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The Effects of plant growth-promoting bacteria (PGPB) inoculation on teff growth, yield, and grain nutrient uptake of two teff varieties under field conditions

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Abstract

Inoculation of PGPB in plants could increase rhizosphere fertility and resulted in more efficient uptake of soil nutrients without harming the environment and human health. The study aimed to examine the effect of PGPB inoculation on the growth, yield, and grain nutrient uptake of teff varieties. The experiment was carried out in a (CRBD) with three replications and 10 treatments. Variance analysis results showed that PL, NTS, SDBM, GY, SY, HI, grain N, and P uptake were highly significant ($P \leq 0.001$) for the main effect of treatment while PL, SDBM, GY, LI, and grain Fe uptake were also significant ($P \leq 0.00$) for variety. The interaction effect of the two factors did not significantly influence teff varieties, agronomic traits, and grain nutrient uptake. Treatment means comparison results revealed that PH and LI were significantly influenced by the application of 100% RDCF. The maximum PH (137.1cm) and LI (75%) were observed on Dz-01-196. Likewise, SDBM and SY significantly ($P \leq 0.001$) influenced by inoculation of the PGPB consortium. The maximum SDBM (18.1 t ha^{-1}) and SY (10.7t/h) were obtained from Dz-01-974. PL, NTS, HI, and GY were significantly affected by inoculation of the PGPB consortium with 50 % RDCF. The maximum PL (55.3cm), NTS (31.8cm), HI (30%), and GY (3.6t/h) were recorded on Dz-01-974. The magnitude of increase in grain yield per hectare is about 120, 590% over the treatment applied 100% RDCF and control, respectively. According to this study, the application of a native PGPB consortium with half dose of chemical fertilizer has increased teff variety yield and yield components as well as grain nutrient uptake significantly and could save 50% chemical fertilizer. Further evaluation and demonstration could be conducted at different sites and agro-ecology is needed to clarify the role of native PGPB inoculants with a reduced dose of chemical fertilizer as biofertilizers that exert beneficial effects on plant growth and development also as grain quality.

Keywords: - Bio-inoculants, consortium, and treatment

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INTRODUCTION

To feed the world population, the intensity of agricultural production has got to be significantly increased (Hasler et al., 2017). Advanced agricultural technologies, like efficient fertilization methods, are required to satisfy worldwide demand because the inefficient and excessive use of chemical inputs result in food contamination and negative environmental outcomes which together have an enormous impact on human health (Meena et al., 2020). Different chemical fertilizers that contain acid radicals, like hydrochloride and sulfuric radicals, and hence increase the soil acidity and adversely affect soil and plant health (Alori & Babalola, 2018).

The increasing awareness of health challenges as a result of the consumption of poor quality crops has led to exploring advanced technologies improving crop productivity and quality of nutrient contents without affecting human health. A reliable alternative to the use of chemical fertilizers is native PGPB inoculants, which can act as biofertilizers and biocontrol agents (Tobergte & Curtis, 2013). They are environmental-friendly and deliver essential nutrients to plants in a more sustainable manner and reduce the utilization of agrochemicals.

The application of PGPB inoculants constitutes a biotechnological tool to enhance plant nutrition and mitigate the negative impact of conventional chemical inputs. Pseudomonas, Bacillus, Azospirillum, Azotobacter, Enterobacter, and Serratia are the main genera of PGPB 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 the synthesis of growth hormones, phosphate solubilization, atmospheric nitrogen fixation, production of lytic enzymes, production of antibiotics, and secondary metabolites that inhibit plant pathogens (Gopalakrishnan et al., 2015).Solomon Zewdie et al., (2000) report, inoculation of teff varieties with indigenous *Azospirillum* isolates was significantly increase grain yield up to 12% over control. Moreover, Delelegn Woyessa and Fassil Assefa (2011) reported that teff variety inoculated with native *Pseudomonas fluorescent* and *Bacillus subtilis* significantly increased grain yield about 28 % and 44% respectively. Souza et al., (2015) reported that plant inoculation with a consortium of several PGPB strains increases plant growth and yield and might be an alternative to inoculation with individual strains, likely reflecting the various mechanisms used by each strain in the consortium.

