Advances in Crop Science and Technology
ISSN: 2329-8863
Research Article Open Access

Screening and Evaluation of Plant Growth Promoting Rhizobacteria from Potential Bread Wheat (*Triticum aestivum L.*) Rhizospheric Soil at Lemo Woreda, Southern Ethiopia

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Abstract

Plant growth-promoting rhizobacteria are a group of bacteria that survive inside and outside of the plant tissue and promote plant growth through direct or indirect mechanisms. Different microbial based approaches, in the form of bio fertilizers, bio-stimulants, and/or bio pesticides are currently proposed as alternatives for improving crop yield. A particular group of microorganisms, termed plant growth-promoting rhizobacteria (PGPR), positively influence plant growth, and represent promising sustainable solutions to increase plant biomass production. Therefore, the current study was conducted with the objective of isolation of plant growth promoting rhizobacteria (PGPRB) from wheat rhizospheric soil and screening for the primary growth-related trait, evaluation of potential PGPRB at the greenhouse for wheat growth performance, and identification through biochemical characterization. Accordingly, in this study, a total of 8 plant growth-promoting rhizobacteria were isolated from the rhizospheric soil by serial dilution. The bacterial isolates were screened for primary growth-promoting traits such as phosphate solubilization, IAA production test at different concentrations of L-tryptophan, and ammonia production test. From the isolated bacteria three isolates such as HUPGPRBW-1, HUPGPRBW-2, and HUPGPRBW-3 were solubilized phosphorous, produced IAA and produced ammonia. The highest IAA production (32.7 µg/ml) was observed in HUPGPRBW-1 isolates and the lowest production (7.5 µg/ml) of IAA was recorded in HUPGPRB W-7 isolates. In this study, 37.5% of isolates fulfilled the primary screening test and were used for further greenhouse evaluation. Accordingly, three isolates were tested for greenhouse experiment using a completely randomized design and all 3 isolates significantly increased all the selected plant growth parameters such as shoot length, root length, shoot, and root fresh and dry weight as compared to the control. Among the 3 isolates, two isolates (HUPGPRBW-1 and 2) showed the highest stimulator effect on the shoot and root growth as compared with the control group. Thus, the use of plant growth-promoting rhizosphere bacteria could be useful to improve wheat production and productivity.

Keywords: Growth; Rhizo-bacteria; Fixation; Organic-farming

Introduction

Wheat (*Triticum aestivum L.*) is one of the globally produced and marketed cereal crops covering 15% of the total growing areas of cereal crops world (Kiss, 2011). It is an important industrial and food grain ranking second after rice worldwide (FAO, 2009; Najafi, 2014). In Ethiopia, major cereal crops are grown in the highlands and these regions are regarded as the largest wheat producer in Sub-Saharan Africa (Efrem et al., 2000).

In 2016 wheat production area in Ethiopia has expanded to 1.7 million ha making the country the leader in terms of total wheat production and area covered in sub-Saharan Africa (CSA, 2016). Nevertheless, the country is still importing high amount of wheat every year in order to address food insecurity problems and fulfill input required for agro-industries. Wheat import has grown significantly over the past decade by an average of 6.6 percent (Samuel et al., 2017). Although total wheat production has increased as a result of expansion of wheat cultivation area and use of excessive chemical fertilizers over the last few years, its productivity per unit area, however, is still low in Ethiopia compared to world wheat production (CSA, 2016).

Report indicated that wheat production has been negatively affected by both biotic and abiotic stresses. Conventional agriculture plays a significant role in meeting the food demands of a growing human population, which has also led to an increasing dependence on chemical fertilizers and pesticides (Santos et al., 2012).

Agricultural practices have focused on maximizing yields by increasing fertilization, mainly N and P fertilizations. However, an excessive use of these compounds causes destruction of soil microbial flora, loss of soil structure, leaching and pollution of water resources, and gaseous emissions to the atmosphere, with irreparable negative consequences on the environment and human health (Zahid et al., 2015).

Therefore, organic farming is the best solution to overcome wheat production constraints and the negative environmental effects of chemical fertilizers [1].

