as reported by Abdalla *et al.,* (2009); El-Shouny *et al.,* (2011); Korir *et al.,* (2017); Kumar and Verma, (2017) & Mohamad and Mohammed, (2020).

Irrespective of inoculation, foliar application of micronutrients (M_1 and M_2) seems a salient significant effect on the groundnut growth aspects in comparison to the unamended one (M_0). For instance, the percentage increases attained for plant height were 10.3 and 10.9%, for number of branches were 24.4 and 24.3% and for shoot dry weight were 29.5 and 24.2% above the unamended treatment in the first season. The corresponding increases attained in the second season were 9.7 and 10.3%, 21.6 and 20.7% and 28.3 and 23.3% in the same order mentioned above, respectively. The promotion that occurred in groundnut growth features of micronutrients may be due to their effects as a metal component of some enzymes or regulators for others and their remarkable role in affecting nodule formation, improving plant growth and promoting photosynthetic activity (Badawi *et al.,* 2011b; Abhigna *et al.,* 2021; Ramya *et al.,* 2022 and Kumar *et al.,* 2023). In this regard, Sabra *et al.,* (2019) and Ramya & Singh (2022) reported that the application of foliar micronutrients (Fe, Zn, Mn, and B) in combination enhanced the availability of micronutrients required for development and growth, leading to an increase in the accumulation of dry matter and the highest values of all groundnut growth characters.

Table 3: Plant height (cm), number of branches (per plant) and dry weight of groundnut shoots (g plant^{-1}) as affected by bacterial inoculation, foliar application of some micronutrients and their interactions after 75 days from sowing

Treatments		**Plant height (cm)**		**Number of branches per plant**		**Dry weight of shoot (g plant^{-1})**	
		2021	**2022**	**2021**	**2022**	**2021**	**2022**
		Overall means of inoculation (I)					
Uninoculated		46.8	50.6	9.4	11.4	27.1	28.5
***Bradyrhizobium* spp.**		50.0	53.9	9.9	12.1	28.6	29.9
***Bradyrhizobium* spp. + PGPRs**		53.5	57.4	12.1	14.5	30.9	32.3
LSD 0.05		3.7	3.8	1.4	2.0	N.S	N.S
		Overall means of micronutrients treatments (M)					
M_0		46.8	50.6	9.0	11.1	24.4	25.8
M_1		51.6	55.5	11.2	13.5	31.6	33.1
M_2		51.9	55.8	11.2	13.4	30.3	31.8
LSD 0.05		2.2	2.1	0.9	1.7	3.2	3.6
		Interaction Effect (I x M)					
Uninoculated	**M_0**	39.9	43.5	8.0	10.0	24.2	25.6
	M_1	46.6	50.4	10.0	12.0	28.2	29.7
	M_2	54.0	58.0	10.3	12.3	28.8	30.3
***Bradyrhizobium* spp.**	**M_0**	46.4	50.3	8.0	10.0	24.5	25.9
	M_1	52.1	56.0	10.7	13.0	30.9	32.4
	M_2	51.4	55.3	11.0	13.3	30.4	31.5
***Bradyrhizobium* spp. + PGPRs**	**M_0**	54.0	57.9	11.0	13.3	24.6	26.0
	M_1	56.1	60.0	13.0	15.6	35.8	37.3
	M_2	50.3	54.2	12.3	14.6	32.2	33.7
LSD 0.05		3.8	3.7	1.5	2.9	5.6	6.3

The data in Table (3) exhibited that all the tested growth features seemed to highly improve as a consequence of joint application of *Bradyrhizobium* and PGPRs inoculum together with foliar application of micronutrients, which was reflected by the higher values of plant growth characters. The synergistic effect between the bacterial inoculation and the application of micronutrients as foliar spray (M_1 level) achieved better values of plant height (56.1 and 60.0 cm), number of branches (13.0 and 15.6 plant^{-1}) and shoot dry weight (35.8 and 37.3 g plant^{-1}) in both seasons, respectively. Excess spray of micronutrients foliar nutrition (M_2 level) led to a decrease in the above - mentioned parameters, but still higher than other tested combinations. Many workers found that inoculated plants reliant on symbiotic nitrogen fixation need micronutrients more than those supplied with mineral nitrogen, indicating that the effect of micronutrients on nitrogen fixation is direct and the symbiosis has a greater micronutrients requirement. Enhancement in groundnut growth as a consequence of synergy between micronutrients application and bacterial inoculation has been evident by several investigators (Daza *et al.,* 2003; Abdel-Wahab *et al.,* 2009; Badawi *et al.,* 2011b and Ravichandra *et al.,* 2015).