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Furthermore, the dual application of PGPB inoculants with chemical fertilizer increased the fertility of the rhizosphere and resulted in a more efficient uptake of soil nutrients by the plant. Therefore, the combination of appropriate rates of chemical fertilizer with PGPB inoculants can have an enormous positive impact on soil quality and crop yield and also improve the quality of grain nutrient contents (Bargaz et al., 2018). Yet, there is no research on the effects of chemical fertilizer and PGPB inoculants co-inoculation on the enhancement of teff plant growth, yield, and yield-related parameters as well as grain nutrient uptake under field conditions. Therefore, it has necessary to assess the effect of PGPB inoculants and chemical fertilizer dual application in crops to optimize the input/output relationship. Supported above goal of this work was to evaluate the effect of individual or consortium native PGPB co-inoculated with a half dose of chemical fertilizer to enhance plant growth, yield, and yield-related traits also as grain nutrient uptake of teff varieties under field conditions.

MATERIAL AND METHODS

Description of the study area

The study was conducted at the Debrezeit Agricultural Research center (DZARC) experimental research site during the 2019 main cropping season. The experimental site is geographically located at 08º-44'N & 38º-58'E and an altitude of 190 meters above sea level. The mean long-term annual rainfall recorded at the station is 660 mm and therefore the average annual minimum and maximum temperatures are 12ºC and 27.4ºC, respectively (WakjiraTesfahun2018). The experimental soil was a silt loam texture composed of 14% clay, 32% sand, and 54% silt: having an organic carbon content of 1.26% which is low according to Roy et al. (2006). According to Olsen et al., 1954, phosphorus (P) rating (mg kg^{-1}), the available P content of experimental site soil (<3) is low. The pH of the soil was 6.96, which is within the range of 4 to 8 and suitable for teff production. Total nitrogen (N) of the soil (0.12%) is medium; as rated by Havlin *et al*., 1999.

Materials Used for experimental trail

The seed of two teff varieties named Magna (DZ-01-196) and Dukem (Dz-01-974) was taken from DZARC. Three potential native PGPB strains were used as a treatment.

Bacterial inoculant preparation

Nutrient broth medium amended with 1% carboxyl methylcellulose (CMC) was prepared and inoculated with the selected potential PGPB strains and shaken for 48hrs in a rotary shaker. After

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shaking, the density of the culture was measured using a turbidimeter bacterial cell concentration of 10^6 to 10^8cfu mL^{-1}. Then the cultures were used for seed inoculation.

Seed surface sterilization and treatment with bacterial inoculants

Teff seeds were surface sterilized with 70% alcohol for 3 min and followed with 1% hypochlorite for 5 minutes and rinsed 5 times with sterile distilled water. The grown effective individual or consortium PGPB were mixed with surface-sterilized seeds of two varieties of teff. The treated seeds were shade dried and immediately sown in the prepared plots. Experimental procedures and treatment are laid out. The land was prepared by tractor plowing. The seedbeds were leveled and compacted before sowing. The treatment of the field experiment has consisted of three native PGPB strains. The treatment was laid out as a random complete block design (RCBD) with three replications and 10 treatments (Table.1). A plot size of 2 m x 2 m (4 m2) with 20 cm row spacing and a total of 5 rows and 30 plots were used. Adjacent plots and blocks were spaced 0.5 and 1 m apart, respectively. Treatments were assigned to each plot randomly. Seed sowings were made as per treatment at rates of 5kg per hectare. Plots were kept free of weeds by hand weeding without using herbicides. Harvesting was done manually using a hand sickle from an area 1.8m x 1.8 m (3.24m2) to measure agronomic traits and other parameters.

Table. 1. Different treatments used for field experimental trial

T24 (Dz-01-196)	T24 (Dz-01-974)	NI1 (Dz-01-196)
T36 (Dz-01-196)	T36 (Dz-01-974)	NI2(Dz-01-974)
T53 (Dz-01-196)	T53 (Dz-01-974)	
TBCS (Dz-01-196)	TBCS (Dz-01-974)	

Agronomic data collection and measurement

At the physiological maturity, plant growth, yield and yield component data were collected before and after harvesting according to the teff descriptor (AlemuAssefa *et al*., 2016).