Organic farming is mostly dependent on the natural micro flora of the soil, which constitutes all kinds of useful bacteria and fungi including the arbuscular mycorrhiza fungi (AMF) and other bacteria

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Received: 02-Oct-2023, Manuscript No: acst-23-112406, **Editor Assigned:** 05-Oct-2023, Pre QC No: acst-23-112406 (PQ), **Reviewed:** 19-Oct-2023, QC No: acst-23-112406, **Revised:** 23-Oct-2023, Manuscript No: acst-23-112406 (R), **Published:** 30-Oct-2023, DOI: 10.4172/2329-8863.1000633

Citation: Alemneh Y, Chimdessa M (2023) Screening and Evaluation of Plant Growth Promoting Rhizobacteria from Potential Bread Wheat (Triticum aestivum L.) Rhizospheric Soil at Lemo Woreda, Southern Ethiopia. Adv Crop Sci Tech 11: 633.

called plant growth promoting rhizobacteria (PGPR).

Bio-fertilizers keep the soil environment rich altogether sorts of micro- and macro-nutrients via organic processes, phosphate and potassium solubilization or mineralization, release of plant growth regulating substances, production of antibiotics and biodegradation of organic matter in the soil (Sinha, 2014).

When bio-fertilizers are applied as seed or soil inoculants, they multiply and participate in nutrient cycling and benefit crop productivity (Singh, 2011). Plant growth promoting rhizobacteria (PGPR) are a group of microorganisms which colonize the rhizosphere of plants, and are capable of fixing nitrogen, dissolving organic and inorganic phosphorus (Han et al., 2015), secreting auxin and antagonizing pathogens, and promoting plant growth (Ahmad et al., 2012). PGPR can exert beneficial effects on plant growth with direct/ indirect mechanisms to produce durum wheat of sufficient quantity and quality. These rhizospheric bacteria enhance plant growth and yield either directly or indirectly; convert directly elements such as nitrogen and phosphorus into nutrients that can be absorbed and utilized by plants and they secrete indole-3- acetic acid (IAA), gibberellins and cytokines to directly promote plant growth (Mohite, 2013). Moreover PGPR colonize plant rihzospheres and inhabit or reduce soil borne diseases and also improve the plants own defense by inducing plant resistance, thereby reducing the adverse effects diseases on plant growth, development and yield (Verma et al., 2015).

Even though there are so many importance of PGPR in promoting crop‘s growth and yield, most of them are not identified specifically for specific species and genotypes. Therefore, this study was, conducted to identify PGPR and evaluate their growth promotion on wheat [2].

Materials and Methods

Description of the study area

Rhizospheric soils were collected from Lemo Woreda, Southern Ethiopia. Lemo Woreda is located at about 230 kilometers away from Addis Ababa to the south, and lies between 70° 22‖ to 70° 45’ 00” Latitude and 37°.40‖ to 38° 00‘ Longitude with an altitudinal range of 1501-2500 m.a.s.l. It is bordered by Silte zone in the north, Kembata Tembaro zone in the South, Gombora Woreda of Hadiya Zone in the North West, and Ana Lemo Woreda of Hadiya Zone in the North East and Shashogo Woreda of Hadiya Zone in the East. The Woreda is characterized by two agro-climatic zones: Dega or the highland (9%) and Weina Dega or midland (91%). Laboratory and greenhouse experiments on bacterial isolation, characterization and evaluation of their growth promotion were conducted in National Agricultural Biolotechnology Research Center at Holeta (NABRC) [3].

Soil sampling for isolation of growth promoting bacteria

The soil samples were collected from southern part of Ethiopia (Lemo wereda) randomly where wheat is frequently cultivated for daily consumption of people and the collected samples were transported to Hollota National Agricultural Biotechnology Research Center (NABRC) Microbial Biotechnology laboratory. The collected soils were grinded and sieved by 2 mm sieve in order to minimize physical size and ready for further process.

