THE EFFECTS OF PLANT GROWTH-PROMOTING BACTERIA (PGPR) INOCULATION ON GROWTH, YIELD, AND GRAIN NUTRIENT UPTAKE OF TEFF VARIETIES UNDER FIELD CONDITION

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ABSTRACT: Inoculation of Plant Growth-Promoting Bacteria **(**PGPR) in plant increase rhizosphere fertility and resulted in more efficient uptake of soil nutrients without harming the environment and human health. The present study aimed to examine the effect of either individual or consortium of PGPR inoculation on growth, yield, and grain nutrient uptake of teff varieties. Three potential PGPR strains (*Pseudomonas fluorescens biotype G*, *Enterobacter cloacae ss disolvens*, and *Serratia marcescens ss marcescen*) were used for this study. Field evaluation was carried out in RCBD with three replications and 10 treatments. Highly significant (P< 0.001) differences were observed among treatments for Plant height (PH), Panicle length (PL), number of the total spikelet (NTS), shoot dry weight (SDBM), Grain yield (GY), and Straw yield (SY). However, the interaction effect of the two factors (treatment x variety) did not significantly influence agronomic traits and grain nutrient uptake of the teff. The highest PH (133.5 cm), PL (53.2), NTS (30.9), SDBM (18.1 tha^{-1}), SY (10.7 tha^{-1}), and GY (2.7 tha^{-1}) were observed on Dukem variety (Dz-01-974) inoculated with PGPR consortium. The magnitude of increase in grain yield per hectare was 450% over the control. Inoculation of consortium native PGPR showed better performance in promoting plant growth, yield, and grain nutrient uptake of teff varieties compared to the control and could be used as bacterial inoculant to enhance teff production and productivity.

Keywords: Biodiversity, Inoculant, PGPR, Treatment, Teff variety.

INTRODUCTION

Teff [*Eragrostis tef* (Zucc.) Trotter] is an indigenous tropical cereal crop of Ethiopia, and the country is the center of origin and diversity for the crop (Vavilov, 1951). Its grain is used to make injera, a traditional fermented pancake that is one of the major staple foods for about 70 million inhabitants (60% of the entire population) (Reda, 2015). Teff grain has an excellent nutritional profile; with high dietary fiber, high

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levels of minerals, proteins, and carbohydrate contents (Baye, 2014). It contains 11% protein and is an excellent source of essential amino acids (Doris, 2002). It has a low glycemic index and is free from gluten and serves as an alternative food source for people with type 2 diabetes and celiac disease (Baye, 2014).

In Ethiopia, about 6.5 million smallholder farmers grow teff, which is equivalent to 30% of the total area allocated to cereals, followed by maize (23%), sorghum (18%), and wheat (17%) (CSA, 2019). In the 2019/2020 cropping season, the total area covered with teff was 3.1 million hectares with a production of 5.74 million tons. The average productivity of teff in Ethiopia is very low (1.85 t/h) (CSA, 2019) at the smallholder farmer level. The main reason for low teff productivity is nutrient deficiency, susceptibility to lodging (Habtegebrial et al., 2007), low genetic yield potential (Haileselassie et al., 2016) and drought, particularly in the low altitudes areas.

Currently in Ethiopia, teff production and productivity improvement practices were dependent on the heavy application of chemical inputs (such as fertilizers, pesticides, herbicides, etc.) which may have a deleterious effect on soil fertility and nutritional value of farm products. Excessive use of chemical inputs causes environmental pollution, and has major impact on human and animal health through an accumulation of heavy metals and other toxic substances (Tchounwou et al., 2012).

Chemical fertilizers contain acid radicals, like hydrochloride and sulfuric radicals, and hence increase the soil acidity and adversely affect biological diversity within the agricultural land. Some plants can also absorb recalcitrant compounds from the contaminated soil and cause systematic disorders of the consumers (Alori and Babalola, 2018). Therefore, the increasing awareness of environmental pollution and product contamination due to indiscriminate use of chemical inputs has led to the search for new biological technology to improving crop productivity and grain quality without threatening consumer's health. Either individual or consortium PGPR application which can act as biofertilizer and biocontrol agent is one of the alternative mechanisms to use hazardous chemical fertilizer (Tobergte and Curtis,

2013). They are environmental-friendly and renewably provide nutrients to maintain soil health and biology without affecting the environment and human health.

