

Response of common bean to plant growth promoting rhizobacteria under different levels of phosphorus

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Abstract

The usage of biofertilizer as alternative or support to mineral fertilizer encourage continuously due to fertilizer cost and environmental pollution. The effect of three phosphorus doses (0, 30, and 60 kg ha⁻¹ P₂O₅) with a control and different commercial biofertilizers, Bontera (*Bacillus amyloliquefociens*, *Bacillus pumilus*, *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus megaterium*, *Trichoderma harzianum*, *Trichoderma kanigi*), Bactoboost (*Bacillus subtilis*, *Bacillus magaterium*, *Loctococcus* spp.), Koklendirici (*Bacillus subtilis*, *Bacillus magaterium*, *Loctococcus* spp.), Lifebac NP (*Bacillus subtilis*, *Bacillus magaterium*), natural organic matter and humic substances (NSAH) (15% organic matter, 6% organic carbon, 13% humic + fulvic acid), and Rhizobia (*Rhizobium leguminosorum*) were investigated. Increasing phosphorus doses positively affected all the investigated characters. Koklendirici biofertilizer positively affected the important yield components, but highest grain yield was determined in the NSAH plots. Increasing phosphorus (P) doses did not affect nitrogen (N), potassium (K), magnesium (Mg), and copper (Cu) contents of the grain while phosphorus, calcium (Ca), iron (Fe), manganese (Mn), and zinc (Zn) contents showed an increase. Difference in climate might have influenced these results. These results indicated that understanding of bio and mineral fertilizer would enable us to use biofertilizer as an alternative to mineral fertilizer to common bean production.

Keywords: PGPR; phosphorus doses; plant nutrition element; yield; yield components

Introduction

Phosphorus is an essential nutrient for plants, but is often not available due to its fixation in soil (Lavakush *et al.*, 2014). Therefore, it is provided to plants chiefly in the form of chemical fertilizers. The increased use of chemicals under intensive cultivation has not only contaminated the ground and surface water but has also disturbed the harmony that existed among the soil, plant and microbial populations (Bahadur *et al.*, 2006). Over the past couple of decades, the use of plant growth promoting rhizobacteria (PGPR) for sustainable agriculture has increased tremendously in various parts of the world (Figueiredo *et al.*, 2008).

Rhizobacteria which contribute to plant growth by enhancing nutrient availability, nitrogen fixation, phosphorous solubilization, or iron acquisition are commonly referred to as biofertilizers (Sharma *et al.*, 2013; Kuan *et al.*, 2016). PGPR help plants in different mechanisms, for example (i) the production of secondary

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metabolites such as antibiotics, cyanide, and hormone like substances, (ii) the production of siderophores, (iii) antagonism to soil borne root pathogens, and (iv) phosphate solubilization (Dubeikovsky *et al.*, 1993). This PGPR activity has been reported in species belonging to *Azospirillum*, *Azotobacter*, *Pseudomonas*, *Bacillus*, *Acinetobacter*, *Alcaligenes*, *Beijerinckia*, *Burkholderia*, *Enterobacter*, *Erwina*, *Flavobacterium*, *Rhizobium*, and *Serratia* (Sturz and Nawak, 2000; Sudhakar *et al.*, 2000; Karlidag *et al.*, 2007). Significant increase in growth and yield of agronomically important crops in response to inoculation with PGPR have been repeatedly reported (Naseri *et al.*, 2013; Talay, 2019). Dobbelaere *et al.* (2002) reported that nitrogen (N) concentration of wheat inoculated with PGPR was unchanged. Tsigie *et al.* (2011) investigated PGPR inoculation of soybean and lentil, and found that *Bacillus subtilis* had increased lentil grain yield by 7% and soybean by 8%. Faramarzi *et al.* (2012) investigated the effects of *Azospirillum lipoferum*, *Pseudomonas putida*, and *Azotobacter chroococcum* on yield and yield components of maize. According to the results, plant growth regulatory bacteria increased the plant height, grain yield, 1000-grain weight, and biological yield. Tozlu *et al.* (2012) reported that pods per plant, seeds per plant, hundred kernel weight, and grain yield increased in bean with PGPR inoculation. Yazdani *et al.* (2009) investigated the effects of phosphate solvent microorganisms and PGPR application on the yield and yield components of the corn. They reported that microorganisms and PGPR application increased 1000-grain weight, seed yield, and harvest index. Ahmad *et al.* (2016) have also reported that grain yield, hundred kernel weight, pods per plant, and seeds per pod increased with PGPR inoculation. Inoculation with PGPR has been shown to result in an increased zinc (Zn) concentration in wheat (Singh *et al.*, 2017). Sonkurt (2018) reported that yield and important yield components of wheat increased after PGPR inoculation. Total nutrient content of macronutrients (Saubidet *et al.*, 2002; Adesemoye *et al.*, 2010) and micronutrients (Ogut and Er, 2016; Singh *et al.*, 2017) increased with PGPR inoculation.

The use of microorganisms to solubilize insoluble phosphate compounds is as an alternative strategy to using phosphatic fertilizers. They do not pollute the environment, do not affect soil health, protect plants against phytopathogens, and a low-cost technology is used for their production (Gupta *et al.*, 2015). This is possible because many phosphorus solubilization bacteria also produce growth regulators, which may enhance plant growth without increasing phosphorus (P) uptake (Leinhos and Vacek, 1994). Use of biofertilizers along with chemical fertilizers may serve as an effective approach for enhancing the crop nutrient requirements, thereby leading to sustainable crop production (Israr *et al.*, 2016).

The aim of this study was to investigate to eliminate or decrease chemical phosphorus fertilizers by using PGPR. Hence, the study was arranged to evaluate the effect of PGPR and different phosphorus doses and their combinations on yield and yield components and nutrient content of bean through a field experiment.