3.3. Yield and some yield attributes

Table 4 shows the groundnut yield parameters as impacted by the co-inoculation of *Bradyrhizobium* and tested rhizobacteria under foliar micronutrients application. The responses of all groundnut yield parameters were found to be parallel to the vegetative growth stage. Irrespective of micronutrients, results illustrated that plants inoculated with *Bradyrhizobium* solely or combined with rhizobacteria exhibited significant increases in all groundnut yield parameters relative to uninoculated plants. *Bradyrhizobium* inoculation significantly increased pods and seed yields (kg fed^{-1}) and their components, i.e., no. of pods (plant^{-1}), pod weight (g plant^{-1}) and seed weight (g plant^{-1}), while straw yield (kg fed^{-1}) insignificantly responded. The positive effect of *Bradyrhizobium* inoculation on yield and its components was accomplished due to the movement of root nodules to improve nitrogen fixation by expanding the number of rhizobia, which created more amounts of bio-fixed nitrogen that driven to improve groundnut yield and its traits. These results are in agreement with those detailed by Abdalla *et al.* (2009), El-Shouny *et al.* (2011) and Ravichandra *et al.* (2015) who found that *Rhizobium* inoculation improved seed yield and its components in groundnut plants. However, the splendid significant effect was observed with the use of the inoculation approach (*Bradyrhizobium* and a mixture of PGPRs) in relative to uninoculated plants or plants inoculated with *Bradyrhizobium* alone. The percentage increments in number of pods plant^{-1} (20.4 and 16.4%), pod weight g plant^{-1} (43.2 and 41.4%) seed weight g plant^{-1} (42.3 and 38.3%), pod yield kg fed.$^{-1}$ (43.1 and 40.4%), seed yield kg fed.$^{-1}$ (42.1 and 38.5%) and straw yield kg fed.$^{-1}$ (6.2 and 5.9%) in both seasons over the uninoculated plants, respectively. Such increments in pods yield may well be attributed to the increment in pods weight plant^{-1} resulting from a number of pods plant^{-1}. These increments may explain their noticeable roles to their colonized plants within the enhancement of N_2-fixation performance, providing with development advancing substances and enhancing nutrient uptake, which reflected on expanding the nutrient status within the rhizosphere and in plant tissues and subsequently improved groundnut yield and its traits. Potentiality for improving plant yield of legumes by combining rhizobacteria with rhizobia has been reported by many scientists (Yadegari and Rahmani, 2010; Rakha and El-Said, 2013; Badawi and El-Sayed, 2015; El-Shaboury and Abo El-Ela, 2015 & Mohamad and Mohammed, 2020).

On the other instance, data in Table (4) obviously exerted that foliar spraying with two levels of tested micronutrients (M_1 and M_2) resulted in significant increases in groundnut yield and some yield attributes above the unamended treatment (M_0). The variance between the two micronutrient doses (M_1 and M_2) could not reach the level of significance. The corresponding percentage increases in no. of pods (per plant), pod weight (g plant^{-1}), seed weight (g plant^{-1}), pods and seed yields (kg fed^{-1}) and straw yield (kg fed^{-1}) in the first season reached (36.9 and 34.5%), (15.1 and 17.4%), (32.2 and 26.2%), (15.3 and 17.4%), (31.6 and 25.8%) and (29.4 and 24.2%), respectively, above the unamended treatments. In the second season, micronutrients behaved the same way in augmenting the groundnut yield characters and recorded percentage increases (33.0 and 28.4%), (14.4 and 15.8%), (29.2 and 23.9%), (14.4 and 16.4%), (29.0 and 23.7%) and (28.2 and 23.2%) in the same order, respectively. The possible cause of such a positive role might be due to the active role of these trace-elements in the activity of bio-substances or the activity of the photosynthetic system of plants and thus, increases the yield attributes and yields of groundnut. These results were collaborated with Arabhanvi *et al.* (2015); Gowthami and Ananada (2017); Sabra *et al.,* (2019) and Noaman *et al.* (2022). Abhigna *et al.* (2021) and Patel *et al.*