Isolation of PGPR bacteria

One gram (1 g) soil was taken and transferred to 9 ml of sterilized 0.85% saline solution. The serial dilution continued up to 1 × 10-8 by taking 1000 µl of diluted sample and poured to the nutrient agar plate media from the dilution factor of 1 × 10-4, 1 × 10-5 and 1 × 10-6 by taking 100 µl of diluted sample and by spreading plate method in 3 replications for each. The plates were incubated at 28°C for 2 days. Individual bacterial colonies were selected and sub cultured on nutrient agar three times for purification hence, pure bacterial isolates were obtained by sub culturing. Then for each isolate, two copies were made; one copy for long term preservation in 40% glycerol at - 80°C and another copy stored in 4°C refrigerators for the active work [4].

Biochemical and morphological characterization of PGPR

Biochemical characterization: Isolates were gram stained according to the methods described in detail below.

Gram staining: The gram staining procedure was carried out according to the method described in Prescott (2002). As briefly described, 100 µl overnight culture of bacterial cell suspension was added to surface sterilized microscopic slide, and it was smeared gently. Then, the slides were inserted into crystal violate and washed by sterilized water. Again, the slides were inserted to iodine solution and washed by sterilized water. Then, the slides were inserted into 97% of ethanol and washed by sterilized water. Finally, the slides were inserted into safranin solution and washed by sterilized water and examined using the 100x objective lens microscopy and purple colored bacteria were gram positive, whereas read colored or colorless bacteria were gram negative [5].

Morphological characterization

A loop full active cell suspension of the isolates were streaked on nutrient agar media and incubated for 24 hours at 28°C then the colony morphology was recorded.

Qualitative determination of plant growth promoting traits

Phosphate solubilization test: Phosphate solubilization activity of plant growth promoting rhizospheric bacterial isolates were detected in plate assay method using Pikovaskaya (PVK) agar by following the method described by Babiye (2019) and Pikovaskaya (1948). CFU/ml calculated by using the formula.

$$\textbf{Colony forming unit} = \frac{number\ of\ colony \times dilution\ factor}{Volume\ of\ culture\ plate}$$

Broth media prepared for 24 hours and then pure fresh overnight culture were transferred to broth media and after 24 hour incubation from broth media one drop of fresh culture media is transferred to each plates that contain PVK agar media. PVK agar medium contained: glucose=10 g; Ca_3 (PO4)2=5 g; (NH4) SO_4=0.5 g; NaCl=0.2 g; $MgSO_4$.7H2O=0.1 g; KCl=0.2 g; NaCl=0.2 g; MnSO4.H2O=0.002 g; $FeSO_4$.7H2O=0.002 g and yeast extract=0.5 g per liter of a media. The plates were incubated for 2-3 days at 28°C after which the isolate that could make a clear hallo zone was selected. Plates without streak of isolates were used as control. The clear hallo zone of the isolate was measured using a ruler. The isolate differentiation was made using phosphate solubilization index calculated with the following formula [6].

Quantitative determination of IAA

Isolates that have the potential to solubilize the phosphate were selected and tested for the production of IAA by using the method described by Thakuria et al. (2004). With a replication of 3 for each isolate, 100 µl of overnight fresh bacterial cell suspension was added to 20 ml of sterile peptone yeast extract broth (which contained per

litter peptone=10 g; beef extract=3 g; NaCl=5 g; L-tryptophan=50 mg; distilled water=1 L; pH=7) in to 50 ml sterilized falcon tubes, and was incubated for 72 h at 28°C in the dark by wrapping with aluminum foil. After 72 hr of incubation, cultured isolates were taken and centrifuged at 10,000 rpm for 10 min, and 10 ml of the supernatant was withdrawn and put in 15 ml test tube, and then added 5 ml of Salkawaski reagent which contained a 1:1 ratio of (50 ml, 35% perchloric acid, and 1 ml per 1.5 M of $FeCl_3$ solution). The culture falcon tubes were incubated at 37°C in the dark for 1 h. Formation of red color in the medium was then considered as the ability of IAA production of isolates [7].