Materials and Methods

The field experiment was conducted during 2017 and 2018 in the experimental area of the Faculty of Agriculture, Eskisehir Osmangazi University, Eskisehir, Turkey (39° 48' N, 30° 31' E; 798 m above sea level). Climatic data of the long-term average and experimental periods of the years are shown in Figure 1. Long-term annual total precipitation is 104.1 mm, and it was 143.4 and 170.2 mm in the experimental periods of years 2017 and 2018, respectively. Annual average temperature was 19.64 °C in 2017 and 20.1 °C in 2018 during the experimental period. Physical and chemical properties of the soil in the experimental areas are presented in Table 1.

Table 1. Soil physical and chemical properties of the experimental area

Experimental Year	Depth (cm)	pH	Lime(%)	Organic matter	P ₂ O ₅ Kg ha ⁻¹	K ₂ O Kg ha ⁻¹	N (%)	Ca (mg kg ⁻¹)	Mg (mg kg ⁻¹)	Cu (ppm)	Mn (ppm)	Fe (ppm)
2017	0-30	7.83	5.40	0.79	45.5	1810	0.03	4197	876	0.95	3.16	1.56
2018	0-30	7.71	7.56	1.65	177.5	2450	0.08	2061	482	0.82	2.94	2.84

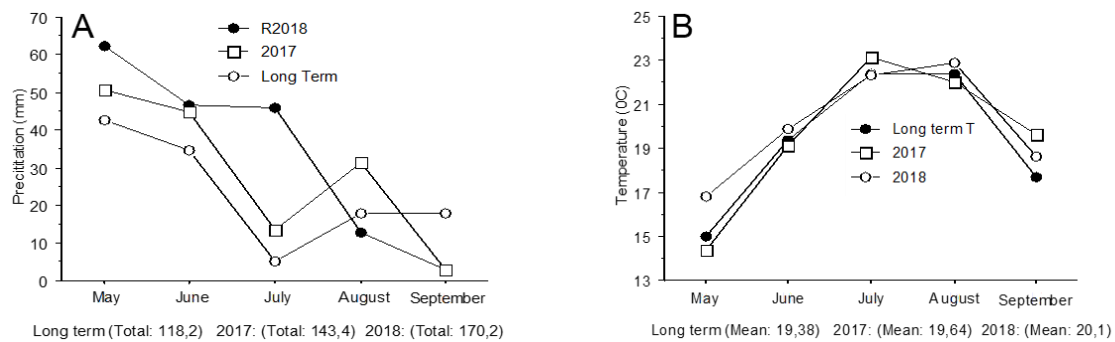


Figure 1. Climatic data of the research area

Experimental design and sampling methods

The experiment was designed as a factorial arrangement in a randomized complete block design with three replications. The effect of three phosphorus doses (0, 30, and 60 kg ha⁻¹ P₂O₅) along with a control and different commercial biofertilizers: Bontera (*Bacillus amyloliquefociens*, *Bacillus pumilus*, *Bacillus subtilis*, *Bacillus licheniformis*, *Bacillus megaterium*, *Trichoderma harzianum*, *Trichoderma kanigi*), Bactoboost (*Bacillus subtilis*, *Bacillus magaterium*, *Loctococcus* spp.), Koklendirici (*Bacillus subtilis*, *Bacillus magaterium*, *Loctococcus* spp.), Lifebac NP (*Bacillus subtilis*, *Bacillus magaterium*), NSAH (15% organic matter, 6% organic carbon, 13% humic + fulvic acid), Rhizobia (*Rhizobium leguminosorum*) were investigated. ‘Topcu’ cultivar of common bean was used in the experiment. Each plot was 7.2 m² (4 m x 1.8 m) and the plants were sown at 45 cm row spacing. The seeding rate was 26 seeds m⁻². The sowing was done on May 04 in both the years. Triple super phosphate, containing 43-45% P₂O₅, was used a phosphorus fertilizer. Ammonium sulfate fertilizer (21%) the dose of 25 kg ha⁻¹ N was applied to all the plots while sowing was done. The seed germination was determined for all the plots. The biological yield per plant (g), number of pods per plant, number of seeds per pod, number of seeds per plant, and grain yield per plant (g) were evaluated on five randomly selected plants in each plot. Each plot was harvested, threshed, and then the biological yield (kg ha⁻¹), harvest index (%), hundred kernel weight (g), and grain yield (kg ha⁻¹) were estimated. The grain samples were grinded, prepared, and analyzed for the content of macronutrients and micronutrients as described by (Kacar and İnal, 2008) using the ICP-OES instrument.

The variance analyses were done based on the general linear model using the StatView package (SAS Institute, 1998). Means were compared using the least significant differences (LSD) test.

Results and Discussion

The effects of bacteria were significant for all the investigated characters, but differences in the investigated characters between the years were all significant, except for harvest index, hundred kernel weight, and calcium (Ca) content. The effects of phosphorus doses were not significant only in case of the number of pods per plant (Tables 2, 3, 4, and 5). While seed germinations, number of seeds per plant, and grain yield per plant were higher in first year and lower in second year (Figures 2A, 4A, B). While biological yield per plant, number of seeds per pod, and biological yield were lower in 0 kg ha⁻¹ P₂O₅ plots in the second year for control plots, they had highest value in the first year (Figures 2B, 3B, and 5A). While number of pods per plant was higher in 30 kg ha⁻¹ P₂O₅ plots in first year for Koklendirici, the same bacteria showed lower values in other plots (Figure 3A). While harvest index was lower in 0 kg ha⁻¹ P₂O₅ plots in the first year for Rhizobia, same bacteria showed higher values in other plots (Figure 5B). While hundred kernel weight was higher in 30 kg ha⁻¹ P₂O₅ plots in the first year for NSAH, the same bacteria showed lower values in other plots (Figure 6A). While grain yield showed superior performance in control plots in the first year, same plots showed lower values in the second year (Figure 6B). Therefore, year × Rhizobia × nitrogen fertilization interaction was significant. While N, P, and iron (Fe) contents of the grain were higher in the second year than in the first year (Figure 7 AB; 9 B). Potassium (K) content of the grain was higher in 0 and 60 kg ha⁻¹ P₂O₅ plots in 2018 for Bactoboost, but the same bacteria caused lower values in 30 kg ha⁻¹ P₂O₅ plots in the same year. (Figure 8A). While Ca and magnesium (Mg) contents of the grain were higher in 60 kg ha⁻¹ P₂O₅ plots in 2018 for Bontera, the same bacteria caused lower values in other plots (Figure 8B; 9A). Manganese (Mn) content of the grain was higher in 60 kg ha⁻¹ P₂O₅ plots in 2018 for Rhizobia, but the same bacteria caused lower values in the other plots (Figure 10A). While Zn content of the grain was lower in 30 kg ha⁻¹ P₂O₅ plots in 2017 for Bontera, the same bacteria caused higher values in 60 kg ha⁻¹ P₂O₅ plots in 2017 (Figure 10B). While copper (Cu) content of the grain was higher in the first year, the same nutrient element was lower in the second year (Figure 11). Therefore year × Rhizobia × nitrogen fertilization interactions are significant.

