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Improving Peanut Productivity Using Phosphorus Sources, Humic Substances, and Plant Growth-Promoting Rhizobacteria (PGPR) Under Sandy Soil Conditions

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Abstract

A field experiment was conductedduring the summer season of 2022 to study the effect of two forms of phosphorus (super phosphate and rock phosphate), humic acids, and plant growth-promotingrhizobacteria(PGPR) on peanut yield (*Arachishypogaea* L.) cv. Giza 6. Data showed that humic acids, a mixture of superphosphate and rock phosphate, and PGPR especially those produce exopolysaccharides are crucial for the growth and yield of peanut plants. A superior increase in the effect of humic acids, followed by phosphorus applications on plant height, number of pods per plant, pod weight per plant, seed weight per plant, 100 pod weight, 100 seed weight, pods and seed yields, and shelling percentage was recorded. The co-inoculation with PGPR especiallythatproduces exopolysaccharides, can affect peanut yield and the abovementioned yield attributes and shelling percentage.Moreover, the application of humic substance resulted in significant increases in protein and oil content compared to untreated samples. Finally, the combination ofhumic acids,PGPR, and mixture of super phosphate and rock phosphate resulted in significant increases in all quality parameters of peanuts as compared to untreated ones.

Keywords: Humic acids, phosphorusforms, PGPR,Peanut,yield and yield components

Introduction

Peanut (*Arachishypogaea* L. .; Family: Fabaceae) is one of the most important legume crops worldwide, especially in Egypt. The crop is primarily grown in the northern regions of the country, including reclaimed desert areas to the east and west of the Nile Delta.Peanut seeds have an impressive nutritional value, as 100 g of seeds contain approximately 4% water, 48% fat, 25% protein, and 21% carbohydrates, including 9% dietary fiber (USDA Nutrient Data). In addition to providing a large amount of dietary energy, it is an excellent source of several B vitamins, vitamin E, and several dietary minerals, such as manganese (95% DV), magnesium (52% DV), and phosphorus (48% DV). 83% of the total fat in the seed is polyunsaturated and monounsaturated fats **(Verheye, 2010)**.Moreover, peanuts are used to produce green leafy hay for livestock feed and the oil extracted from its seeds is widely used in various industries.

Humic acids, are the primary constituents of soil organic matter. The presence of humic acids in soil has many beneficial effects on plant growth(**Nardi*et al.*,2002, ; Kadam and Wadje, 2011**), these benefits can be classified into direct and indirect effects. The indirect effects refer to the improvement in soil properties such as aggregation, aeration, permeability, water-holding capacity, and the transport and availability of micronutrients.While the direct effects involve the uptake of humic acids into the plant tissue, resulting in various biochemical effects(**Sarir*et al.*, 2005**). Humic acids can affect the solubility of many nutrient elements by binding with metallic cations to form complexed forms or chelating agents. Many studies have shown that humic acids can improve soil properties, enhance water retention, decrease soil bulk density, and increase total porosity and soil organic matter content(**Atiyeh*et al.*, 2002; Rahmat*et al.*, 2010).**Applying humic acid to sandy soils can be beneficial as it adds essential organic material, which is necessary for water retention. This helps to improve root growth and enhance the sandy soil's ability to retain vital plant nutrients without leaching them out (**Khaled and Fawy, 2011**).

Plant growth promoting rhizobacteria (PGPR) , play a crucial role in enhancing soil quality, bioremediation, and stress control to develop eco-friendly and sustainable agriculture (**Yadav *et al.*, 2019**). PGPR can be utilized as biofertilizers and biopesticides, which can improve plant growth through direct mechanisms like nitrogen fixation, growth regulates production, and phosphate solubilization. Bio-inoculation with PGPR can increase the germination rate and biomass content and provide essential nutrients like N, P, and K to plant roots. They also improve plant growth directly by enhancing the production of phytohormones, siderophores, biofilm, exopolysaccharides as well as increasing the nutrient availability in the rhizosphere or indirectly by protecting plants from pathogens attack **(Kohler *et al.*, 2006)**.