Plant height (PH): Plant height was measured at physiological maturity from the ground level to the tip of the panicle from five randomly selected teff crops in each plot.

Panicle length (PL): It is the length of the panicle from the node where the first panicle branches emerge to the tip of the panicle, which was determined from an average of five randomly selected teff crops per plot.

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The number of total spikes (NTS): The number of total spikes was determined by counting the spikes of each selected plant.

The number of fertile tillers (NFT): The number of tillers was determined by counting the fertile tillers.

Grain yield (Kg/ha^{-1}): Grain yield was measured by harvesting the crop from each pot.

Straw yield (Kg/ha^{-1}): After threshing and recording the grain yield, the straw yield was measured by drying the straw to a constant weight.

Harvest index: harvest index was calculated as the ratio of grain yield per plot to total shoot dry biomass per plot

Lodging index: the level of lodging was measured just before the time of harvest by visual observation based on the degree of 1-5, where 1 (0-15^o) indicates no lodging, 2 (15-30^o) 25 % lodging, 3 (30-45^o) 50 % lodging, 4 (45-60^o) 75 % lodging and 5 (60-90^o) 100% lodging (Donald, 2004). The degree was determined lodged by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation. Data recorded on lodging percentage is subjected to the arc sign transformation described for percentage data by Gomez and Gomez (1984)

Methods of data analysis

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

RESULT

Effect of PGPB inoculation on teff agronomic traits

Two-way analysis of variance (ANOVA) results showed that in Table.2. teff agronomic traits like plant height, panicle length, number of total spikes, shoot dry biomass, grain yield, and straw yield were significantly affected by treatment at 0.1% probability level while the harvest index significantly influenced at 1 % probability. The panicle length, shoot dry biomass, and straw yield are significantly affected by variety at 1% probability, while plant height and lodging index significantly influenced at 5 % probability. However, the interaction effect of variety * treatmentand block did not significantly influence teff agronomic traits.

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

S.O.V	DF	Growth, yield, and yield-related parameters								
		PH	PL	NTS	NFT	SDW	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

Note: *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability level, respectively; NS: not significant.

Effect of PGPB inoculation on teff growth-related traits

Plant height (PH)

The effects of the native PGPB application on plant height of teff are presented in Table. 3. Both varieties of teff were inoculated with individual or consortium PGPB significantly (P<0.001) increased plant height compared to the uninoculated treatment plots. The longest plant height (133.5cm) was observed on Dz-01-974 inoculated with the consortium of PGPB, and the minimum (84.1cm) was observed on uninoculated Dz-01-196.

Panicle length (PL)

The panicle lengths of both varieties were significantly (P<0.001) increased by inoculation of either individual or consortium PGPB. The longest panicle length (53.2cm) was observed on Dz-01-974 inoculated with the bacterial consortium and the shortest (31.7cm) was observed on uninoculated Dz-01-196, which increased the panicle length up to 168% over the uninoculated one. (Table.3)

Number of total spikes (NTS)

Individual treatment means the comparison result is presented in Table. 3 showed that the number of total spikes of Dz-01-196 was significantly (P<0.01) affected by the inoculation of either individual or consortium PGPB. The minimum number of total spikes (18.4) was observed on uninoculated Dz-01-196, and the maximum number of total spikes (30.9) was recorded on Dz-01-974 inoculated with PGPB consortium, which exceeds the number of total spikes to 168 % over the control.

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Number of fertile tillers (NFT)

The result is presented in Table 3 showing that the number of fertile tillers were significantly affected by *Enterobacter cloacae ss dissolvens* inoculation. The maximum NFT (12.3) was observed on Dz-01-974 and the shortest (5.1) was recorded on uninoculated Dz-01-196.