Table 2. Effects of different phosphorus doses and PGPR on some traits of common bean

	Seed germinations	Biological yield per plant (g)	Number of pods per plant	Number of seed per pod	Number of seed per plant
2017	33.59 a	50.68 a	25.93 a	3.63 a	85.59 a
2018	15.91 b	39.88 b	17.77 b	3.51 b	60.88 b
Mean	24.75	45.28	21.85	3.57	73.23
0 kg/ha p ₂ o ₅	23.50 b	42.74 b	21.43	3.60 ab	72.65 b
30 kg/ha p ₂ o ₅	25.40 a	43.49 b	22.34	3.45 b	69.84 c
60 kg/ha p ₂ o ₅	25.34 a	49.61 a	21.79	3.65 a	77.21 a
Mean	24.75	45.28	21.85	3.57	73.23
Control	25.86 a	47.41 b	20.38 b	3.65 b	74.55 b
Bontera	24.58 c	37.79 d	20.73 b	3.21 c	61.82 d
Bactoboost	23.03 e	39.24 d	20.01 b	3.52 b	66.00 c
Koklendirici	26.00 a	52.26 a	23.04 a	4.00 a	84.99 a
Lifebac NP	23.61 d	50.54 a	24.17 a	3.79 ab	81.84 a
NSAH	25.16 b	44.86 c	23.57 a	3.20 c	71.89 b
Rhizobia	25.00 bc	44.86.c	21.06 b	3.61 b	71.57 b
Mean	24.75	45.28	21.85	3.57	73.23
Year	**	**	**	*	**
Phosphorus doses	**	**	ns	**	**
Bacteria	**	**	**	**	**
Year x phosphorus	**	**	**	ns	**
Year x bacteria	**	**	**	**	**
Phosp. x bacteria	**	**	**	**	**
Year x phosp. x bac.	**	**	**	**	**

ns: non-significant, *: p≤0.05, **: p≤0.01. Means in the same column with different letters are significant.

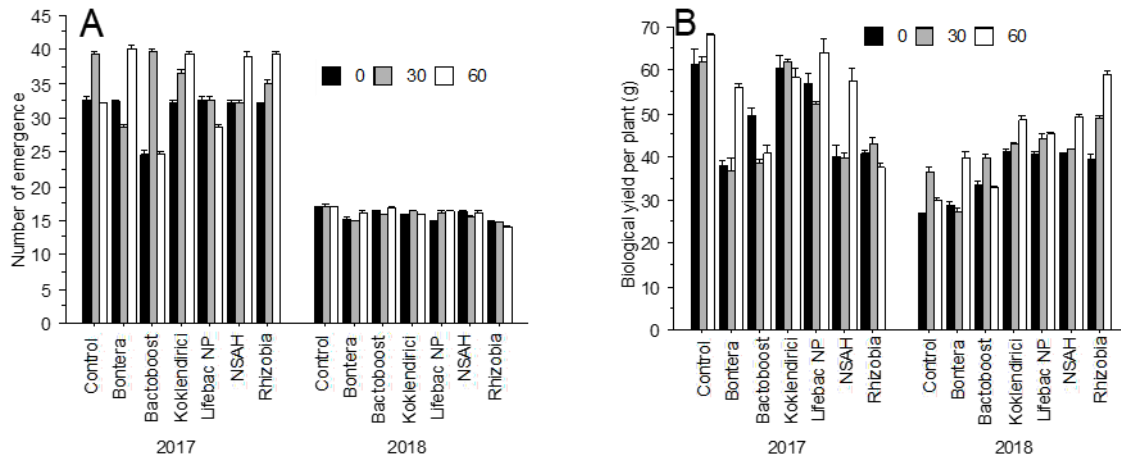


Figure 2. The interaction between year, phosphorus doses and PGPR on seed germination (A) and biological yield per plant (B) of common bean [LSD 1%: 1.211 (A);1%: 5.385 (B)]