Exopolysaccharides (EPS) are natural polymers of high molecular weight secreted by microorganisms as secondary metabolites into their environment **(Flemming and Wingender, 2001)**. EPSs establish the functional and structural integrity of biofilms, and are considered the fundamental component that determines the physicochemical properties of a biofilm. EPS provides compositional support and protection of microbial communities from the harsh environments as well as their role in microbial aggregation, plantmicrobe interaction, surface attachment, and bioremediation (**Ercole *et al.*, 2007**).

Phosphorus is one of the most essential elements for plant growth and development after nitrogen. Phosphorus plays a critical role in several vital functions, such as photosynthesis, the transformation of sugar to starch, protein information, nucleic acid production, nitrogen fixation, and oil formation. It is also part of all biochemical cycles in plants (**Mehrvarz and Chaichi, 2008**).The structures of both DNA and RNA are linked together by phosphorus bonds. Phosphorus is a vital component of ATP, the "energy unit" of plants. ATP forms during photosynthesis has phosphorus in its structure, and processes from the beginning of seedling growth through to the formation of grain and maturity. Thus, phosphorus is essential for the general health and vigor of all plants. Plants absorb phosphorus from soil solutions as a phosphate anion. A large amount of P applied as a fertilizer becomes immobile through a precipitation reaction with highly reactive Fe^{+2}, Ca^{+2}, and Mg^{+2} in acidic and calcareous, alkaline, or normal soils (**Awasthi*et al.*, 2011**). Therefore, the efficiency of P fertilization throughout the world is around 10–25%. Soil inoculation with phosphate-solubilizing microorganisms such as phosphate-solubilizing bacteria (PSB) and humic acids is usually effective on phosphate solubility.

This study aimed to investigate the effect of different sources of phosphorus, humic acids, and PGPR, as well as how they interact with each other, on the yield and yield components of peanut plants (*Arachishypogaea* L.).

Materials and Methods

Experimental location

One season field experiment was carried out at Ismailia Agricultural Research Station, Agricultural Research Canter,Egypt(lat. 30° 35' 30" N, long. 32° 14' 50" E.) during the summer season of 2022, using sprinkler irrigation system was applied.

Experimental designand treatments

A split-split plot design with three replicates was used, the field was well prepared, plowed twice, leveled, compacted, and divided into experimental units. Each plot area was 10.5 m^2, contained five ridges, each 60 centimeters apart and 3.5 meters long, Treatments were as follows:

- Main plots included two plots:
  - Without humic substances
  - With humic substances
- Sub-main plots (three sources of phosphorus):
  - Single super phosphate (SSP)(15.5 % P_2O_5) with the recommended dose of mineral P fertilizers (200 kg P_2O_5 fed^{-1})
  - Rock phosphate (RP) (28.30% P_2O_5) with the recommended dose of mineral P fertilizers (200 kg P_2O_5 fed^{-1})
  - Halfdose of Single super phosphate + half dose of Rock phosphate.
- Sub-sub-plots (the plants were inoculated with three PGPR inocula):
  - *Bradyrhizobium* sp.
  - PGPR(*Ochrobactrum intermedium, Paenibacillus Polymyxa* and *Enterobacter cloacae*).
  - PGPR-producing EPS (*Bacillus cereus* and *Bacillus albus*)

Experimental soil and additives

The mechanical, chemical, and nutritional properties of the cultivation soil was analyzed according to **Page *et al.*, (1982)** and **Klute (1986)**as presented in **Table (1)**.

Compost at a rate of 10 m^3/fed was mixed thoroughly with the topsoil layer of 0-20 cm for two weeks before sowing. While, humic substanceswere used at the rate of 4 L/fed(applied twice at 30 and 45 days after sowing).

The chemical analysis of compost and humic substances are shown in Tables 2 and 3.