Table 3: Means of PGPB and chemical fertilizer co-inoculation effects on growth-related traits

Treatment	Teff growth-promoting traits							
	PH		PL		NTS		N FT	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem
Control	84.1b	88.8b	31.7b	33.5b	18.4b	19.5b	5.1[a]	5.7b
Serratia marcescens ss marcescens	122.5[a]	128.9a	44.3a	50.1a	27.9a	29.7a	9.7[a]	8.6ab
Pseudomonas fluorescens biotype G	124.8[a]	129.6a	43.6[a]	51.5a	26.1[a]	30.7a	6.9[a]	7.4ab
Enterobacter cloacae ss dissolvens	125.5a	133.1a	43.0[a]	50.9a	27.7[a]	29.6a	8.0a	12.3a
Bacteria consortium	128.7[a]	133.5[a]	46.7[a]	53.2a	28.6[a]	30.9a	9.8a	10.3ab
LSD (0.05) %	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

Note: Different letters indicate significant differences at P≤0.05 according to the LSD test. And NS: not significant

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

Shoot dry biomass (SDBM)

Individual treatment means comparison results showed that the shoot dry biomasses of both varieties were significantly (P< 0.001) influenced by inoculation of PGPB inoculants either alone or in combination. The maximum shoot dry biomass (18.1 t ha^{-1}) was obtained from Dz-01-974 inoculated with the PGPB consortium, and the minimum (5.8 t ha^{-1}) was obtained from uninoculated Dz-01-196. The consortium inoculation exceeded shoot dry biomass by about 312% over control (Table.4).

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Grain yield (GY)

Individual treatment mean comparison result is presented in Table 4 showing that grain yield of both varieties were significantly ($P<0.001$) influenced by inoculation of either individually or consortium PGPB. The maximum grain yield (2.7 t ha^{-1}) was obtained from Dz-01-974 inoculated with the bacteria consortium, and the minimum grain yield (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.

Straw yield (SY)

Results of the individual treatment means showed that the application of PGPB alone or in combination was significantly ($P<0.001$) affecting the SY. The lowest SY (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 PGPB consortium, which exceeds 306 % over control plots (Table.4).

Harvest index (%)

The results of the individual treatment mean revealed that the harvest index of both varieties was significantly ($P<0.05$) influenced by the application of either individual or consortium PGPB Table.6). The minimum (16%) was observed on untreated Dz-01-974, and the maximum harvest index (27 %) was observed on Dz-01-196 inoculated by PGPB consortium, which increases the harvest index up to 169% over the control (Table.4).

Lodging index (%)

The results of the individual treatment mean are given in Table 4 showing that no significant difference was observed on the lodging index of the two varieties on inoculation by PGPB inoculants although differences were recorded between inoculated and uninoculated treatments.

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Table 4: Means of PGPB and chemical fertilizer co-inoculation on teff growth, yield, and yield-related traits

Treatment	Teff yield and yield-related parameters (tone per hector)									
	SDBM t ha^{-1}		GY t ha^{-1}		SY t ha^{-1}		HI %		LI %	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem
Control	5.8^{b}	5.9b	0.60^{b}	0.61b	3.5b	3.7b	17c	16b	19	18
Serratia marcescens ss marcescens	14.0^{a}	16.5a	1.9^{a}	2.3a	7.9a	9.6a	25a	24a	29	32
Pseudomonas fluorescens biotype G	13.8^{a}	16.4a	1.7b	2.4a	7.4a	9.4a	22^{b}	25a	30	28
Enterobacter cloacae ss dissolvens	13.7^{a}	17.2a	1.6b	2.6a	7.6a	9.9a	20^{b}	26a	32	30
Bacteria consortium	13.8^{a}	18.1a	2.0a	2.7a	7.7a	10.7a	27a	26a	30	25
LSD 5%	1.02	0.20	0.20	0.15	0.20	0.88	0.08	0.04	4.63	2.57
p-value	0.001	0.001	0.003	0.001	0.04	0.001	0.07	0.01	0.7	0.9

Note: Different letters indicate significant differences at P≤0.05 according to the LSD test. And NS: not significant