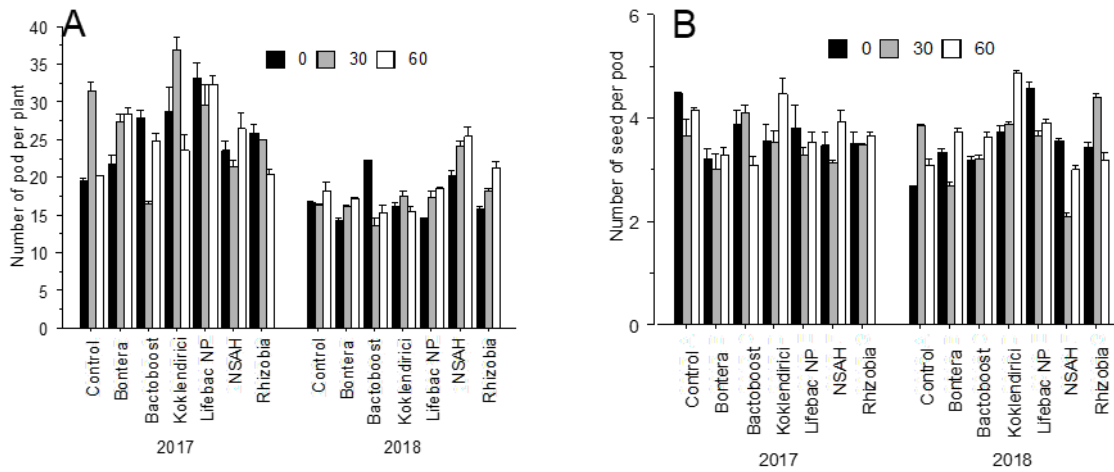


Figure 3. The interaction between year, phosphorus doses and PGPR on number of pods per plant (A) and number of seed per pod (B) of common bean [LSD 1%: 4.116 (A);1%: 0.624 (B)]

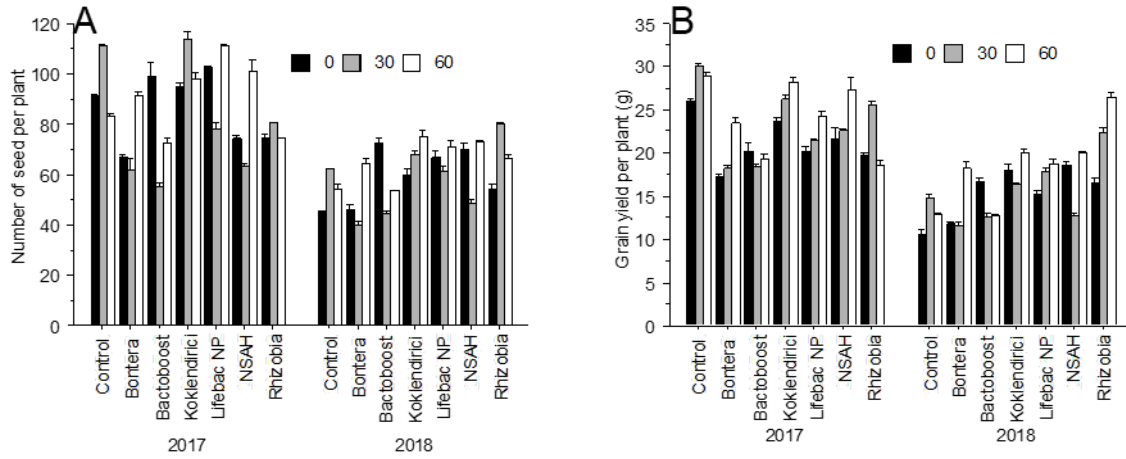


Figure 4. The interaction between year, phosphorus doses and PGPR on number of seed per plant (A) and grain yield per plant (B) of common bean [LSD 1%: 7.641 (A); 1%: 1.893 (B)]

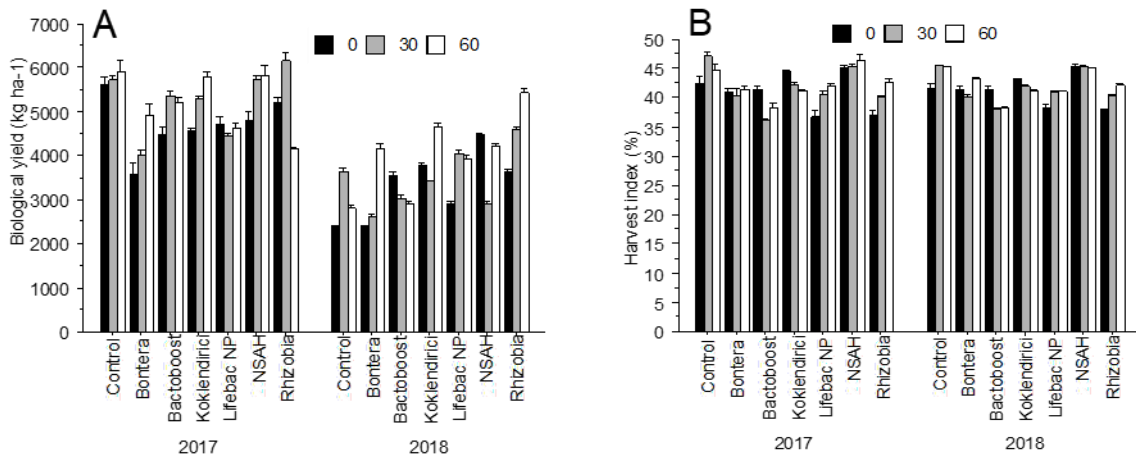


Figure 5. The interaction between year, phosphorus doses and PGPR on biological yield (A) and harvest index (B) of common bean [LSD 1%: 46.53 (A); 5%: 1.619 (B)]

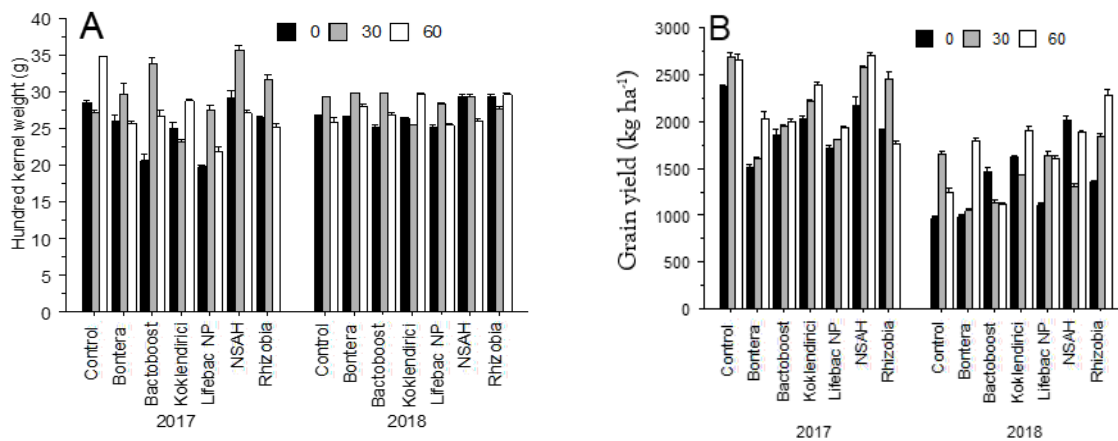


Figure 6. The interaction between year, phosphorus doses and PGPR on hundred kernel weight (A) and grain yield (B) of common bean [LSD 1%: 1.836 (A); 1%: 14.15 (B)]