Table 1. Physiochemical properties of the experimental soil

Mechanical and chemical properties								
Coarse sand %	Fine sand %	Silt %	Clay %	Textural class	Ca CO3 %	Organic matter %	pH (1:2.5)	EC (dSm^{-1}) in soil paste extract
68.0	24.6	3.53	3.83	Sandy	1.4	0.35	7.72	0.46
Soluble ions in soil paste extract (meq l^{-1})								
Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}	
1.04	0.97	1.31	0.99	-	1.90	1.22	1.19	
Available macronutrients (mg Kg^{-1})								
N			P			K		
17.45			5.12			118		

Table 2. Physical and chemical properties of the compost

Properties	Value
EC value (1:10) (dSm^{-1})	7.90
pH value (1:10)	6.70
Moisture content (%)	28.00
Organic matter (%)	44.48
Organic carbon (%)	25.80
Total nitrogen (%)	1.42
C/N ratio	18.17
Soluble ammonia-N (ppm)	615.00
Soluble nitrate-N (ppm)	362.00
Total P (%)	0.57
Total K (%)	0.82

Table 3. Physical and chemical properties of the humic acids

Humic acid (%)	Fulvic acid (%)	Dry matter (%)	O.M. (%)	C/N ratio	pH	Ec (dSm^{-1})
14.8	3.5	24.0	70.0	14.0	7.7	0.98
Macronutrients concentration (%)			Micronutrients concentration (mg kg^{-1})			
N	P	K	Fe	Mn	Zn	
3.60	0.13	3.15	435	210	236	

Peanut seeds

Giza 6 variety was obtained from the Oil Crops Research Department, Field Crops Research Institute, ARC, Giza, Egypt.

Bacterial inocula

Bradyrhizobium sp.and non-producing EPS strains namely *Ochrobactrum intermedium(MG309678.1)* , *PaenibacillusPolymyxa* (MG309677.1) and *Enterobactercloacae*or(MG309676.1) as well as PGPR producing EPS strains namely *Bacillus cereus*(MW916285) and *Bacillus albus* (MW916307) were obtained from the biofertilization unit, Fac. Agric. Ain Shams University.

The PGPR inocula were prepared separately in nutrient broth medium and incubated at 30°C for 2 days to reach 10^7 CFU/ml. Equal dose from each cell suspension were mixed and applied **(Yaoyao et al. 2017).**

Cultivation

The phosphorus forms at a rate of 200 kg fed^{-2} in the form of p_2o_5 and potassium sulfate (48% K_2O) at a rate of 50 $kgfed^{-1}$ were incorporated into the soil for all studied treatments before sowing. On May 25th, the peanut seed was sown with hills 20 centimeters apart. The plots were irrigated immediately after sowing, and plants were thinned to one plant per hill after 15 days of sowing and before the first irrigation. All treatments received ammonium sulfate (20.5% N) at a rate of 20 kg N/fed after germination as an activator dose.

Estimations

At the harvest time, ten plants will be randomly taken from the second inner two rows of each experimental unit. These plants will be used to determine several yield components such as pod number per plant, seed number per plant, pod weight in grams per plant, seed weight in grams per plant, 100-pod and seed weight in grams, pod yield in kilograms per feddan, seed yield in kilograms per feddan, and shelling percentages. The oil percentage in the seeds will be determined by using a Soxhlet apparatus and petroleum ether as an organic solvent, as described by **A.O.A.C (1990).**The oil yield in kilograms per feddan will be estimated by multiplying the seed yield in kilograms per feddan by the seed oil percentage.Finally, the shelling percentage will be calculated using the following equation**Kurt *et al.* (2016)**:

$$\text{Shelling }\% = \frac{\text{Seed weight/plant}}{\text{Pod weight/plant}} \quad \text{x}$$

Statistical Analysis

All data were statistically analyzed according to the technique of analysis variance (ANOVA) and the least significant difference (L.S.D) method was used to compare the differencebetween the means of treatment values to the methods described by **Gomez and Gomez, (1984).** All statistical analyses were performed using analysis of variance technique by means of CoSTATE Computer Software.