Effects of PGPB inoculation on teff grain nutrient uptake

The result of the analysis of variance (ANOVA) is presented in Table 6 showing that the teff grain nitrogen (N), phosphorus (P), and calcium (Ca) uptake was significantly affected by treatment at 1% probability level, but grain sulfur (S) uptake was significantly influenced by treatment at 1 % probability. Teff grain iron uptake was significantly influenced by the teff variety at 0.1% probability. Whereas, teff grain magnesium (Mg) and iron (Fe) uptake was significantly affected by teff variety at 5% probability level. There was no significant difference in grain potassium (K) and Zinc (Zn) uptake by both factors (Table.6)

Table 5: Mean square of treatment and variety effects on tef grain nutrient uptake

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

Note: *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability level, respectively; NS: not significant.

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Effect of PGPB inoculation on teff grain N, P, S, K, Mg, Ca, Zn and Fe uptake

The result of the individual treatment means is presented in Table 7. Application of either individual or consortium PGPB inoculants was significantly improved teff grain N uptake. The maximum teff grain N (1.85 %) uptake was observed on the teff variety inoculated with PGPB consortium, and the minimum (1.42 %) uptake was recorded on uninoculated control. Similarly, teff grain P uptake was significantly affected by inoculation of either individual or consortium PGPB inoculants. The maximum grain P (3.35 %) uptake was observed on the teff variety inoculated with the PGPB consortium, and the minimum grain P (0.67 %) uptake was observed on uninoculated treatment. Furthermore, the application of single or consortium PGPB inoculants significantly influenced grain sulfur (S) uptake. The maximum grain S (1.61) %) uptake was recorded due to the inoculation of the PGPB consortium, and the minimum grain S (0.3.38 %) uptake was recorded from uninoculated treatment. Moreover, teff varieties inoculated with different PGPB inoculants significantly affect grain Ca uptake. The maximum grain Ca (0.19%) was observed in two varieties. The results indicated that the grain potassium, magnesium, zinc, and iron uptake was not significantly affected by the application of single or consortium PGPB inoculants.

Table 7: Means of PGPB and chemical fertilizer co-inoculation on tef grain nutrients content improvement

Treatment	N %	Ph %	S	K %	Mg %	Ca %	Zn%	Fe %
Control	1.42 ^{b}	0.67^{c}	0.38c	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

Note: Different letters indicate significant differences at $P \leq 0.05$ according to the LSD test. And NS: not significant

DISCUSSION

The present study results showed that inoculation of PGPB either alone or in combination significantly ($P<0.05$) increased teff variety growth, yield and yield related parameters over the control. Similarly, Kumar *et al*., (2017) reported that inoculation of PGPB either alone or in various combinations significantly ($P \leq 0.05$) increased the growth and yield of wheat compared to untreated controls. Within the present study revealed that inoculation of PGPB consortium significantly enhanced the growth, yield and yield components of the two teff varieties over the control. Furthermore, Meena *et al*., (2016c) reported that the application of PGPB as a consortium of compatible strains has been more effective than their single application in the practical field. 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. Kumar *et al*., (2017) reported that triple inoculation of Enterobacter with *Serratia marcenscens* and *M. arborescens* has significantly increased the plant height of wheat up to 14 % followed by dual inoculation up to 11% over control. Indigenous PGPB consortium is more suitable to beat the challenges like biotic and a biotic stress condition as that they have adapted to environmental conditions and can produce some growth-promoting substances which could have led to enhanced initiation of cellular division and cell elongation, leading to maximum plant length.

Panicle length and therefore the number of total spikes are the most important traits affecting plant growth. In our study, teff varieties, panicle length and therefore the total number of spikes were significantly affected by inoculation of either single or consortium PGPB. Longer panicles allow more spikes that contain a better number of grains and higher plant height. This is often according to the findings of Temesgen (2012) and Haftamu *et al*. (2009), who reported that panicle length and therefore the total number of spikes showed a positive correlation with plant height.