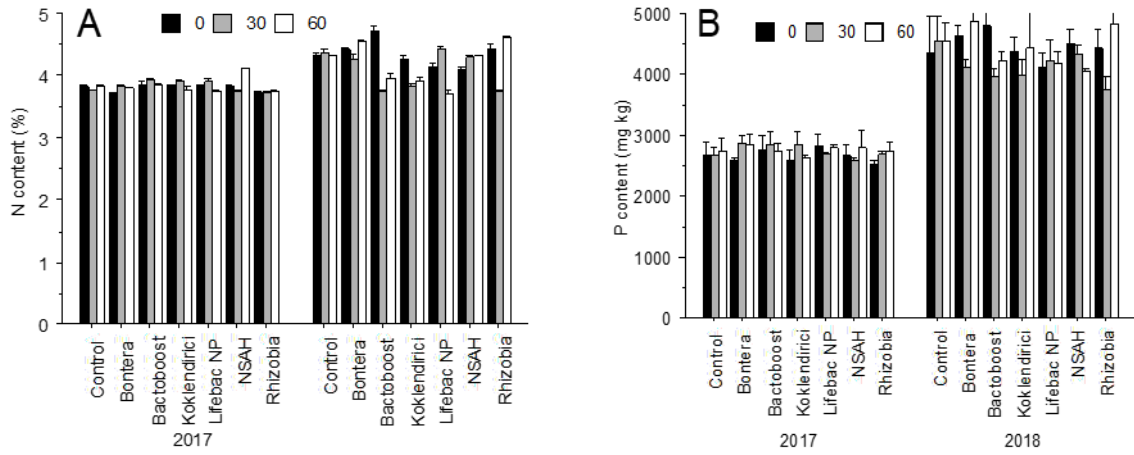


Figure 7. The interaction between year, phosphorus doses and PGPR on N content (A) and P content (B) of common bean [LSD 1%: 0.152 (A);1%: 183.0 (B)]

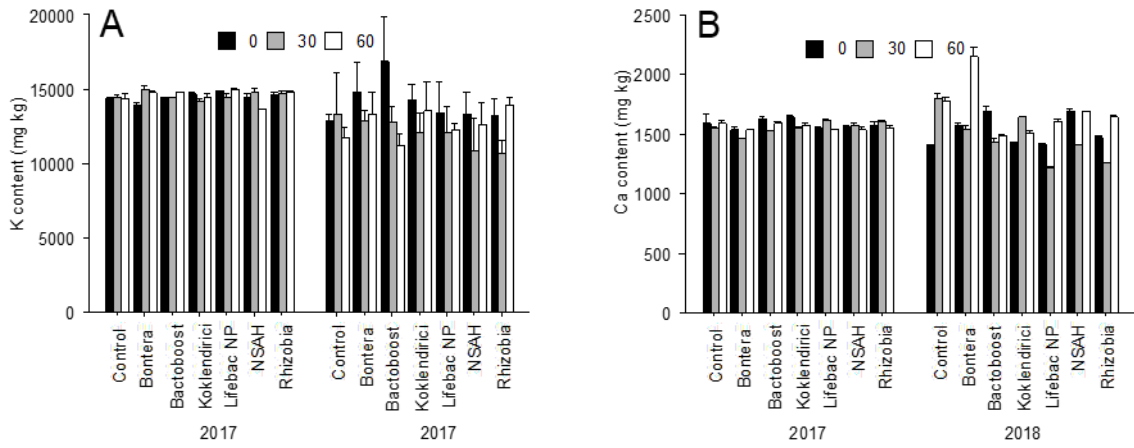


Figure 8. The interaction between year, phosphorus doses and PGPR on K content (A) and Ca content (B) of common bean [LSD 1%: 1181.0 (A);1%: 88.20 (B)]

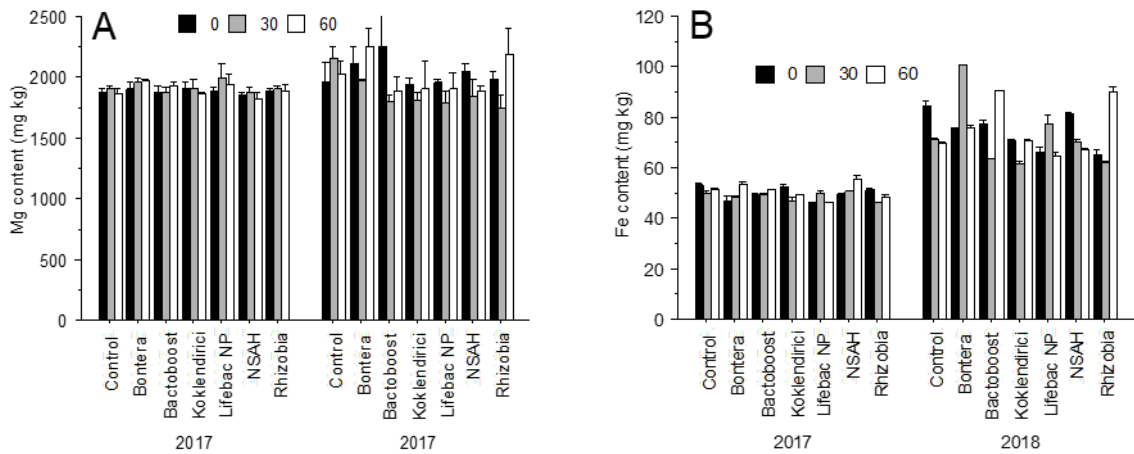


Figure 9. The interaction between year, phosphorus doses and PGPR on Mg content (A) and Fe content (B) of common bean [LSD 1%: 85.56 (A);1%: 3.915 (B)]