Table 4: Number of pods plant^{-1}, pods weight (g plant^{-1}), seed weight (g plant^{-1}), pod yield (kg fed^{-1}), seed yield (kg fed^{-1}) and straw yield (kg fed^{-1}) of groundnut as affected by bacterial inoculation, foliar application of some micronutrients and their interactions

Treatments		Number of pods per plant		Pods weight (g plant^{-1})		Seeds weight (g plant^{-1})		Pod yield (kg fed.$^{-1}$)		Seed yield (kg fed.$^{-1}$)		Straw yield (kg fed.$^{-1}$)	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Overall means of inoculation (I)													
Uninoculated		28.5	31.7	40.3	43.7	22.2	25.3	1372.0	1496.2	755.9	859.8	2891.5	3041.2
***Bradyrhizobium* spp.**		30.7	34.4	51.2	55.1	29.6	33.0	1742.6	1875.4	1007.7	1121.5	2851.5	3000.3
***Bradyrhizobium*+PGPRs**		34.3	36.9	57.7	61.8	31.6	35.0	1963.4	2100.2	1074.4	1191.0	3070.6	3222.3
LSD 0.05		2.1	2.3	1.7	N.S	1.3	1.3	43.8	60.1	55.2	60.1	N.S	N.S
Overall means of micronutrients treatments (M)													
M_0		25.2	28.5	44.9	48.6	23.3	26.4	1526.5	1654.2	794.0	899.4	2492.6	2636.3
M_1		34.5	37.9	51.7	55.6	30.8	34.1	1759.6	1892.4	1045.0	1160.0	3224.7	3378.7
M_2		33.9	36.6	52.7	56.3	29.4	32.7	1791.9	1925.2	998.9	1112.8	3096.3	3248.7
LSD 0.05		2.8	3.6	1.6	N.S	2.0	3.3	69.1	86.6	38.7	86.6	329.1	371.7
Interaction Effect (I x M)													
Uninoculated	**M_0**	24.3	27.4	35.1	38.6	17.6	20.4	1194.9	1314.4	598.1	694.3	2511.5	2656.8
	M_1	28.3	31.6	40.7	44.4	23.7	26.8	1386.2	1511.3	805.1	911.3	2876.4	3025.4
	M_2	33.0	36.0	45.1	48.1	25.4	28.6	1534.9	1662.9	864.3	973.6	3286.7	3441.2
***Bradyrhizobium* spp.**	**M_0**	25.3	28.8	48.5	52.4	25.2	28.4	1650.3	1781.2	857.9	966.2	2468.4	2611.7
	M_1	33.8	37.3	53.1	57.0	33.3	36.7	1804.9	1939.2	1131.7	1249.7	3148.4	3300.8
	M_2	33.1	37.2	52.1	56.0	30.4	33.8	1772.6	1905.7	1033.4	1148.6	2937.6	3088.6
***Bradyrhizobium*+ PGPRs**	**M_0**	26.0	29.3	51.0	54.9	27.2	30.5	1734.2	1866.9	925.9	1037.7	2497.9	2642.3
	M_1	41.3	44.9	61.4	65.5	35.3	38.8	2087.6	2226.7	1198.4	1318.9	3649.3	3808.3
	M_2	35.6	36.6	60.8	64.9	32.3	35.7	2068.3	2207.0	1099.1	1216.3	3064.5	3216.4
LSD 0.05		4.8	6.3	3.5	N.S	2.8	4.4	119.8	196.5	67.1	150.1	570.0	643.8

PGPRs: Inoculation with mixture of *Pseudomonas fluorescens, Bacillus polymyxa, Bacillus megaterium* and *Bacillus circulans*
M_0: Without micronutrients addition (M_0), spraying with tap water.
M_1: Spraying of Fe, Mn, Zn and B in solution consisted of 300g $FeSO_4.7H_2O$ + 150g $MnSO_4.1H_2O$ + 100g $ZnSO_4.7H_2O$ + 60g H_3BO_3 /600L water/fed.
M_2: Spraying of Fe, Mn, Zn and B in solution consisted of 600g $FeSO_4.7H_2O$ + 300g $MnSO_4.1H_2O$ + 200g $ZnSO_4.7H_2O$ + 120g H_3BO_3 /600L water/fed.