Results And Discussions

Effect of humic acids on yield components per plant

The effect of humic acids on groundnut plants resulted in a significant increase in various growth characteristics. These characteristics include number of pods per plant, pod weight per plant, seed weight (g/plant), 100 pod weight, 100 seed weight, and shelling percentage. (Tables 4 and 5)

The application of humic acid improvesPeanut growth due to the presence of growth-promoting acids such as indole acetic acid (IAA), gibberellins, and auxins in its structure(**Zandonadi*et al.*, 2010**). These acids are directly involved in various processes such as cell respiration, oxidative phosphorylation, photosynthesis, protein synthesis, and enzymatic reactions.

Humic acids also affects cell membranes, led to enhance transport of minerals, improved protein synthesis, plant hormone-like activity, the solubilization of micro and macro elements, the reduction of active concentrations of toxic minerals, and an increased population of microbes (**Peuravouri*et al.*, 2004**).

Effect of phosphorus forms on yield components

Tables 4 and 5declared that mineral phosphorous fertilizer can affect number of pods per plant, pod weight per plant, seed weight (g/plant), 100 pod weight, 100 seed weight, and shelling percentage. Phosphorous fertilizers play a crucial role in providing essential nutrients to all plants. These fertilizers activate metabolic processes that are responsible for building phospholipids and nucleic acids. Phosphorus is particularly important for legumes and other crops as it is a key component of ATP, which helps in energy transformation in plants. It also encourages the formation of new cells, promotes plant vigor, and hastens leaf development, which in turn helps in harvesting more solar energy and better utilization of nitrogen. The findings of this research are consistent with those of **Malik *et* al (2003) and Rathour*et* al . (2015).**

Effect of PGPR on yield components

The data presented in Tables 4 and 5, demonstrate the effects of co-inoculation with PGPR on peanut yield attributes .The results indicate that inoculation with the tested microorganisms led to significant increases in yield attributes when compared to the uninoculated treatment. Co-inoculation of peanuts with Bradyrhizobia and any of the tested PGPRsespecially those produce exopolysaccharide resulted in a significant increase in the peanut yield when compared to the uninoculated control. It is worth noting that PGPRs have been shown to significantly improve the productivity and quality of many legumes when co-inoculated with rhizobia. Microorganisms have the ability to improve N2-fixation performance, nutrient availability, and uptake from the soil, which leads to the production of acids like hormones, siderophores, and phosphate solubilization, as well as the improvement of nutrients and water uptake. This leads to a synergistic effect which has been observed in various studies, including those conducted by **Yadav and Verma (2009); Verma*et al.* (2010).**

PGPR producing EPS has been reported to significantly enhance plant height, root length, number of leaves, and plant dry matter content **Harahap*et al*., 2018**. Additionally, **Khan *et al* (2018)** reported the beneficial effects of PGPR producing EPSon chlorophyll content, leaf protein and sugar content, shoot and root weight in chickpea plants grown under sandy soil condition. Plant roots play a key role in water use efficiency (WUE) and adaptation to drought. Root biomass was greater in STM196-inoculated plants, and alterations of the root architecture as a result of the presence of the bacteria may have enhanced the water absorption capacity.

Table 4. Effect of phosphorus form, humic acids, and PGPR as well as their interactions on Yield components characters per plant

Treatments			Yield components characters		
	P fertilizer	Bio	No. of pods/plant	Pod weight (g/plant)	Seed weight (g/plant)
With humic acids	SP	control	71	66	44
		PGPR1	118	82	58
		PGPR2	114	85	56
	RP	control	82	55	38
		PGPR1	99	86	62
		PGPR2	80	77	56
	SP+ RP	control	80	58	38
		PGPR1	120	79	56
		PGPR2	101	85	64
With out humic acids	SP	control	58	57	36
		PGPR1	92	65	42
		PGPR2	97	63	45
	RP	control	50	43	33
		PGPR1	64	59	40
		PGPR2	95	60	45
	SP+ RP	control	58	62	36
		PGPR1	89	66	40
		PGPR2	99	71	48
L.S.D. at 0.05					
humic(A)			*	*	**
P fertilizer (B)			ns	*	*
Bio-fertilizer(C)			***	***	***
A x B			***	**	**
A x C			***	Ns	Ns
B x C			*	Ns	Ns
A x B x C			***	Ns	Ns