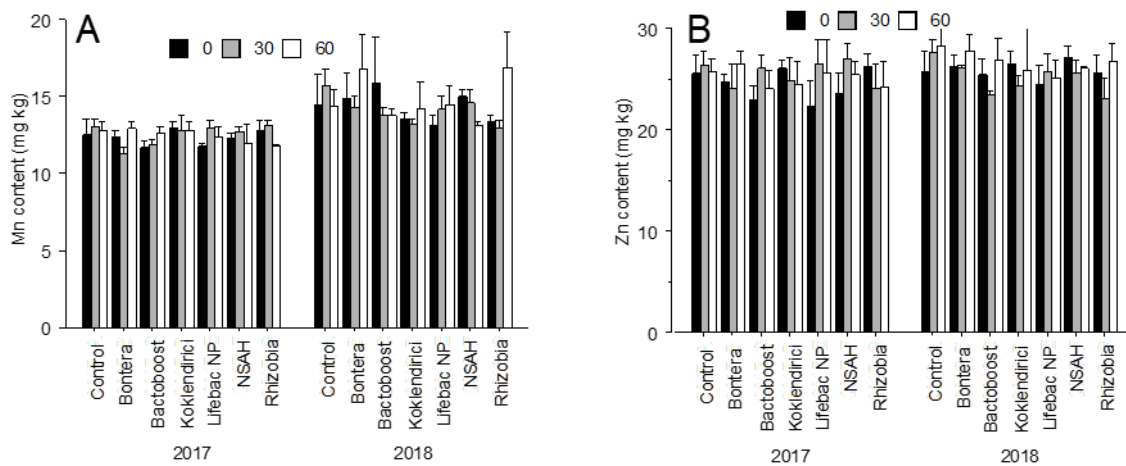


Figure 10. The interaction between year, phosphorus doses and PGPR on Mn content (A) and Zn content (B) of common bean [LSD 1%: 0.845 (A);1%: 1.477 (B)]

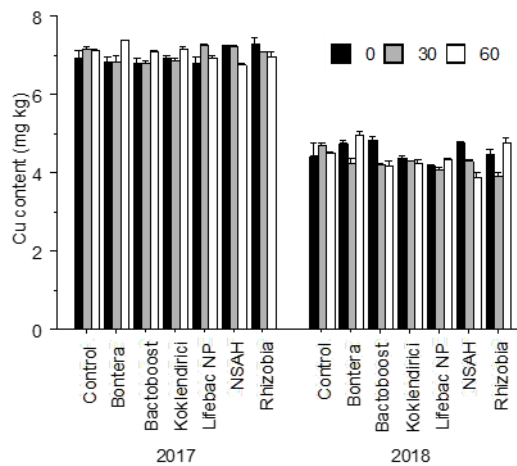


Figure 11. The interaction between year, phosphorus doses and PGR on Cu content of common bean [LSD 1%: 0.360]

The first-year values were higher than the second-year values of all the statistically significant characters (Table 2, 3). The temperature in the second year was higher than in the first year of our research (Figure 1). Flowering and pollination are negatively affected by high temperature; therefore, yield and yield components decrease. Grain yield was 2112 kg ha⁻¹ and 1499 kg ha⁻¹ in the first and second year, respectively (Table 3). Warland *et al.* (2006) reported that grain yield decreased when the temperature increased by 1.5 °C. Aytekin and Caliskan (2015) reported that any stress during the generative periods caused a decrease in grain yield of beans. Number of pods per plant was 25.93 in the first year, and 17.77 in the second year. Bozoglu and Gulumser (2000) and Ulker (2008) reported that the number of pods per plant was affected by environmental conditions. Anlarsal *et al.* (2000) and Kacar *et al.* (2004) reported that high temperatures caused small grains in beans. Ashraf and Hafeez (2004) and Rodríguez *et al.* (2005) reported that high temperature caused a decrease in the assimilation and accumulation; therefore, the plant growth decreased. In addition, high temperatures negatively affect the bacteria. The decrease in the effectiveness of bacteria due to high temperature might have caused lower yield and yield components in the second year. The amount of N, P, and Fe in the soil was higher in the second year of our experiment (Table 1). Therefore, N, P, and Fe contents in the seeds might be higher in the second year. Similarly, Cu content in the soil and in the seeds was higher in the first year.

Although Mg, Mn, and Zn were higher in the soil in the first year, their content in seeds was higher in the second year. Amount of K in the soil was greater in the second year, but its content in seeds was higher in the first year (Table 1). The reasons for these results could be climate and soil conditions, or competition between nutrients. The temperature was higher in the second year of our experiment (Figure 1). The water and nutrient uptake in plants are quicker at high temperatures. The higher N, P, Mg, Fe, Mn, and Zn contents in seeds may be due to the higher temperature in the second year of our experiment.