(2022) added that supplementing micronutrients through foliage might have resulted in better nutrient balance in the plants leading to increased yield components.

At given interaction treatments, results in Table (4) elicited that groundnut yield and yield components were significantly influenced by micronutrients foliar application in conjugation with *Bradyrhizobium* and rhizobacteria co-inoculation. In both seasons, the average maximum number of pods (41.3 and 44.9 per plant), pods weight (61.4 and 65.5g plant^{-1}), seeds weight (35.3 and 38.8 g plant^{-1}), pods yield (2087.6 and 2226.7 kg fed^{-1}), seeds yield (1198.4 and 1318.9 kg fed^{-1}) and straw yield (3649.3 and 3808.3 kg fed^{-1}) were recorded with foliar application of micronutrients level (M_1) along with *Bradyrhizobium* and PGPRs inoculation. It was predominant to all other treatments in this regard and enrolled the most elevated mean value of all considered yield and yield attributes. While, the average minimum number of pods (24.3 and 27.4 plant^{-1}), pods weight (35.1 and 38.6 g plant^{-1}), seeds weight (17.6 and 20.4 g plant^{-1}), pods yield (1194.9 and 1314.4 kg fed^{-1}), seed yield (598.1 and 694.3 kg fed^{-1}) and straw yield (2511.5 and 2656.8 kg fed^{-1}) were always attained in the case of uninoculated unamended (M_0) treatment. Excess spray of micronutrients in foliar nutrition (M_2 level) led to an insignificant decrease in the above mentioned parameters compared to (M_1 level), but was still higher than other tested combinations and came at the second rank. The increase in pod and seed yields and yield attributes due to bacterial inoculation and micronutrients foliar application might be due to its vital role in enhancing cell division, the cell elongation process and promotion of photosynthetates transportation from vegetative organs to reproductive organs, leading to the production and accumulation of more carbohydrates and auxins, which favors the retention of more flowers, ultimately leading to more number of reproductive parts per plant and yield. Many investigators confirmed that the application of micronutrients in combination with bacterial inoculation increased the supply of nutrients required for growth and development, which resulted in an increase in dry matter accumulation in the reproductive parts (Ravichandra *et al.,* 2015; Mohamad and Mohammed, 2020; Abhigna *et al.,* 2021 and Patel *et al.,* 2022). They elicited that the promotive effect of bacterial inoculation was magnified by the presence of micronutrients, due to enhanced nodulation and nitrogen fixation, resulting in a high legume yield and its yield parameters.

3.4. Shelling percentage and seed quality

Shelling percentage and seed quality (estimated by seed crude protein, oil percentage and oil yield) of *Bradyrhizobium*-groundnut symbiosis along the two consecutive seasons as affected by foliar spraying of micronutrients, inoculation with PGPRs and their interactions are given in Table (5). Once again, the results of the shelling percentage and groundnut seed quality characters in both seasons took a trend parallel to the results of the vegetative growth stage and yield.