Test for ammonia production

Isolates which had the potential to solubilize phosphorus and able to produce IAA were further tested for Ammonia (NH3) production following the method described by Cappuccino and Sherman (1992). Pure overnight 100 µl culture of fresh bacterial cell suspension was inoculated in 30 ml of peptone broth (4%) in triplication and was incubated at 28°C for 72 hours. After incubation, 2 ml Nessler's reagent which contained (potassium iodide=50 gm; saturated mercuric chloride=35 ml; distilled water=25 ml; potassium hydroxide (40%)=400 ml) was added using serological pipette. The formation of yellow to brown precipitate showed the presence of NH3. For the control, Nesslers reagent was added to the broth without inoculums. Then, the produced NH3 was quantified by reading the OD at 530 nm comparing the potential of isolate with the standard of produced ammonia.

Evaluation of isolates for wheat growth promotion

Inoculum preparation

The isolates which have the potential to pass the screening test were considered for greenhouse evaluation by following the method described by Idris et al. (2009). Flasks which have the capacity of 250 ml were selected and filled with 150 ml of nutrient broth and were sterilized with steam sterilization method, and cooled down overnight by putting at the hood. Then, 100 µl of pure overnight suspension culture was added to the broth and incubated at incubator shaker for 72 h by adjusting rpm 150 per minute and temperature 28°C. After 72 h of incubation, the standard concentration was adjusted at 1 × 10-9 [8].

Results and Discussion

Morphological and cultural characteristics of plant growth promoting rhizobacteria from wheat rhizosphere

The wheat rhizosphere isolates showed diverse morphology and cultural characteristics variations such as colony shape, size, and color. On the basis of their gram reaction, 3 of the isolates were found to be gram- positive and 5 were gram-negative bacteria. Regarding the shape of isolates, 4 isolates showed rod shape, 3 showed cocci / oval and 1 showed oval shape. Generally, the colonies produced were irregular or regular surfaces, circular, translucent, opaque, white, off-white, and yellow with smooth or irregular margins (Table 1). The variation in morphological characteristics of different isolated observed during the study was similar to that reported previously by Hafeez et al. (2006).

Efficiency of rhizobacteria isolates on phosphate solubilization and ammonia production

In this study, a total of 8 isolates were subjected to morphological characterization. Among these isolates, three isolates such as HUPGPRBW-1, HUPGPRBW-2 and HUPGPRBW-3 showed positive effects on the production of ammonia and phosphate solubilization (Table 2).

Phosphate solubilizing microbes were detected by the formation of clear zones around their colonies. The halo zone was produced due to the solubilization of insoluble phosphates, which in turn was mediated via the production of organic acids in the surrounding medium. In line with the report of Gaur (1990) who revealed that phosphate solubilizing microorganisms formed clear zones by solubilizing suspended tri-calcium phosphate due to the release of organic acids into the surrounding medium.

Generally, it has been found that the organisms isolated from the rhizosphere of legumes have been found to be more efficient in

Table 1: Morphological and cultural characteristics of plant growth promoting rhizobacteria from wheat rhizosphere.

Isolates	Shape of the colony	Colony color	Colony size	Gram stain
HUPGPRBW-1	Rod	Blue green/red	Irregular size with wrinkled surface	+ve
HUPGPRBW-2	Rod	White	Flat, with Irregular edge	-ve
HUPGPRBW-3	Rod	Pink	Irregular size with swarming growth	-ve
HUPGPRBW-4	Cocci-bacilli/oval	Light pink	Regular size/circular	-ve
HUPGPRBW-5	Cocci, oval	Yellowish	irregular size/circular	-ve
HUPGPRBW-6	Oval	Light pink	Regular size/circular	+ve
HUPGPRBW-7	Cocci-bacilli/oval	Red	irregular size/circular	-ve
HUPGPRBW-8	Rod	Light white	Regular size/rough	+ve

Table 2: Effect of rhizobacteria isolates on phosphate solubilization and ammonia production.