Effect of interaction between humic acids, phosphorus forms, and PGPR on yield components

Combining co-inoculation bacteria, humic acids, and phosphorus in legume plants has been found to increase peanut yield attributes compared to the use of each component separately. This is because when the seeds are inoculated with a suitable *Rhizobium* strain as well as PGPR and given small amounts of phosphorus during the early growth stage, it stimulates root nodulation, resulting in increased biological nitrogen fixation.

This process improves yield components such as the number of branches and pods per plant, the number of seeds per pod, and seed weight (**Dahmardeh*et*and Ramroodi, 2010 andMorad*et al.*, 2013). Singh and Reddy (2011)** found that the inoculation of P-solubilizing bacteria along with rock phosphate led to a significant increase in the yield, nutrient uptake, and available P of wheat and maize plants compared to the control.

Table 5. Effect of sources of phosphorus, humic acids, and bio applications as well as their interactions on seed yield per plant.

	Treatments		Yield components characters		
	P fertilizer	Bio	100 pod wt.(g)	100seed wt.(g)	Shelling (%)
With humic acids	SP	Control	155.0	59.63	67
		PGPR1	215.0	77.10	71
		PGPR2	191.6	78.60	66
	RP	Control	140.3	61.00	70
		PGPR1	213.3	77.87	72
		PGPR2	203.3	81.63	73
	SP+ RP	Control	136.0	58.07	66
		PGPR1	224.3	77.46	71
		PGPR2	225.0	79.47	75
With out humic acids	SP	Control	128.3	51.53	63
		PGPR1	181.6	65.50	65
		PGPR2	184.6	67.10	72
	RP	Control	139.3	44.16	77
		PGPR1	173.6	64.83	68
		PGPR2	194.6	67.07	74
	SP+ RP	Control	145.0	51.67	58
		PGPR1	178.3	71.33	61
		PGPR2	172.0	74.67	68
L.S.D. at 0.05					
humic(A)			*	*	
P fertilizer (B)			*	**	
Bio-fertilizer(C)			***	***	
A x B			**	***	
A x C			Ns	Ns	
B x C			*	Ns	
A x B x C			*	Ns	

Effect of humic acids on Peanut yield per fedan

Data presented in **Table 6** illustrate the impact of humic acids on peanut crop yield. The yield of pods and seeds was higher in crops treated with humic acids compared to the control group. The reason for this could be the induction of carbon and nitrogen metabolism caused by humic acids. As per **Nardi*et al.* (2009)**, the exogenous application of humic acids increases the activity of enzymes involved in glucose metabolism, such as glucokinase, phosphoglucose isomerase, aldolase, and pyruvate kinase. In addition, primary enzymes linked to N assimilation, like nitrate reductase, glutamate dehydrogenase, and glutamine synthetase, are also stimulated by humic substance application, **(Canellas *et al.*, 2015). (Patil*et al.*, 2010)** reported that applying humic acids promotes plant growth, increases crop resistance, improves crop quality, and protects the agricultural ecological environment. It also increases root growth, root penetration, and chlorophyll density, thereby aiding in photosynthesis. Increasing the levels of proteins, fibers, and sugars can improve quality and yield.

Effect of phosphorus form on peanut yield

Table 6 also show the effect of mineral phosphorus fertilizer and rock phosphate on peanut crop yields (pod and seed yield) and biological yield. The results indicate that the application of phosphorus increases both the total yield and biological yield. This positive outcome can be attributed to the essential role of phosphorus in legumes, which helps in root formation and the development of healthy lateral and fibrous roots. Additionally, phosphorus is crucial in seed formation as it plays a significant role in protein synthesis, phospholipids, and phytin (**Rahman *et al.*, 2008**), all of which are essential for plant growth.