Regardless of foliar spray with micronutrients, it is evident that plants inoculated with *Bradyrhizobium* solely or combined with rhizobacteria showed significant increases in shelling percentage and seed quality characters in relative to the uninoculated plants. *Bradyrhizobium* inoculation significantly increased shelling percentage, crude protein percentage and oil yield, while oil percentage insignificantly responded. The positive effect of *Bradyrhizobium* inoculation was achieved due to the pronounced increase in nitrogen bio-fixation, which enhances the vegetative growth of plants, and consequently enhances the protein and oil contents of groundnut seeds. These results are in agreement with those reported by Abdalla *et al.* (2009); El-Shouny *et al.,* (2011) and Ravichandra *et al.* (2015). However, a splendid effect was observed with the use of inoculation approach treatment (*Bradyrhizobium* and a mixture of PGPRs), which attained increases in shelling percentage (11.4 and 6.0%), seed crude protein percentage (23.3 and 19.5%), seed oil percentage (2.9 and 3.2%) and seed oil yield (42.2 and 41.5%) in both seasons over the uninoculated treatment. These positive results could be attributed to the promotive effects of such biofertilizers, acted as plant growth promoters, which increase N_2-fixation and its uptake, add some nutrients to the soil, and stimulate root development, leading to enhanced vegetative growth and improve overall health of plant and consequently, the groundnut seed quality. In fact, using such inoculants interfered with the oil synthesis pathway, and probably most of the fixed carbon in the plant was used to synthesize the oil during the protein synthesis in the seeds. It means that at first, protein components such as amino acids are synthesized and then the plant uses these substances in order to synthesize the oil and therefore enhance its content. Our results are consistent with those of several researchers who have confirmed the beneficial role of

Bradyrhizobium and a mixture of PGPRs in improving legume seed quality (Desoky *et al.,* 2011; Radwan *et al.,* 2012; Badawi and El-Sayed, 2015 & Mohamad and Mohammed, 2020).

As shown in Table (5) foliar spraying with the two tested levels of micronutrients (M_1 and M_2) led to a significant increase in the shelling percentage and groundnut seed quality parameters compared to the unamended treatment (M_0). The results also indicated a relative superiority of the foliar spray treatment (M_1) over the (M_2) treatment. In the first season, the corresponding percentage increases in shelling percentage, crude protein percentage and oil yield reached (14.7 and 7.9 %), (6.6 and 2.7%) and (33.6 and 25.8%), respectively, above the unamended treatment. In the second season, micronutrients behaved the same way in enhancing the above characters and recorded percentage increases (13.2 and 6.9%), (5.3 and 1.3%) and (30.8 and 24.7%) in the same order, respectively. While, seed oil percentage recorded insignificant increases in both investigated seasons. The positive effect of micronutrients fertilization might be due to its favorable effects in stimulating nodulation and the growth of the root system, consequently increasing the efficiency of the roots in absorbing various nutrients, which leads to greater utilization of assimilates into the pods and ultimately increased number of filled pods and shelling percentage. It is also necessary for building proteins, the synthesis of lipids and other compounds, as well as having a measurable impact on yield and seed quality. Many studies have illustrated the importance of micronutrients application in combination on groundnut seed quality (Abdel-Motagally *et al.,* 2016; Gowthami and Ananda, 2017; Hirpara *et al.,* 2019; Sabra *et al.,* 2019; Kheravat *et al.,* 2020; Ramya *et al.,* 2022 and Reddy *et al.,* 2023).

Table 5: Shelling (%), seed crude protein (%), seed oil (%) and oil yield (kg fed^{-1}) of groundnut as affected by bacterial inoculation, foliar application of some micronutrients and their interactions

Treatments		**Shelling %**		**Seed crude protein %**		**Seed oil %**		**Oil yield (kg fed^{-1})**	
		2021	**2022**	**2021**	**2022**	**2021**	**2022**	**2021**	**2022**
		Overall means of inoculation (I)							
Uninoculated		51.83	56.24	20.90	23.26	46.43	45.50	351.4	391.2
***Bradyrhizobium* spp.**		54.70	57.71	23.80	25.96	46.63	46.50	481.5	524.2
***Bradyrhizobium* + PGPRs**		57.72	59.60	25.76	27.80	47.78	46.96	499.8	553.7
LSD 0.05		2.40	2.70	0.40	1.21	N.S	N.S	25.4	38.08
		Overall means of micronutrients treatments (M)							
M_0		51.85	54.21	22.78	25.12	46.57	45.91	370.8	413.2
M_1		59.46	61.37	24.28	26.45	47.46	46.55	495.5	540.4
M_2		55.93	57.97	23.40	25.45	46.80	46.22	466.4	515.4
LSD 0.05		3.50	3.51	0.46	0.69	N.S	N.S	22.1	37.9
		Interaction Effect (I x M)							
Uninoculated	**M_0**	50.10	52.86	20.83	22.93	47.52	45.52	284.2	316.0
	M_1	58.06	60.32	21.46	23.59	47.80	46.13	384.7	420.4
	M_2	56.34	58.54	20.41	23.26	44.59	44.84	385.3	437.0
***Bradyrhizobium* spp.**	**M_0**	52.02	54.30	23.54	25.36	47.43	46.01	407.0	444.5
	M_1	57.55	59.20	24.31	26.68	47.59	46.77	514.9	565.7
	M_2	58.29	60.24	23.55	25.85	47.01	46.76	499.0	543.5
***Bradyrhizobium* + PGPRs**	**M_0**	53.45	55.49	24.37	26.25	45.47	46.20	421.1	479.1
	M_1	62.78	64.58	27.08	29.10	48.31	47.30	563.3	616.3
	M_2	53.16	55.12	25.83	28.05	46.83	46.52	538.4	584.6
LSD 0.05		6.07	6.08	0.81	1.19	1.61	1.11	38.3	65.7