Isolates	Ammonia production	Phosphate solubilization	PSI (mm)
HUPGPRBW-1	+ve	+ve	#######
HUPGPRBW-2	+ve	+ve	#######
HUPGPRBW-3	+ve	+ve	7.2
HUPGPRBW-4	-ve	-ve	0
HUPGPRBW-5	-ve	-ve	0
HUPGPRBW-6	-ve	-ve	0
HUPGPRBW-7	-ve	-ve	0
HUPGPRBW-8	-ve	-ve	0

HUPGPRBW (Haramaya University Plant Growth Promoting Rhizobacteria Wheat isolates)
PSI (Phosphate Solubilize Index)

solubilizing phosphates than those from the non-rhizosphere or from the root zone of non-legumes (Gull et al., 2004). But the proportion of phosphate solubilization found here in the rhizosphere of wheat (non-legumes) was satisfactory and encouraging. Isolation and characterization of these beneficial bacteria may be an indication of the environmental and ecological conditions of the sampled area having the potential to produce and synthesize PGPRB. Only 3 out of 8 isolates were able to produce ammonia, this is one of the indications these isolates belong to Pseudomonas and Bacillus bacterial genera. Idriset al. (2009) reported that the ammonia production potential of rhizosphere bacteria depends on the soil nutrient availability and species of bacteria.

Based on extrapolation of the 8 identified isolates to the PGPRB properties, it was revealed that the majority of phosphate solubilizers were Bacillus and Pseudomonas especially isolates such as HUPGPRW-1 and HUPGPRW-2 and these isolates produce a substantial amount of ammonia. This is line with this Tilak et al. (2005) who reported that Pseudomonas and Bacillus to be the main phosphate solubilizer bacteria. Phosphorus (P) is one of the major essential macronutrients for plants and is applied to soil in the form of chemical fertilizer, a large portion of soluble inorganic. Phosphate applied to the soil is immobilized rapidly and becomes unavailable to plants (Goldstein, 1986).

Microorganisms are involved in a range of processes that affect the transformation of soil P and are thus an integral part of the soil P cycle. Hence, the finding of the present study demonstrated that a diverse group of potential phosphate solubilizing bacteria are associated with the wheat rhizosphere and could serve as efficient bio-fertilizer candidates for improving the P-nutrition of crop plants [9].

The extent of auxin production by rhizobacterial isolates

IAA production was quantified from the supernatant absorbance using a spectrophotometer with a wavelength of 530 nm. It was then calculated using IAA standard curve. The control treatment was un-inoculated TSB media with Salkowski's solution. Each treatment was repeated three times. A total of 10 ml of IAA standard 100 ppm was diluted into concentrations of 80 ppm, 40 ppm, 10 ppm, and 5 ppm in a test tube. AS much as 2 ml of each concentration was placed in a test tube and added with 2 ml of Salkowski reagent (ratio 1: 1). It was then incubated for 60 minutes at room temperature. After incubation, the solution turned pink. The IAA standard solution absorbance was measured at a wavelength of 530 nm and a standard curve was plotted to show the relationship between the concentration of the standard IAA solution (x) and absorbance (y) of IAA production. The production yield of IAA is presented in µg / ml.

This study revealed that all selected (8) isolates were exhibited the capacity to produce indoleacetic acid (IAA). Moreover, isolates varied greatly in the amount of auxins production and indicated in Table 3. In this study, 8 isolates showed auxin production ranges from 32.7 to 7.5 µg/ml. The highest auxin production was observed in HUPGPRBW-1 isolates, on the other hand, the lowest auxin production was recorded in the HUPGPRBW-7 isolate. Among the 8 isolates, HUPGPRBW-1, HUPGPRBW-2, and HUPGPRBW-3 are the first top consecutive amount of IAA relative to other isolates indicating that IAA production depends on bacterial growth, their metabolic activities, and growth medium among other things. The result of phosphate solubilization and IAA production has taken together showed that isolates HUPGPRW-1, HUPGPRW-2, and HUPGPRW-3 were among the best top-performing isolates.

Table 3: Effect of rhizobacteria isolates on auxin production.