Effect of PGPR onPeanut yield

The data in Table 6 also shows that *Bradyrhizobium* inoculation alone or in combination with any of the tested PGPR resulted in significant increases in all peanut yields as compared to the uninoculated treatments. These positive results can be attributed to the root exudates that serve as suitable substrates for associative microorganisms. These microorganisms release plant-promoting acids, mainly indole acetic acid, gibberellins, and cytokinins, which stimulate plant growth, nutrient absorption, nutrient efficiency, and the metabolism of photosynthates. These findings support the research of **Kloepper (2003), Tilak*et al.* (2005), and Verma*et al.* (2010).**

Polysaccharides are hygroscopic and therefore, may uphold a higher water content in the colony micro-environment than in the bulk soil as water potential declines **Roberson and Firestone (1992).** Polysaccharides-producing bacteria were capable of maintaining higher soil moisture content and growth of plants even in sandy soils (**Khan *et al*., 2017**). The greater release of soluble carbohydrates into the rhizosphere soil of plants inoculated with PGPR possibly improved the survival efficiency of microorganisms under water deficit conditions. Besides this, the extracellular polysaccharides released by PGPR in the rhizosphere, with the adjacent mineral particles, can form rhizosheath around the plant roots and thus protect them from desiccation for a longer period of time (**Khan *et al*., 2018).**

Effect of interaction between humic acids, phosphorus forms, and biofertilizationon peanut yield

Table 6 provides information about the impact of interactions between humic acids, sources of phosphorus, and PGPR on pod and seed yield, as well as the biological yield of peanut crops. According to the data, the plants that received 100% SSP+ humic acids + PGPR had the highest values for these parameters, followed by 50% SSP+ 50% RP +humic acids +PGPR. This could be attributed to the release of organic acids that can either reduce the pH of the surrounding soil or directly dissolve the mineral phosphate, or to the chelating properties of the organic acids produced by bio, such as acetate, lactate, oxalate, citrate, and others. Similar results were reported by **Atiyeh*et al.* (2002),** who found that humic acid was effective in promoting plant growth and development due to the presence of plant growth regulators like IAA, GAs, and CKs.

Table 6. Effect of phosphorus forms, humic acids, and bio applications as well as their interactions on Yield characters per fed.

Treatments			Yield (kg fed^{-1})		
	P fertilizer	**Bio**	**pod yield Kg/fed**	**Seed yield Kg/fed**	**biological yield/fed**
With humic acids	SP	**Control**	**1698**	**984**	**2683**
		PGPR1	**1944**	**1178**	**3123**
		PGPR2	**2311**	**1213**	**3524**
	RP	**Control**	**1627**	**960**	**2587**
		PGPR1	**1691**	**1163**	**2854**
		PGPR2	**1770**	**1205**	**2975**
	SP+ RP	**Control**	**1758**	**1012**	**2770**
		PGPR1	**2124**	**1242**	**3366**
		PGPR2	**2217**	**1255**	**3472**
With out humic acids	SP	**Control**	**1691**	**943**	**2634**
		PGPR1	**1717**	**1128**	**2845**
		PGPR2	**1878**	**1137**	**3014**
	RP	**Control**	**1558**	**939**	**2498**
		PGPR1	**1624**	**1082**	**2706**
		PGPR2	**1751**	**1102**	**2853**
	SP+ RP	**Control**	**1562**	**988**	**2550**
		PGPR1	**1878**	**1219**	**3097**
		PGPR2	**1944**	**1230**	**3174**
L.S.D. at 0.05					
humic(A)			*	*	*
P fertilizer (B)			***	*	***
Bio-fertilizer(C)			***	***	***
A x B			***	*	***
A x C			***	*	***
B x C			**	*	**
A x B x C			*	*	*

Effect of humic acids on quality parameters

The impact of humic substance treatments on protein and oil content, as well as protein and oil yield fed^{-1} were shown in Table (7). The results show that the protein and oil content of treated samples was higher than that of untreated samples. Humic acids promote plant growth by improving the assimilation of major and minor elements, activating enzymes, modifying membrane permeability, and increasing protein synthesis, which ultimately promotes biomass production (**Ulukan, 2008**). Humic acids may also interact with cell membranes and act as nutrient carriers. The ability of humic acids to stimulate fatty acid biosynthesis may explain the increase in oil content in seeds. According to **(Noroozisharaf and Kaviani 2018),** humic acid improves the expression of phenylalanine ammonia-lyase, which stimulates the production of phenylpropanoid by transforming tyrosine to P-coumaric acid and phenylalanine to trans-cinnamic acid.