The application of PGPR inoculants constitutes a biological tool to enhance plant nutrition and mitigating the negative impact of conventional chemical inputs. *Pseudomonas*, *Bacillus*, *Azospirillum*, *Azotobacter*, *Enterobacter*, and *Serratia* are the main genera of PGPR that enhance crop productivity and grain quality (Ferreira et al., 2019). Its application can increase plant growth, yield, yield components, and grain nutrient uptake by improving the availability of essential nutrients, growth hormones, production of different lytic enzymes, and secondary metabolites, which inhibit plant pathogens (Gopalakrishnan et al*.,* 2015). According to Zewdie et al. (2000), inoculation of teff varieties with indigenous *Azospirillum* isolates significantly increased grain yield up to 12% over the control. Similarly, Woyessa and Assefa (2011) reported that teff varieties inoculated with native *Pseudomonas fluorescent* and *Bacillus subtilis* showed significant increase in grain yield by 28% and 44% respectively.

In the last two decades, the synergy of two or more PGPR inoculants has been investigated after simultaneous inoculation in the same plant (Mpanga et al., 2019). It has been reported that inoculation with consortia of PGPR has better plant growth promotion as compared to individual inoculations because individual strains supplement each other for their beneficial traits (Singh et al., 2014). According to the report by Wang et al. (2020), the application of PGPR consortia can increase the production and growth of maize and cucumber plants compared to the inoculation of individual bacteria. Moreover, Souza et al. (2015) reported plant inoculation with a consortium of several PGPR strains increases plant growth and yield than individual strains, likely reflecting the various mechanisms used by each strain in the consortium. Despite the various plant growth promotion and biocontrol benefits associated with PGPR listed in the literature, research conducted to examine the effect of native PGPR application on teff to improve growth, yield, and grain nutrient uptake is limited. This study aimed to examine the effect of

individual or consortium native PGPR inoculation on the growth, yield, and yield-related traits as well as grain nutrient uptake of teff varieties under field conditions.

MATERIALS AND METHODS

Description of the study area

The study was conducted at the Debrezeit Agricultural Research Center (DZARC) during the 2019 main cropping season. The research site is geographically located at 08°44'Nand 38°58'E and has an altitude of 1900 m a.s.l. DZARC is located 47 km southeast of Addis Ababa. The mean long-term annual rainfall recorded at the station is 660 mm and the average annual minimum and maximum temperatures are 12°C and 27.4°C, respectively (Wakjira, 2018). The texture of soil in the experimental site was silt loam and composed of 14% clay, 32% sand, 54% silt and its organic carbon content was about 1.26%, which is considered to be low (Roy et al., 2006). According to Olsen et al. (1954) phosphorus (P) rating (m kg^{-1}), the available P content of the experimental site's soil is low (<3). The pH of the soil was 6.96, which is within the suitable range (4 to 8) for teff production and the total nitrogen (N) of the soil (0.12%) is medium; as rated by Havlin et al. (1999).

Materials used in the experiment

Two teff varieties named Magna (Dz-01-196) and Dukem (Dz-01-974) were obtained from DZARC. The teff varieties were selected based on consumer and farmer's preferences for injera making quality and market demand, respectively. Three potential PGPR strains: *Pseudomonas fluorescens biotype G*, *Enterobacter cloacae ss disolvens*, and *Serratia marcescens ss marcescen* identified from teff varieties in a previous study were used as inoculants (Tsegaye et al., 2021). The three PGPR strains were selected from 65 potential PGPR, based on different plant growth-promoting (PGP) traits such as plant growth and yield-enhancing properties, biotic and abiotic stress tolerance property, in addition to seed germination

capability during laboratory and greenhouse evaluation. Detailed information on the bacteria used for the present study is given in Table 1.

Table 1. Potential PGPR strains selected for field experimental trail.

Code of bacterial isolates	PGP properties			Biocontrol properties			Abiotic stress tolerance properties			Seed germination status
	PS	IAA	NF	Pro	HCN	EPS	SL	pH	TP	SVI
Serretia marcescens ss marcescen	+++	+++	+	+++	+	++	5	4,5,7, 9	40	530
Pseudomonas fluorescent biotype G	+++	+++	++	++	+++	+++	10	5,7, 9	30	470
Enterobacter cloacae ss disolvens	++++	++	+++	+++	+	+++	15	5,7	40	540

Note: PS=phosphate solubilization, IAA=indole acetic acid, NF=nitrogen fixation, EPS=exopolysaccharide, SL=salinity, TP=temperature, SVI seed vigor index, +=low, ++=moderate, +++=high and ++++=extreme high. (Source: Tsegaye et al., 2021).