Table 3. Effects of different phosphorus doses and PGPR on some traits of bean

	Grain yield per plant (g)	Biological yield (kg ha ⁻¹)	Harvest index (%)	Hundred kernel weight (g)	Grain yield (kg ha ⁻¹)
2017	22.93 a	5052 a	41.74	27.31	2112 a
2018	16.46 b	3591 b	41.77	27.61	1499 b
Mean	19.69	4322	41.75	27.46	1805
0 kg/ha P ₂ O ₅	18.35 c	4004 c	41.24 b	26.06 c	1651 c
30 kg/ha P ₂ O ₅	19.36 b	4343 b	41.72 b	28.91 a	1810 b
60 kg/ha P ₂ O ₅	21.36 a	4618 a	42.31 a	27.42 b	1954 a
Mean	19.69	4322	41.75	27.46	1805
Control	20.54 b	4341 c	44.45 a	28.75 ab	1935 b
Bontera	16.81 c	3616 e	41.24 c	27.55 cd	1498 d
Bactoboost	16.68 c	4090 d	38.97 d	27.13 de	1587 c
Koklendirici	22.11 a	4578 b	42.36 b	26.35 e	1934 b
Lifebac NP	19.67 b	4108 d	39.92 d	24.72 f	1638 c
NSAH	20.51 b	4656 ab	45.38 a	29.43 a	2109 a
Rhizobia	21.53 a	4861 a	39.96 d	28.33 bc	1936 b
Mean	19.69	4322	41.75	27.46	1805
Year	**	**	ns	ns	**
Phosphorus doses	**	**	**	**	**
Bacteria	**	**	**	**	**
Year x phosphorus	**	**	ns	**	**
Year x bacteria	**	**	ns	**	**
Phosp. x bacteria	**	**	**	**	**
Year x phosp. x bac.	**	**	*	**	**

ns: non-significant, *: p≤0.05, **: p≤0.01. Means in the same column with different letters are significant.

Increasing phosphorus doses positively affected all the investigated characters. Yield and important yield components increased with increasing phosphorus doses (Table 2, 3). Ahmad (2001) reported that the number of seeds per pod, 1000-kernel weight, and grain yield per plant were significantly affected by the phosphorus levels in common bean. Baydemir (2013) reported that 1000-kernel weight and grain yield increased with increasing phosphorus doses. Turuko and Mohammed (2014) found significant increase in leaf area, dry matter, and grain yield with phosphorus application in common bean. Mtua (2015) reported that increasing phosphorus doses increased biological and grain yields in common bean. Increasing phosphorus dose did not affect N, K, Mg, and Cu contents in the seeds in our experiment. The highest values were observed in the 0 kg ha⁻¹ P₂O₅ plots (Tables 4, 5). Brohi *et al.* (1994) and Sonmez and Yilmaz (2000) reported that increasing phosphorus doses increased the K content. Aydemir and İnce (1988) reported that phosphorus doses reduced Mg content. Anderson and Simon (1991) and Sonmez and Yilmaz (2000) reported that phosphorus fertilization reduced the Cu content. Sen (2018) reported that phosphorus application reduced Fe and Cu content, but increased Mn content. In our experiment, P, Ca, Fe, Mn, and Zn contents in the grain were increased due to the increased phosphorus doses (Tables 4, 5). Brohi *et al.* (1994), Sonmez and Yilmaz (2000) and Sen (2018) reported that phosphorus doses increased P content in the grain. Matula and Tuma (1994)

indicated that phosphorus fertilization increased Mn content in seeds. Sen (2018) reported that phosphorus applications increased Ca content in seeds. Phosphorus fertilization increased the intake of some nutrients because it enhances root development (Hinsinger, 2001). Mtua (2015) reported that nutritional elements were significantly affected by increasing phosphorus doses, and phosphorus doses did not affect the N content in the seeds but increased the P, K, Ca, Mg, Fe, Cu Mn, and Zn contents. The different consequences may be due to different climate and soil conditions.

Table 4 Effects of different phosphorus doses and PGPR on some traits of common bean

	N content in grain (%)	P content in grain (mg kg ⁻¹)	K content in grain (mg kg ⁻¹)	Ca content in grain (mg kg ⁻¹)	Mg content in grain (mg kg ⁻¹)
2017	3.82 b	2645.08 b	14529.3 a	1564.15	1900.48 b
2018	4.21 a	4270.92 a	13126.7 b	1560.81	1954.61 a
Mean	4.01	3458.00	13828.0	1562.48	1927.54
0 kg/ha P ₂ O ₅	4.07 a	3465.64 a	14264.5 a	1551.96 b	1938.21 a
30 kg/ha P ₂ O ₅	3.98 b	3420.15 b	13387.6 c	1515.21 c	1907.28 b
60 kg/ha P ₂ O ₅	4.00 b	3488.21 a	13832.0 b	1621.75 a	1937.15 a
Mean	4.01	3458.00	13828.0	1562.48	1927.54
Control	4.07 ab	3488.60 b	13593.0 bc	1614.38 ab	1956.73 b
Bontera	4.09 a	3606.63 a	14027.1 abc	1631.80 a	2023.82 a
Bactoboost	4.01 bc	3432.79 bc	14072.5 ab	1558.74 cd	1882.83 d
Koklendirici	3.92 d	3375.48 c	14183.5 a	1556.54 cd	1877.76 d
Lifebac NP	3.96 cd	3428.00 bc	13695.1 abc	1487.05 e	1925.94 bc
Nsah	4.06 ab	3431.98 bc	13502.1 c	1574.56 bc	1888.92 cd
Rhizobia	4.00 bc	3442.53 bc	13722.9 abc	1517.76 de	1936.81 b
Mean	4.01	3458.00	13828.0	1562.48	1927.54
General mean	4.01	3458.00	13828.0	1562.48	1927.54
Year	**	**	**	ns	**
Phosphorus doses	**	**	**	**	**
Bacteria	**	**	**	**	**
Year x phosp.	**	**	**	**	**
Year x bacteria	**	**	**	**	**
Phosp. X bacteria	**	**	**	**	**
Y. X phosp. X bac.	**	**	**	**	**

ns: non-significant, *: p≤0.05, **: p≤0.01. Means in the same column with different letters are significant.