The present study results suggested that shoot dry biomasses of both varieties were significantly increased by inoculation of either individual or consortium PGPB inoculants. The maximum shoot dry biomass was obtained from Dz-01-974 inoculated by PGPB consortium. This could be due to an increase in the supply of unavailable nutrients by the inoculated bacterial consortium which can boost plant growth and development, consequently the shoot dry biomass of the teff varieties, however, the lowest shoot biomass was observed in the plots where no fertilizer and PGPB

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inoculants application this indicates that the experimental soils limit in releasing essential soil nutrients in adequate amount to support teff plant growth and development without any external addition of inputs.

There have been significant differences in teff grain yield by the inoculation of either individual or consortium PGPB. The highest grain yields were obtained from Dz-01-974 inoculated with PGPB consortium, which exceeds 450 % over control. Sarma *et al*. (2009) reported that a mixture of two *fluorescent Pseudomonas strains* increased Vigna mungo yield by 300 % in comparison to the control. These results indicated that the consortium of native PGPB might increase the nutritional assimilation of the plant by using various PGP mechanisms like phosphate solubilization, nitrogen fixation, and different secondary metabolite production.

The straw yield of cereal crops is an important agronomic parameter that has sensitive to soil nutrient level or the nutrients applied from external sources. Application of either single or combined PGPB inoculants significantly affects straw yield. The maximum straw yield (10.7 t ha^{-1}) was obtained from Dz-01-974 inoculated with the PGPB consortium. This could be due to the interaction effect of the bacterial consortium that improves the supply of unavailable nutrients to the host plant. The increment of teff variety straw yield is useful as animal feeds are superior in weight gain and improve lactation ability.

Harvest index (HI) indicates the balance between the productive parts of the plant and the reserves. High harvest index indicates the presence of good partitioning of biological yield. In the present study, the individual treatment mean results revealed that the harvest indices of the teff varieties were significantly increased by inoculation of either single or consortium PGPB inoculants over control. The maximum harvest index (27%) was observed on Dz-01-196 inoculated with PGPB consortium. These results showed that PGPB consortium could improve the supply of essential nutrients to the plant and increase the harvest index. In this study, no significant difference was observed on the lodging index between the two varieties of teff on inoculation by PGPB either alone or in a consortium, although differences were occurred between inoculated and uninoculated treatments (Table.4). In general, the present study confirmed that PGP bacterial consortium was capable of enhancing the growth, yield, and yield-related parameters of the two varieties. However, the bacterial consortium displayed a marked difference in their effect on several features of growth and productivity of teff. The variation could be caused by differences in the degree of compatibility

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between the bacterial consortium and teff varieties. Inoculation of either individual or consortium PGPB inoculants significantly ($P \leq 0.05$) improved grain N, P, and Ca uptake of two teff varieties over control. Mantelin andTouraine (2004) reported that plants inoculated with PGPR significantly increased the uptake of nutrient elements like Ca, K, Fe, Cu, Mn, and Zn through proton pump ATPase. Bacillus and Microbacterium inoculants improve the uptake of mineral elements by crop plants (Karlidag et al.2007). Kumar *et al*., (2017) reported that co-inoculation of *Enterobacter* with *S. marcescens* and *M. arborescens* enhanced grain N and P uptake of wheat varieties in the field experiment. As shown in the result nitrogen-fixing and P-solubilizing activities of the tested strains significantly influenced better N and P uptake by wheat, which ultimately impacted on better growth and yield of wheat by the application of PGPB. Likewise, Selvakumar and others (2008) reported that the application of *S. marcescens* and *Enterobacter* enhances nutrient uptake of wheat plants.

CONCLUSION AND RECOMMENDATION

The results of this study indicated that inoculation of PGPB consortium in teff varieties significantly increased plant height, panicle length, shoot dry biomass, grain yield and straw yield, grain N, P, and Ca uptake. This study suggested that the utilization of PGPB consortium as bio inoculants could be an efficient approach in supplementing fertilizer requirements to sustain teff productivity and reduce the cost of production without harming the environment and human health. Further evaluation and demonstration might be conducted by the inoculation consortium PGPB inoculants under different environmental conditions are needed to clarify their role as bioinoculantss that exert beneficial effects on plant growth and development.

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