PGPR strains compatibility test

Compatibility among the three selected PGPR strains was tested to formulate bacterial consortia. The method described by Nikam et al. (2007) with slight modifications was used for *in-vitro* bacterial compatibility testing. PGPR cultures streaked on nutrient agar plates in such a way that for every single bacterial culture in the center of the plate, other cultures streaked radiating from the center. The plates were incubated at 30°C for 48 hrs and the zone of inhibition was observed and recorded. Bacterial strains which do not show a zone of inhibition on the growth medium indicate the compatibility of the strains.

Bacterial inoculant preparation

Nutrient broth medium amended with 1% carboxyl methylcellulose (CMC) was prepared and inoculated with the selected potential PGPR strains and shake for 48 hrs in a rotary shaker. After shaking, the density of the culture was measured using a turbidimeter, bacterial cell concentration of 10^6cfu mL^{-1}, and then the cultures used for seed inoculation.

Seed surface sterilization and treatment with bacterial inoculants

Teff seeds were surface sterilized with 70% alcohol for 3 minutes, followed by 1% hypochlorite for 5 minutes, and rinsed 5 times with sterile distilled water. Ten ml of the suspension (10^6 cfu mL^{-1}) of the individual bacterial cells or its consortium were mixed with 2 g of surface-sterilized seed sand used for each plot. The consortium was prepared by mixing an equal amount of suspension of each PGPR cell that has the same $cfumL^{-1}$ (Casanovas et al., 2000). The treated seeds were shade dried for 4 hours and immediately sown in prepared plots.

The field layout and trial management

The land was prepared by tractor plowing and the seedbeds were leveled and compacted before sowing the treated seeds. The experiment was laid out as a randomized complete block design (RCBD) with three replications and 10 treatments. An uninoculated plot was used as a control. A plot size of 2 m x 2 m (4 m^2) with 20 cm row spacing, and a total of 10 rows and 30 plots were used. The spacing between plots and blocks was 0.5 and 1 m, respectively. Inoculated seeds of two varieties were hand drilled at the rate of 5 kg per hectare i.e. 2g/plot. Plots were kept free of weed by hand weeding without using herbicides.

Agronomic data collection, measurement, and grain nutrient analysis

At physiological maturity, plant growth, yield, and yield related data were collected before and after harvesting according to Assefa et al. (2016). Ten plants were selected from the central two rows of each plot to measure plant growth and growth-related parameters. Harvesting was done manually using hand sickle from an area of 1.8 m x 1.8 m (3.24 m^2) to measure grain yield, straw yield, and yield-related parameters. In addition Lodging index (LI) which shows the level of lodging was measured just before the time of harvest by visual observation. It was determined by the angle of inclination of the main stem from the vertical line to the base of the stem measured in 1-5 scale, where 1 (0-15^o) indicates no lodging, 2 (15-30^o) indicates 25% lodging, 3 (30-45^o) indicates 50% lodging, 4 (45-60^o) indicates 75% lodging and 5

(60-90^{o}) indicates 100% lodging (Donald, 2004). Data recorded on lodging percentage was subjected to arc sign transformation described for percentage data by Gomez and Gomez (1984).

Nutrient analysis

Teff grain powder (100 g) were prepared from each treatment and sent to laboratories at Debrezeit and Jimma agricultural research centers for macro and micronutrient analysis.

Data analysis

All collected data were analyzed using the R software version 3.6 statistical analysis system following the appropriate procedures of RCBD. A two-way analysis of variance (ANOVA) was conducted to test the significance level of the variables at $p \leq 0.05$. A comparison of the individual treatment means was performed using the least significant difference (LSD).

RESULTS

Effect of PGPR inoculation on teff agronomic traits

Analysis of variance (ANOVA) for agronomic traits showed that traits like plant height, panicle length, number of total spikelet, shoot dry biomass, grain yield, straw yield, and harvest index were significantly affected by PGPR inoculants at 0.1% probability level, while lodging index was significantly affected at 5% probability level. On the other hand, the interaction effect of variety and treatment did not significantly affect the agronomic traits of the two varieties (Table 2).