The highest seed germinations, biological yield per plant, number of seeds per pod, number of seeds per plant, and grain yield per plant were observed in Koklendirici plots. Koklendirici biofertilizer positively affected the important yield components. While the highest number of pods per plant was observed in the Lifebac NP plots, the highest biological yield was observed in the Rhizobia plots. Biofertilizers affected the harvest index, hundred kernel weight, and grain yield, and the highest values were observed in the NSAH plots (Table 2, 3). PGPR are beneficial native soil bacteria that colonize plant roots and result in increased plant growth (Cleyet-Marcel *et al.*, 2001; Braneix *et al.*, 2005), production of plant growth regulators (De Freitas, 2000), and plant water and nutrient uptake (Okon and Labandera-Gonzalez, 1994; Jacoud *et al.*, 1999). Fayetorbay *et al.* (2014) reported that the effect of bacteria on the number of pods per plant was insignificant, but it increased the 1000-kernel weight and grain yield in Hungarian vetch. Onder *et al.* (1999) examined the combination of two different microbial fertilizers with three phosphorus doses in common bean and they found statistical differences in hundred kernel weight and grain yield per plant. Talay (2019) reported that biofertilizers

increased the 1000-kernel weight and grain yield in barley. Naseri *et al.* (2013) reported that when rapeseed was inoculated with *Azotobacter* and *Pseudomonas*, the grain yield increased by 15.8% and 13.7%, respectively.

Table 5. Effects of different phosphorus doses and PGPR on some traits of bean

	Fe content in grain (mg kg ⁻¹)	Mn content in grain (mg kg ⁻¹)	Zn content in grain (mg kg ⁻¹)	Cu content in grain (mg kg ⁻¹)
2017	49.75 b	12.47 b	24.85 b	7.01 a
2018	73.92 a	14.22 a	25.75 a	4.39 b
Mean	61.83	13.34	25.30	5.70
0 kg/ha P ₂ O ₅	61.97 ab	13.03 b	25.12 b	5.75 a
30 kg/ha P ₂ O ₅	62.45 a	13.20 b	25.52 a	5.63 b
60 kg/ha P ₂ O ₅	61.10 b	13.81 a	25.25 ab	5.73 a
Mean	61.83	13.34	25.30	5.70
Control	63.23 b	13.61 ab	26.22 a	5.80 ab
Bontera	66.56 a	13.41 bc	25.22 bc	5.83 a
Bactoboost	63.53 b	12.75 d	25.10 bcd	5.65 bc
Koklendirici	58.47 d	13.23 bc	25.47 bc	5.64 bc
Lifebac NP	58.36 d	13.05 cd	24.49 d	5.59 c
Nsah	62.17 bc	13.49 ab	25.78 ab	5.68 abc
Rhizobia	60.55 c	13.88 a	24.81 cd	5.73 abc
Mean	61.83	13.34	25.30	5.70
General mean	61.83	13.34	25.30	5.70
Year	**	**	**	**
Phosphorus doses	**	**	*	**
Bacteria	**	**	**	**
Year x phosphorus	**	**	**	**
Year x bacteria	**	**	**	**
Phosp. X bacteria	**	**	**	**
Year x phosp. X bac.	**	**	**	**

ns: non-significant, *: p≤0.05, **: p≤0.01. Means in the same column with different letters are significant.

In addition, they reported that the number of pods per plant, number of seeds per pod, and hundred kernel weight also increased. Yedagari and Rahmani (2010) reported that treatment with PGPR significantly increased pods per plant, number of seeds per pod, 100 seeds weight, seed weight per plant, pod weight per plant, total dry matter, as well as seed yield and protein content. The highest N, P, Ca, Mg, Fe, and Cu contents were determined in Bontera plots. Bontera biofertilizer positively affected the plant nutrients. While the highest K content was observed in the Koklendirici plots, the highest Mn content was observed in the rhizobia plots. Khan *et al.* (2022) reported that bacteria increased N, P, K content in beans. Biofertilizers did not affect the Zn content, and the highest values were observed in the control plots (Table 4,5). PGPR enhances plant development as it increases nutrient uptake by solubilizing inorganic and organic phosphorus, and producing organic acid and acid phosphatase (Puenta *et al.*, 2004; Cakmakci *et al.*, 2005). Nguyen *et al.* (2019) reported that N, P, K, Mg, Zn, and Cu contents increased in wheat with PGPR. Kutlu *et al.* (2019) studied on 35 bacteria, and reported that the N, P, and K increased with the application of bacteria. Yagmur (2019) reported that P, K, Ca, Mg, Na, Fe, Cu, Mn, and Zn contents increased in tomato with the application of PGPR in soil.

Conclusions

Increasing phosphorus doses positively affected all the investigated characters. Koklendirici biofertilizer positively affected the important yield components, but the highest grain yield were observed in the NSAH

plots. Biofertilizers present a realistic option for sustainable agriculture for common bean production. To improve soil fertility and plant growth, effective biofertilizers are a promising tool to maintain the agricultural resources. The use of PGPR strains in agricultural practices is strongly encouraged as they might prove to be a sustainable solution to improve the efficiency of chemical fertilizers. Increasing phosphorus doses did not affect N, K, Mg, and Cu contents of grain, but increased P, Ca, Fe, Mn, and Zn contents. Phosphorus fertilization increased the intake of some nutrients enhancing root development. Different climate and soil conditions might have influenced the results, leading to the difference. This study shows that Bontera can promote nutrient uptake in common bean. The use of biofertilizer enhances soil phosphorus availability which might be suitable for common bean cultivation. It could reduce the negative impacts on environment caused by excessive application of chemical fertilizers. Producers can alleviate the yield loss caused by phosphorus deficiency using biofertilizers. When considering yield and yield components, NSAH can be suggested for sustainable common bean cultivation without any chemical fertilizer under semi-arid mild environments.

Authors' Contributions

H.I.E. and N.K. planned the experiment; O.F. and E.T. conducted the experiment; E.T. made the analysis; N.K. wrote the article. This article was extracted from the M.Sc. thesis of the first author O. Filiz. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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