Effect of Phosphorus forms on quality parameters

Regarding the impact super phosphate and rock phosphate fertilizers on the percentage of protein and oil contentas well as protein and oil yield fed^{-1}, Table 7 reveal that there were significant variations on quality parametersbased on the type of fertilizer used. The highest percentage of protein and oil content was recorded from the application of SP fertilizer. It is believed that the superiority of the phosphorus fertilizer treatment can be attributed to its role in improving chlorophyll content and nodulation during the growth stage of plants.

Effect of PGPR on quality parameters

Table 7provide data on the effect of co-inoculation treatments on the protein and oil content as well as protein and oil yield fed^{-1} of peanuts. The results show that *bradyrhizobium* inoculation, either alone or in combination with other microorganisms, significantly increases all peanut quality parameters compared to the uninoculated treatments. These positive effects are attributed to the ability of plant growth-promoting rhizo-microorganisms to enhance plant growth, nutrient absorption, nutrient use efficiency, and photosynthate metabolism. These findings are consistent with the results of previous studies by **Kloepper (2003), Tilak*et al.* (2005), and Verma*et al.* (2010).** Co-inoculation of rhizobia and plant growth-promoting rhizo-microorganisms is an effective strategy for improving the productivity of legumes and providing them with natural bio-protection against phytopathogens under a sustainable agriculture system (**Verma*et al.*, 2010)**. The ability to solubilize Ca-P complexes is attributed to the PSMs' ability to reduce the pH of their surroundings by releasing organic acids or protons. The organic acids secreted can directly dissolve the mineral phosphate through anion exchange of PO4 2- by acid anion or chelate both Fe and Al ions associated with phosphate.

Sandy soil has very low aggregate stability so, one effort to improve aggregate stability is with indigenous bacterial-producing exopolysaccharide. Exopolysaccharide-producing bacteria are currently receiving considerable attention in improving aggregate stability. Exopolysaccharides that are attached to the wall of soil particles will further fill the pores of the soil through a process called bio-clogging (**Harahap*et al*., 2018**). Exopolysaccharide (EPS) is produced by Gram-negative and Gram-positive bacteria. According to **Alami*et al.* (2000)**, the increase of soil aggregate stability in the area around rooting has been obtained with the addition of inoculant exopolysaccharide-producing bacteria.

Effect of interaction between humic acids, phosphorus forms, and biofertilization quality of peanuts

Based on the results mentioned above, it can be concluded that co-inoculation with humic acids and sources of phosphorus fertilizers is an effective strategy for increasing the productivity of legumes. It also provides natural protection to legume plants against phytopathogens in a sustainable agriculture system (**Verma*et al.*, 2010**). The combination of humic acids and phosphorus fertilizers promotes plant growth, enhances nutrient absorption and efficiency, and improves the metabolism of photosynthates.

Table 7. Effect of phosphorus forms, humic acids, and bio applications as well as their interactions on *Yield quality characters*