Table 2. Mean square of treatment, variety, treatment * variety effects on teff agronomic traits.

S.O.V	DF	Growth, yield, and yield-related traits								
		PH	PL	NTS	NFT	SDBM	GY	SY	HI	LI
TM	4	2129.5***	290.2***	120***	24.8ns	11.6***	0.31***	3.4***	0.01**	0.78Ns
VT	1	240.8*	264.0**	41.3NS	3.7Ns	5.4**	0.06Ns	2.5**	0.001	20.8*
TM*VT	4	2.6NS	9.3NS	2.5NS	6.6Ns	0.36Ns	0.03NS	0.23ns	0.001NS	3.1Ns
Error	20	45.2	9.3	10.9	9.5	0.30	0.009	0.25	0.001	4.20

PH=plant height, PL=panicle length, NTS=number of total spikelet, NFT=number of fertile tiler, SDBM=shoot dry weight, GY=grain yield, SY=straw yield, HI=harvest index, LI=lodging and *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; NS=not significant, S.O.V=source of variation, TM=treatment, VT=variety, DF= degree of freedom.

Effect of PGPR inoculation on teff varieties growth and growth-related traits

Teff varieties inoculated with individual or consortium PGPR showed significantly (P<0.001) increased plant height compared to control (Table 3). The longest PH (133.5 cm) observed on Dukem variety (Dz-01-974) inoculated with the consortium of the PGPR, and the shortest PH (84.1 cm) was observed on uninoculated Magna variety (Dz-01-196). Similarly, the panicle length of both varieties was significantly (P<0.001) increased by inoculation of either individual or consortium PGPR. The longest PL (53.2 cm) observed on Dz-01-974 inoculated with the bacterial consortium and, the shortest PL (31.7 cm) was observed on uninoculated Dz-01-196, which increased panicle length up to 168% over the control. The number of total spikelet of Dz-01-196 was significantly (P<0.01) affected by the inoculation of either individual or consortium PGPR. The smallest NTS (18.4) was observed on uninoculated Dz-01-196 and the highest NTS (30.9) was recorded on Dz-01-974 inoculated with PGPR consortium, which exceeds the number of total spikelet up to 168% over the control. The number of fertile tillers was significantly affected by *Enterobacter cloacae ss dissolvens* inoculation. The maximum NFT (12.3) was observed on Dz-01-974 and, the shortest PL (5.1) was recorded on uninoculated Dz-01-196.

Table 3. PGPR inoculation effects on teff varieties' growth and growth-related traits.

Treatment	Mean teff growth-promoting traits							
	PH		PL		NTS		NFT	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem
Control	84.1[b]	88.8[b]	31.7[b]	33.5[b]	18.4[b]	19.5[b]	5.1[a]	5.7[b]
Serratia marcescens ss marcescens	122.5[a]	128.9[a]	44.3a	50.1[a]	27.9[a]	29.7[a]	9.7[a]	8.6a[b]
Pseudomonas fluorescens biotype G	124.8[a]	129.6[a]	43.6[a]	51.5[a]	26.1[a]	30.7[a]	6.9[a]	7.4[ab]
Enterobacter cloacae ss dissolvens	125.5a	133.1[a]	43.0[a]	50.9[a]	27.7[a]	29.6[a]	8.0[a]	12.3[a]
Bacteria consortium	128.7[a]	133.5[a]	46.7[a]	53.2[a]	28.6[a]	30.9[a]	9.8[a]	10.3[ab]
LSD (5%)	8.35	13.49	5.94	5.11	6.02	6.04	4.24	6.71
P-value	0.001	0.001	0.001	0.001	0.01	0.01	0.23	0.24

PH=plant height, PL=panicle length, NTS =number of total spikelet, NFT=number of fertile tiller and the letters (a, b) indicate significant differences at P≤0.05 according to the LSD test.