Data regarding groundnut seed quality and shelling percentage showed a significant interaction between micronutrients foliar spraying levels and bacterial inoculation (Table 5). Data confirmed again the superiority of mixture inoculation treatment (*Bradyrhizobium* and PGPRs) combined with micronutrients as spraying foliar application (M_1 level), which surpassed the other tested treatments. Such treatment recorded the greatest shelling percentage (62.87 and 64.58%) and those of seed crude protein percentage (27.08 and 29.10%), while seed oil percentage (48.31 and 47.30%) and seed oil yield (563.3 and 616.3 kg fed^{-1}) in both tested seasons, respectively. Hence, the promotive effect of *Rhizobium* might be magnified by the presence of rhizobacteria and applied micronutrients, which act to enhance the above characters. The result substantiates the findings of many researchers (Ravichandra *et al.,* 2015; Mohamad and Mohammed, 2020; Abhigna *et al.,* 2021 and Patel *et al.,* 2022) who found the synergistic effect of rhizobacterial inoculation (PGPRs) and micronutrients addition in improving legume-*Rhizobium* symbiosis, productivity and legume seed quality.

3.5. Nutrients uptake

Nitrogen, phosphorus and potassium uptake of groundnut seeds and straw as affected by bacterial inoculation, foliar spraying of some micronutrients and their interactions are shown in Table (6). The results confirmed again that the response of nutrients uptake in both seasons took a similar trend to the results of the vegetative stage and yield characters.

Dealing with bacterial inoculation, it is evident that *Bradyrhizobium* inoculation treatment affected groundnut nutrients uptake of seeds and straw in both seasons. When seeds were inoculated with rhizobia it led to an increase in the N-uptake of seeds by (52.1-46.1%) and straw by (17.1-22.0%) above the uninoculated plants in both tested seasons. Also, a similar trend was found for seed P-uptake, which increased by (44.9-49.8%) and straw (16.6-11.7%) in the same order, respectively. The corresponding increases recoded for K-uptake in groundnut seeds were (7.4-7.9%), while K-uptake in groundnut straw showed an insignificant response. However, a splendid effect was observed with the use of a mixture of *Rhizobium* and PGPRs, which caused promotive impression in all nutrients uptake of groundnut seeds and straw relative to uninoculated plants. It led to significant increases in N-uptake of seeds and straw by (75.7-65.9%) and (52.9-53.0%), in P-uptake of seeds and straw by (56.7-62.5%) and (31.5-23.4%), respectively, above the uninoculated treatment in both seasons. The corresponding increases recoded for K-uptake in groundnut seeds were (8.5-8.9%), while K-uptake in groundnut straw showed an insignificant increase (8.2– 7.4%) in relative to uninoculated plants. In fact, this improvement in the N, P and K uptake could be ascribed to the biological role of such biofertilizers in promoting plant growth, N_2-fixation performance as well as the mobilization of insoluble nutrients followed by the enhancement of their uptake by the plants. Such promotion is confirmed by many investigators (Van-Loon and Bakker, 2003; Desoky *et al.,* 2011; Radwan *et al.,* 2012 & Mohamad and Mohammed, 2020). They found that the co-inoculation with *Rhizobium* and associative bacteria, which in turn profoundly stimulate root biomass and provide it with more branching and a larger surface area, indirectly enhanced nutrient uptake capacity.