Treatments			Yield quality characters			
	P fertilizer	Bio	Oil (%)	oil yield (kg/fed)	Protein (%)	Protein yield (kg/fed)
With humic acids	SP	control	45.3	446	23.13	227.63
		PGPR1	47.4	559	28.69	338.03
		PGPR2	47.8	580	28.81	349.59
	RP	control	44.5	427	23.75	228.00
		PGPR1	46.6	542	26.94	313.37
		PGPR2	47.2	569	29.81	359.24
	SP+ RP	control	45.9	464	23.31	235.84
		PGPR1	48.6	603	28.25	350.77
		PGPR2	47.9	601	28.00	351.40
With out humic acids	SP	control	44.2	417	23.06	217.4
		PGPR1	46.4	523	28.31	319.37
		PGPR2	46.8	532	28.88	328.21
	RP	control	42.9	403	22.94	215.46
		PGPR1	45.8	496	29.44	318.61
		PGPR2	45.9	506	30.13	332.08
	SP+ RP	control	45.3	448	23.81	235.27
		PGPR1	47.5	579	30.63	373.42
		PGPR2	47.6	585	26.75	329.03
L.S.D. at 0.05						
humic(A)			*	**	*	*
P fertilizer (B)			**	*	*	*
Bio-fertilizer(C)			***	***	***	***
A x B			***	*	*	*
A x C			ns	Ns	ns	Ns
B x C			ns	Ns	***	**
A x B x C			ns	Ns	**	**

Conclusion

The study concludes that humic acids, mixture of super phosphate and rock phosphate, and PGPR especially those produce exopolysaccharide are crucial for the growth and yield of peanut plants. The application of these acids can improve the yield and yield components of peanuts. Inoculation of peanuts with PGPR may enhance sustainable agricultural production. PGPR increases soil fertility throughproduction of biological N2 fixation and phosphatesolubilization, enhance plant growth, and increasecrop production by synthesis of phytohormones andreducing ethylene levels and suppressing phytopathogensthat cause plant diseases and stimulate toleranceto biotic and abiotic stress.The positive perspective of this study emphasizes the significant impact of humic acids, sources of phosphorus, and PGPR on the growth and yield of peanut plants and their quality.

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تحسين إنتاجية الفول السوداني باستخدام مصادر الفوسفور والمواد الدبالية والبكتريا الجذرية المعززة لنمو النبات(PGPR) في ظروف التربة الرملية

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أجريت تجربة في محطة بحوث الاسماعيلية التابعة لمركز البحوث الزراعية – جمهورية مصر العربية ، خلال الموسم الصيفي لعام 2022 . وذلك بهدف دراسة تأثير مصدرين من السماد الفوسفاتي (سوبر فوسفات و صخر الفوسفات) والمواد الهيومية وكذلك التلقيح بالكبتريا المحفزة لنمو النبات PGPR(المنتجة و الغير منتجة للسكريات العديدة) علي محصول الفول السوداني ومكوناته من صنف جيزه 6 . أظهرت النتائج أن المواد الهيومية ،وخليط من السوبرفوسفات والفوسفات الصخري،و PGPR خاصة تلك التي تنتج السكريات العديدة ضرورية لنمو وإنتاجية نباتات الفول السوداني.

كما أوضحت النتائج أن إضافة المواد الهيومية يليه التسميد الفوسفاتي أعطي اعلي استجابة لطول النبات وعدد القرون لكل نبات ووزن القرون لكل نبات ، ووزن 100 قرن وكذلك وزن 100 بذرة علاوة علي الوزن الكلي لمحصولي القرون والبذور ، والنسبة المئوية للقصف . كذلك أوضحت الدراسة أن التلقيح بالعزلة من بكتريا PGPRخاصة تلك المنتجة للسكريات العديدة أن لها القدرة في التأثير علي طول وعدد القرون للنبات وكذلك الوزن الجاف للقرون والبذور لكل نبات وايضا وزن 100 قرن وبذرة وبالاضافة إلي نسبة القصف . بالنسبة لبكتريا الجذور فانها تعمل علي تنشيط نمو النبات من خلال العديد من الاضافات البيوكيميائيةكما اوضحت الدراسة ان اضافة الهيومات أدت لزيادة معنوية في محتوي البذور من البروتين والزيت مقارنة بعدم إضافة الهيومات . بالاضافة إلي ذلك فإن التسميد بالهيومات والتلقيح بالبكتريا الجذرية موضع الدراسة أدي إلي زيادة معنوية في جميع صفات الجودة لمحصول الفول السوداني مقارنة بالكنترول .