Effect of PGPR inoculation on teff yield and yield-related traits

Individual treatment means comparison results showed that the shoot dry biomass, grain yield, and straw yield of both varieties were significantly (P< 0.001) influenced by inoculation of PGPR inoculants either alone or in combination (Table 4). The maximum SDBM (18.1 tha^{-1}) was obtained from Dz-01-974 (Dukem) inoculated with the PGPR consortium, and the minimum SDBM (5.8 t ha^{-1}) was obtained from uninoculated Dz-01-196 (Magna). The consortium inoculation exceeded shoot dry biomass by about 312% over the control. Regarding the grain yield, the maximum GY (2.7 t ha^{-1}) obtained from Dz-01-974 was inoculated with the PGPR consortium, and the minimum GY (0.60 t/ ha^{-1}) was recorded from uninoculated Dz-01-196. The magnitude of increase in grain yield was higher by about 450% over the uninoculated plots. Similarly, the lowest straw yield (3.5 t ha^{-1}) was obtained from uninoculated Dz-01-196, and the highest SY (10.7 t ha^{-1}) was obtained from Dz-01-974 inoculated with the PGPR consortium, which exceeds by 306% over the control plots. The results of the individual treatment mean comparison revealed that the harvest index (HI) of both varieties was significantly (P<0.05) influenced by the application of either individual or consortium PGPR. The minimum HI (16%) was observed on untreated

Dz-01-974, and the maximum HI (27%) was observed on Dz-01-196 inoculated by the PGPR consortium, which increases harvest index up to 169% over the control.

Table 4. Effect of PGPR inoculation on yield, and yield-related traits of tested teff varieties.

Treatment	Mean teff yield and yield-related parameters (tone/ha)									
	SDBM t ha^{-1}		GY t ha^{-1}		SY t ha^{-1}		HI %		LI %	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Duke
Control	5.8^{b}	5.9^{b}	0.60^{b}	0.61^{b}	3.5^{b}	3.7^{b}	17^{c}	16^{b}	20^{a}	21^{a}
Serratia marcescens ss marcescens	14.0^{a}	16.5^{a}	1.9^{a}	2.3^{a}	7.9^{a}	9.6^{a}	25a	24^{a}	25^{a}	27^{a}
Pseudomonas fluorescens biotype G	13.8^{a}	16.4^{a}	1.7^{b}	2.4^{a}	7.4^{a}	9.4^{a}	22^{b}	25^{a}	26^{a}	24^{a}
Enterobacter cloacae ss dissolvens	13.7^{a}	17.2^{a}	1.6^{b}	2.6^{a}	7.6^{a}	9.9^{a}	20^{b}	26^{a}	24^{a}	27^{a}
Bacteria consortium	13.8^{a}	18.1^{a}	2.0^{a}	2.7^{a}	7.7^{a}	10.7^{a}	27^{a}	26^{a}	25^{a}	24^{a}
LSD (5%)	1.02	0.20	0.20	0.15	0.20	0.88	0.08	0.04	2.63	2.57
p-value	0.001	0.001	0.003	0.001	0.04	0.001	0.07	0.01	0.55	0.62

SDBM=shoot dry biomass, GY=grain yield, SY=straw yield, HI=harvest index, LI=lodging index and different letters indicate significant differences at P≤0.05 according to the LSD test.

Effects of PGPR inoculation on teff grain nutrient uptake

The result of ANOVA indicated that a significant difference (P≤0.01) was observed on teff varieties on grain nitrogen (N), phosphorus (P), and calcium (Ca) uptake by treatment (Table 5). Grain magnesium (Mg) and iron (Fe) uptake were significantly affected by a variety at a 5% probability level.

Table 5. ANOVA for treatment and variety effects on teff grain nutrient uptake.

S.O.V	D.F	N %	P %	S	K %	Mg %	Ca %	Zn %	Fe %
TM	4	1.76**	1.88**	0.45*	0.006^{Ns}	0.001^{Ns}	0.06**	0.00001Ns	0.0002Ns
VT	1	0.01^{Ns}	0.06^{Ns}	0.001^{Ns}	0.003^{Ns}	0.01*	0.001^{Ns}	0.00002Ns	0.01*
Error	4	0.003	0.05	0.03	0.005	0.0004	0.001	0.00001	0.0003

N=nitrogen, P=phosphorus, S=Sulphur, K=potassium, Mg=magnesium, Ca=calcium, Zn=zinc, Fe=iron and *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability level, respectively; Ns: not significant, S.O.V=source of variation, D.F= degree of freedom, TM=treatment, VT=variety.