Regardless of inoculation, foliar spraying with micronutrients ($M_1$and M_2) appears to have a significant effect on the uptake of macronutrients in groundnut seeds and straw compared to the unamended one (M_0). However, excess spray of micronutrients foliar nutrition (M_2 level) led to a decrease in macronutrients uptake, but still higher than unamended treatment (M_0). For instance, the percentage increases achieved in the first season for seeds N-uptake were (36.5 and 21.6%), for seeds P-uptake (42.7 and 19.9%) and for seeds K-uptake (7.0 and 5.4%), respectively, above the unamended treatment. The corresponding increases attained in the second season were (34.0 and 21.1%), (43.5 and 14.1%) and (6.4 and 4.1%), respectively, in the same order mentioned above. The same trend occurred in the straw, which recorded increases in N-uptake (33.7 and 18.5%), P-uptake (63.5 and 37.8%) and K-uptake (30.3 and 29.6%) above the unamended treatment (M_0). The percentage increases attained in the second season were (30.4 and 13.8 %), (38.6 and 7.5%) and (29.9 and 26.4%), respectively. The promotion in groundnut nutrients uptake may be due to foliar spraying of micronutrients in combination (Fe, Zn, Mn and B) as a metal components of some enzymes or regulators for others, which are necessary for nodule formation and dry matter accumulation. In addition, its remarkable role in the metabolic processes and growth of the root system, which in turn reflected positively on the chemical content of groundnut seeds and straw. Several investigations confirmed a significant role of foliar spraying of micronutrients in the concentration and uptake of nutrients by groundnut (Aboyeji *et al.,* 2019; Sabra *et al.,* 2019; Sabra *et al.,* 2020; Abhigna *et al.,* 2021; Ramya *et al.,* 2022 and Kumar *et al.,* 2023).

At given interaction treatments, the data in Table (6) ratifies that the highest values in each groundnut seed or straw nutrients uptake (i.e., N, P and K) were achieved due to foliar application of micronutrients in combination with *Bradyrhizobium* and rhizobacterial co-inoculation compared to other combination treatments. For instance, the average maximum N-uptake values of seeds (51.93 and 61.43 kg fed^{-1}), P-uptake (11.4 and 12.42 kg fed^{-1}) and K-uptake (28.05 and 27.69 kg fed^{-1}) were recorded in both seasons by foliar spraying of micronutrients (M_1 level) along with *Bradyrhizobium* and PGPRs co-inoculation. The greatest maximum values for the straw N-uptake (110.43 and 92.45 kg

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Table 6: Nitrogen, phosphorus and potassium uptake (kg fed^{-1}) of groundnut seeds and straw as affected by bacterial inoculation, foliar application of some micronutrients, and their interactions