Isolates	IAA produced (µg/ml)
HUPGPRBW-1	32.7
HUPGPRBW-2	26.7
HUPGPRBW-3	21.3
HUPGPRBW-4	18.1
HUPGPRBW-5	11.1
HUPGPRBW-6	9.5
HUPGPRBW-7	7.5
HUPGPRBW-8	10.4

Effect of selected rhizobacteria isolates on vegetative growth of wheat

The greenhouse experiment was based on the best-performed isolates were considered. Accordingly, 3 isolates were selected (HUPGPRBW-1, HUPGPRBW-2, and HUPGPRBW-3) based on their phosphate solubilization capacity as well as auxin production rate. All of the selected inoculants increased the height of the wheat plant over the contro. The highest shoot length was observed with HUPGPRBW-1 (44.00 cm) isolates which were significantly ($P<0.05$) higher than the control (24.66 cm). Among the treatments, the plant inoculated with HUPGPRW- 3 had the smallest plant height (35.33 cm). Subsequently, the results of shoot fresh weight and dry weight are also in line with the results of plant height. The increase in plant height in the rhizobacteria inoculated wheat plants is due to increased rates of cell division and expansion at their meristematic regions in response to plant growth-promoting rhizobacteria. Similar results have been reported by Sharifi et al. (2018). In addition to this increases in plant height and leaf area were observed in different crops inoculated with Pseudomonas, Bacillus, and Azotobacter strains (Siddiqui et al., 2006) reported that plant growth-promoting rhizobacteria might enhance plant height and productivity by synthesizing phytohormones, increasing the local availability of nutrients, facilitating the uptake of nutrients by the plants decreasing heavy metal toxicity in the plants antagonizing plant pathogens.

The effect of rhizobacteria isolates on root growth was observed and all results were summarized in Table 4. In all the treatments, root growth was stimulated as compared with the control group. Among the selected isolates HUPGPRW-1 showed the highest root growth (20. cm) as compared with the rest of the isolated. In the meantime, HUPGPRW-3 isolates showed the lowest root growth (13.00 cm) among the treatments. Successively, the results of shoot fresh weight and dry weight are also in line with the results of root length.

In general, in the pot experiment, the selected inoculants significantly improved the growth of wheat compared to the control. A previous study also reported that inoculation of plants with rhizobacteria generally improved plant growth and yield under greenhouse conditions (Kang et al., 2014). These growth improvements could be due to the inoculants'high P-solubilizing ability and the production of growth-promoting substances such as IAA (Kang et al., 2014). Likewise, promotion in growth parameters and yields of various crop plants in response to inoculation with rhizobacteria were reported by Gravel et al. (2007). Among the treatments, HUPGPRBW-1 isolates were found superior in enhancing plant height over the other treatments. This could be due to high P- solubilizing and mineralizing ability from P- sources, production of growth-promoting substances such as IAA (Akhtar and Siddiqui, 2009).

Correlation analysis for agronomic parameter

This study also analyzed the correlation between the selected

Table 4: Effect of three selected rhizobacteria isolates on shoots and root growth of wheat.

Treatment	Shoot length (cm)	Shoot fresh weight (g)	Shoot dry weight (g)	Root length(cm)	Root fresh weight (g)	Root dry weight (g)
Control	24.66 c	4.66c	0.600c	6.33 c	0.56 c	0.36 d
HUPGPRBW-1	44.00 a	19.66 a	1.833b	20.00 a	2.86 a	1.83 a
HUPGPRBW-2	36.00b	13.66b	2.866 a	14.33 b	1.76 b	0.63 bcd
HUPGPRBW-3	35.33 b	13.00 b	1.700b	13.00 b	1.73 b	0.43 cd

Table 5: Correlation, relationship for PH, SFW, SDW, RL, RFW and RDW.