Effects of PGPR inoculation on teff grain macro and micronutrient uptake

Individual treatment means comparison showed that teff grain nitrogen (N%), phosphorus (P%), Sulphur (S%), and calcium (Ca%) uptake were significantly affected by individual or consortium PGPR inoculation (Table 6).

Table 6. Individual treatment means of PGPR inoculation on teff grain nutrient content improvement.

Treatment	N %	P %	S %	K %	Mg %	Ca	Zn%	Fe
Control	1.42 ^{b}	0.67^{c}	0.38^{c}	0.44^{a}	0.09^{a}	0.06^{b}	0.00^{a}	0.04^{a}
Serratia marcescens ss marcescens	1.78 ^{a}	2.44^{b}	1.28^{ab}	0.36^{a}	0.12^{a}	0.07^{b}	0.05^{a}	0.05^{a}
Pseudomonas fluorescens biotype G	1.76^{a}	2.18^{b}	1.41^{ab}	0.42^{a}	0.14^{a}	0.08^{a}	0.00^{a}	0.04^{a}
Enterobacter cloacae ss dissolvens	1.71^{a}	2.07^{b}	1.06b	0.31^{a}	0.13^{a}	0.09^{a}	0.05^{a}	0.04^{a}
Bacteria consortium	1.85 ^{a}	3.35^{a}	1.61a	0.44^{a}	0.14^{a}	0.19^{a}	0.05^{a}	0.05^{a}
LSD (0.05)	0.17	0.60	0.40	0.17	0.09	0.09	0.006	0.09

N=nitrogen, P=phosphorus, S=Sulphur, K=potassium, Mg=magnesium, Ca=calcium, Zn=zinc, Fe=iron, different letters indicate significant differences at P≤0.05 according to the LSD test.

The maximum teff grain N (1.85%), P (3.35%), S (1.61%), and Ca (0.19%) uptake was observed on teff variety inoculated with PGPR consortium, and the smallest grain N (1.42 %), P (0.67%), S (0.38%), and Ca (0.06%) uptake was recorded on uninoculated control. Either individual or consortium PGPR inoculation did not significantly affect uptake of potassium (K), Zinc (Zn), magnesium (Mg), and iron (Fe) although differences were recorded between the inoculated and uninoculated treatments.

DISCUSSION

Results in the present study showed that the compatibility of the three PGP strains and their inoculation either alone or in combination significantly increased growth, yield, yield-related parameters, and grain nutrient uptake of the two teff varieties over the control. Similarly, Kumar et al. (2017) reported that inoculation of PGPR either alone or in various combinations significantly ($P \leq 0.05$) increased the growth and yield of wheat compared to untreated controls.

The study indicated that the Dukem (Dz-01-974) variety responded better for all agronomic traits than Magna (Dz-01-196) variety to PGPR treatment either alone or in combination. Each teff variety responded differently to different bacterial inoculation indicating bacterial physiologic, metabolic, and root colonization ability differences, as well as the existence of some degree of specificity that might affect growth, yield, and other parameters of the varieties. Zewdie et al. (2000) reported that higher grain yield responses were observed for the teff variety Dz-01-096 compared to Dz-01-354 by the inoculation of the Azospirilium isolates.

Inoculation of the PGPR consortium on the two teff varieties showed better performance on plant growth, yield, and grain nutrient uptake than the individual inoculants. Grain and biomass yield were significantly ($P<0.001$) increased by the inoculation of PGPR consortium. Meena et al. (2016) reported that the application of PGPR as a consortium of compatible strains has been more effective than their single application in the practical field. Similarly, Souza et al. (2015) reported that plant inoculation with a consortium of several bacterial strains might be an alternative to inoculation with individual strains, likely reflecting the various mechanisms employed by each strain within the consortium. PGPR consortium has a synergetic effect to mobilize essential nutrients, synthesizing different hormones, and suitably beating the challenges like biotic and abiotic stress conditions as that they had adapted to different environmental conditions.

Plant height, panicle length, and the number of total spikelet are the most important traits affecting plant growth (Idota et al., 2015). In our study, on the tested teff varieties plant height, panicle length, and the number of total spikelet were significantly affected by inoculation of PGPR. Woyessa and Assefa (2011) reported inoculation of *Pseudomonas fluorescent* and *Bacillus subtilis* significantly increased growth of teff variety. Longer plant height and panicles allow more spikelets that contain better number of grains.