Treatments		Seed nutrients uptake (kg fed^{-1})						Straw nutrients uptake (kg fed^{-1})					
		N		P		K		N		P		K	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
		Overall means of inoculation (I)											
Uninoculated		25.26	31.98	5.94	6.10	25.02	24.59	57.45	48.11	12.43	13.36	33.76	39.00
***Bradyrhizobium* spp.**		38.42	46.71	8.61	9.14	26.87	26.53	67.25	58.69	14.49	14.92	34.81	39.26
***Bradyrhizobium*+PGPRs**		44.38	53.05	9.31	9.91	27.14	26.78	87.83	73.61	16.35	16.49	36.54	41.87
LSD 0.05		2.29	2.30	0.83	1.07	1.14	0.71	19.84	20.65	3.49	1.94	N.S	N.S
		Overall means of micronutrients treatments (M)											
M_0		30.16	37.10	6.58	7.03	25.30	25.09	60.34	52.42	10.78	12.94	29.20	33.71
M_1		41.18	49.71	9.39	10.09	27.08	26.69	80.67	68.35	17.63	17.93	38.06	43.82
M_2		36.68	44.93	7.89	8.02	26.66	26.12	71.51	59.64	14.86	13.91	37.85	42.60
LSD 0.05		1.41	4.22	0.43	0.94	0.31	0.54	10.20	8.52	2.03	2.50	5.76	7.85
		Interaction Effect (I x M)											
Uninoculated	**M_0**	19.95	25.49	4.73	5.04	24.06	23.96	49.50	41.76	9.11	11.80	30.53	35.86
	M_1	27.60	34.34	6.67	7.10	25.50	25.26	58.65	49.70	13.79	15.88	35.16	41.45
	M_2	28.25	36.12	6.42	6.15	25.50	24.55	64.19	52.88	14.38	12.41	40.63	45.09
***Bradyrhizobium* spp.**	**M_0**	32.30	39.21	7.08	7.57	25.81	25.72	62.45	56.69	11.28	12.64	27.37	30.66
	M_1	44.03	53.35	10.10	10.76	27.70	27.13	72.95	62.89	18.13	16.79	38.39	44.85
	M_2	38.93	47.56	8.66	9.08	27.12	26.75	66.36	56.49	14.06	15.34	35.51	41.50
***Bradyrhizobium*+ PGPRs**	**M_0**	38.24	46.61	7.94	8.49	26.02	25.61	69.07	58.82	11.95	14.37	29.63	34.62
	M_1	51.93	61.43	11.40	12.42	28.05	27.69	110.43	92.45	20.96	21.13	43.93	48.21
	M_2	42.87	51.11	8.58	8.83	27.35	27.06	84.00	69.56	16.15	13.98	34.10	38.07
LSD 0.05		2.45	7.31	0.75	1.63	0.54	0.94	17.67	14.77	3.52	4.34	9.97	13.60

PGPRs: Inoculation with mixture of *Pseudomonas fluorescens, Bacillus polymyxa, Bacillus megaterium* and *Bacillus circulans*
M_0: Without micronutrients addition (M_0), spraying with tap water.
M_1: Spraying of Fe, Mn, Zn and B in solution consisted of 300g $FeSO_4.7H_2O$ + 150g $MnSO_4.1H_2O$ + 100g $ZnSO_4.7H_2O$ + 60g H_3BO_3 /600L water/fed.
M_2: Spraying of Fe, Mn, Zn and B in solution consisted of 600g $FeSO_4.7H_2O$ + 300g $MnSO_4.1H_2O$ + 200g $ZnSO_4.7H_2O$ + 120g H_3BO_3 /600L water/fed.

fed^{-1}), P-uptake (20.96 and 21.13 kg fed^{-1}) and K-uptake (43.93 and 48.21 kg fed^{-1}) were always attained in the case of abovementioned treatment. Whereas, excess spray of micronutrients foliar nutrition (M_2 level) in combination with co-inoculation treatment came at the second rank. It is clear that such a combined treatment may act to improve sandy soil quality by influencing its chemical and organic highlights, production of particular activator compounds that have the capacity to enhance the accessibility of inaccessible forms of nutrients driving to boost the uptake of nutrients. The results affirmed the discoveries of numerous researchers (Badawi *et al.,* 2011b; Dijkstra *et al.,* 2013; Ravichandra *et al.,* 2015 & Mohamad and Mohammed, 2020) who found the superiority of plants, which co-inoculated with rhizobia and PGPRs and amended with foliar spraying with micronutrients in improving the uptake of nutrients.

4. Conclusion

The obtained findings clearly displayed that utilization of the micronutrients foliar spray and the biofertilization technology for cultivating the groundnut is considered a convenient strategy for conserving soil fertility and improving groundnut growth, yield and yield attributes. Accordingly, it seems quite logical to conclude that the maximum production of groundnut pods, growth parameters, yield attributes, quality traits and uptake of nutrients can be secured by the contribution of the biofertilization approach (a mixture of *Bradyrhizobium* and PGPRs) at sowing, besides the foliar spraying of micronutrients (spraying of Fe, Mn, Zn and B in solution consisted of 300g $FeSO_4.7H_2O$ + 150g $MnSO_4.1H_2O$ + 100g $ZnSO_4.7H_2O$ + 60g H_3BO_3 /600L water/fed) added at the vegetative and pod formation stages. The study findings also raised the expectation that further investigation on different groundnut varieties in multi-locations under different soil conditions would be needed to confirm the results and reach the level of recommendation.

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