	PIH	SFW	SDW	RL	RFW	RDW
SFW	0.754***					
SDW	0.747***	0.624**				
RL	0.705***	0.708***	0.733***			
RFW	0.703***	0.916***	0.625**	0.670**		
RDW	0.682**	0.657**	0.807***	0.714***	0.692**	

Where ** moderate (significance), *** strong (highly significance), PSH: Plant Shoot Height; PSFW: Plant Shoot Fresh Weight; PSDW: Plant Shoot Dry Weight; RL: Root Length; RFW: Root Fresh Weight and RDW: Root Dry Weight

growth parameters and the results were indicated in Table 5. The results revealed that plant height, fresh and dry weight, and root length, root fresh, and dry weight positively correlated with each other. This study showed a strong correlation with plant height all the selected growth traits except root dry weight. This may be due to the positive effect of rhizobacteria on plant height and development. In line with this similar research was reported by Indris et al. (2009) and Birhanu Babiye et al. (2019).

Summary

A plant growth-promoting rhizosphere bacterium is very important to improve agricultural productivity. It offers many advantages over the use of synthetic chemicals and can contribute towards sustainable and eco-friendly approaches. In this study, the wheat rhizosphere bacteria were isolated from wheat rhizosphere and all the isolates were subjected to growth-promoting tests such as phosphate solubilization and IAA production. The phosphate solubilization by using PVK culturing media.

Among the 8 selected isolates, three isolates (HUPGPRBW-1, HUPGPRBW-2, and HUPGPRBW-3) showed better performance related to phosphate solubilization and IAA production. The study has also shown that rhizobacteria have greater efficiency to solubilize phosphate and the potentials of rhizobacteria could be effectively exploited for the production of eco-friendly phosphate solubilizing bio-fertilizer for sustainable agriculture.

Those potential selected isolates were subjected for further greenhouse evaluation and biochemical characterization and three of the most potential isolates and their combination were evaluated in a greenhouse at Holeta National Agricultural Biotechnology Research Center. Plant data parameters were collected after 35 days of inoculation.

For plant shoot height, all the three isolates significantly increased plant height when compared to the control. But when compared to each other, HUPGPRBW1 isolates significantly increased the plant shoot height better than the other. For plant shoot fresh and dry weight, three of isolates significantly increased compared to the control. For root length, all the isolates significantly increased root length when compared to the control but when compared to each other, they have different potential. For root length growth, as shoot parameter here in root also HUPGPRBW1 similarly shows significant increment. Correlation coefficient analysis revealed that plant shoot height, plant shoot fresh and dry weight, root length, root fresh and dry weight growth and growth-related traits had a highly significant ($p<0.01$) positive correlations with each other [10].

Conclusion

The present study, therefore suggests that the use of PGPRB isolates as bio-inoculants might be beneficial for wheat cultivation. Microbial inoculants play a significant role in regulating the dynamics of organic matter decomposition and the availability of plant nutrients such as nitrogen, phosphorus, potassium. From this study, it has been shown that the use of bacterial inoculants had the highest value of the growth parameters monitored while the control had the lowest value measured. Most of the isolates significantly increased shoot length, root length, and fresh and dry weight of wheat. This result suggested that PGPRB are able to enhance the production of IAA and solubilization of phosphorus thereby improving the growth of the wheat plants.

Based on the findings of the current study, the following recommendations and feature line of work have been suggested.

Recommendations

- The results are promising for the design of potentially active wheat growth promoting PGPR strain which would be beneficial for improvement of wheat production and productivity for sustainable agriculture at the area.
- Usage of PGPR could replace chemical fertilizers at the area for better production of wheat and reduce environmental pollution as well.
- The experiment was conducted using soil collected from the southern part of Ethiopia; is realistic to conduct similar experiments for other parts of Ethiopia.
- The experiment was conducted at in vivo level for wheat only; it is realistic to carry out a similar experiment at field and for other crops as well across wider ranges of agro ecology.

Acknowledgement

This study was funded by Southern Agricultural Research Institution (SARI) and with great support of Hollota national biotechnology agricultural research center especially microbial laboratory staff by giving permission for laboratory work and data collection to be done of

this experiment. The authors thanks all those who have participated by giving advance comments from developments of proposal to the final write-up. Birhanu Babiye and Dr. Manikkandan M thanks for their great assistance.

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