In this study, shoot dry biomasses of both varieties were significantly increased by inoculation of either individual or consortium PGPR inoculants. The maximum shoot dry biomass was obtained from Dz-01-

974 inoculated by the PGPR consortium. Similarly, Kausar and Shahzad (2006) reported that inoculation of maize with PGPR strains caused a significant increase in shoot dry matter. This could be due to an increase in the availability of essential soil nutrients and other substances through the synergistic effects of the PGPR consortium that can boost the shoot dry biomass of the teff varieties. The lowest shoot biomass was observed on the plots where no inoculants were applied. This indicated that the experimental soils had limitations in releasing essential nutrients in adequate amounts to support teff plant growth and development without additional inputs.

There were significant differences in teff grain yield by the inoculation of either individual or consortium PGPR. The highest grain yield was observed on Dz-01-974 inoculated with PGPR consortium, which exceeds 450% over the control. Sarma et al. (2009) reported that a mixture of two *Fluorescent pseudomonas* strains increased the yield of *Vigna mungo* by 300% in comparison to the control. These could be for the reason that a consortium of PGPR increases the availability of the nutrients that are essential to enhance the yield of the plant by using various PGP mechanisms like phosphate solubilization, nitrogen fixation, production of the different secondary metabolites as well as improving plants' tolerance to biotic and abiotic stress factors.

The straw yield of cereal crops is an important agronomic parameter that is sensitive to soil nutrient availability or the nutrient applied from external sources (Tamene et al., 2017). In the present study, the application of consortium PGPR inoculants significantly ($P<0.001$) affects straw yield. Zafar-ul-Hye et al., (2020) reported multi-strain inoculation with PGPR are more effective than single-strain inoculation to improve wheat (*Triticum aestivum*) straw yield. This could be due to the interaction effect of the bacterial consortium that improves the supply of unavailable nutrients and different hormones to the teff varieties.

Harvest index indicates the balance between the productive parts of the plant and the reserves. It indicates the presence of good partitioning of biological yield. In the present study, the individual treatments mean result revealed that the harvest index of the teff varieties significantly increased by inoculation of

consortium PGPR inoculants over control. These results showed that the PGPR consortium could improve the supply of essential nutrients to the plant and increase the harvest index.

No significant difference was observed on lodging index between the two varieties of teff upon inoculation by PGPR either alone or in a consortium although differences occurred between inoculated and uninoculated treatments. PGPR inoculant might improve teff varieties stem strengthen through regulating the supply of nutrient and increase root growth to prevent lodging problems.

Inoculation of either individual or consortium PGPR inoculants significantly improved grain N, P, S and Ca uptake of the two teff varieties over the control. Mantelin and Touraine (2004) reported that plants inoculated with PGPR significantly increase uptake of nutrient elements like Ca, K, Fe, Cu, Mn, and Zn through proton pump ATPase. Moreover, Karlidag et al. (2007) reported that inoculation of Bacillus and micro bacterium inoculants improved uptake of mineral elements by apple plants. Furthermore, Kumar et al. (2017) reported that co-inoculation of *Enterobacter* with *S. marcescens* and *M. arborescens* improved grain N and P uptake of wheat variety in field experiment.

In general, the present study confirmed that the PGPR consortium application was capable of enhancing the growth, yield, yield-related parameters, and grain nutrient uptake of the two teff varieties. However, the bacterial consortium displayed a marked difference in their effect on several features of growth and productivity of Dukem (Dz-01-974) teff variety. The variation perhaps originated by PGPR consortium are differences in exerting PGP mechanisms and synergy to supplying essential nutrients to the teff varieties.

CONCLUSION AND RECOMMENDATION

This study concluded that the utilization of native PGPR either alone or consortium as bio inoculants could reduce the global dependence on hazardous chemical inputs, which threaten the environment, human health, as well as biodiversity. Furthermore, sustained teff production and productivity without affecting grain yield and quality of the grain nutrients is an important agricultural practice to meet

consumer's demand at the regional and national level. Further evaluation and demonstration could be conducted by inoculation of either individual or consortium PGPR inoculants on different crop varieties under different environmental conditions to explain the role of native PGPR as bacterial inoculants.

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