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Research Article

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

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ABSTRACT. The study aimed to examine the effects of PGPR and chemical fertilizer inoculation on the growth, yield, and grain nutrient uptake of teff varieties. Field experiments were carried out in a Randomized Complete Block Design (RCBD)consisting of six treatments. For this, two varieties were sown in plots (size: 2×2m each) arranged with (4×2) factorial. Two types of chemical fertilizer and four PGPR inoculants (three strains of PGPR either alone or in a consortium form). The results of the variance analysis showed that panicle length, the number of total spikelets, shoot dry biomass, grain yield, straw yield, harvest index, grain nitrogen, and phosphorus uptake were highly significant ($P \leq 0.001$) for the treatment while panicle length, shoot dry biomass, grain yield, lodging index, and grain iron uptake were also significant ($P \leq 0.00$) for teff variety. The interaction effect of the two factors did not significantly affect teff varieties agronomic traits and grain nutrient uptake. Treatment means comparison results revealed that plant height and lodging index were significantly influenced by the application of 100% recommended dose of chemical fertilizer. The maximum plant height (143.6 cm) and lodging index (55%) were observed on Dz-01-196. Panicle length, number of total spikelets, harvest index, and grain yield were significantly affected by the inoculation of the PGPR consortium along with the 50 % recommended dose of chemical fertilizer. The maximum panicle length (55.3 cm), number of total spikelets (31.8), harvest index (30%), and grain yield (3.6 t/h) were recorded on Dz-01-974, which increase 5.3 and 1.2 folds over the treatment receiving 50% and 100% recommended dose of the chemical fertilizer respectively. Application of a native PGPR with a half dose of chemical fertilizer could be a viable approach to reduce pollution, lodging index, cost of chemical fertilizer and sustain teff farming systems without affecting grain yield and quality.

Keywords: *Biofertilizer, Bioinoculant, Strains and Variety*

INTRODUCTION

In Ethiopia, teff is cultivated on an area of about 3 million hectares taking up about 24.02 % of the total grain crop area. This makes teff the first among cereals in the country in area coverage [1]. Despite large area coverage, its productivity is very low. The average national yield of teff is about 1.75 tons per ha [2]. Some factors contributing to the low yield of teff are low soil fertility and inadequate use of chemical fertilizer, weeds, and also lodging [3, 4].

In teff crops production, nutrient management is an important practice to obtain maximum yields. Nowadays in Ethiopia, farmers are heavily using chemical fertilizers to improve teff yield and this is considered as one of the main sources for environmental pollution and destroying soil health. The application of chemical fertilizers can increase teff productivity but its continuous use has great impacts on human health, and the environment [5]. The overuse of nitrogen fertilizers has negative effects on soil, air, and water. In the case of higher doses of nitrogen fertilizer application, the plants become less efficient in taking up of nitrogen, and it is lost through the process of denitrification [6]. Likewise applied phosphate fertilizer is fixed by different cations and exist in unavailable form. The continuous use of higher levels of chemical fertilizers by the farmers has led to the problem on rhizosphere colonizing beneficial microbes and soil properties, which is proving detrimental effects to the teff crop production and productivity. The negative effects of chemical fertilizers can be avoided by using biofertilizers with low doses of chemical fertilizers. The combination of these fertilizers is cost-effective and environment friendly [7].

Plant growth-promoting rhizobacteria (PGPR) settle in plant roots actively and promote plant growth. PGPR such as *Azospirillum*, *Azotobacter*, *Bacillus*, *Enterobacter, Pseudomonas*, *Serratia, and Streptomyces* [8,9] when used as seed or soil inoculants they show beneficial effects on plant growth, development, and yield through the synthesis of growth hormones, N-fixation, and solubilization of phosphate [10]. They are a natural source of fertilizers that improve the efficiency of soil and plants [11]. The phosphate solubilizing bacteria when applied as bio-inoculants, it enhance the uptake of phosphorous by plants [12]. Phosphorous is considered as an essential part of plant nutrition for their germination and healthier vigor. It helps plant root development and various metabolic processes [13]. The majority of applied phosphorus fertilizers are unavailable to plant, it is converted into an insoluble form such as iron phosphates, aluminum phosphates, and calcium phosphates [7]. The problem of unavailability of Phosphorous can be solved by using beneficial microorganisms that ensure P availability to crop plants by producing various kinds of organic acids [15, 16]. Zerihun Tsegaye *et al.,* [17] reported that Phosphate solubilizing activity is related to the microbial production of organic acids, which chelate the cation bound to phosphate, thereby converting it to a soluble form. Furthermore, the dual application of PGPR 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 PGPR inoculants either alone or in a consortium form can have an enormous positive impact on soil quality, crop yield, or grain nutrient contents [18]. Yet, there is no research on the effects of dual application of PGPR and reduced rates of chemical fertilizer to enhance growth, yield, and yield-related parameters as well as grain nutrient uptake of teff under field conditions. The objectives of this study were to examine the effects of either individual or consortium PGPR with a half dose of chemical fertilizer on growth, yield, yield-related traits also as grain nutrient uptake of two varieties of teff.

MATERIAL AND METHODS

Description of the study area

The study was conducted at the DZARC experimental research site during the 2019 main cropping season. The experimental site is geographically located at 08^{o}-44'N latitude & 38^{o}-58'E longitude and an altitude of 190 meters above sea level. DZARC is located 47km southeast of Addis Ababa. The mean long-term annual rainfall recorded at the station is 660 mm and therefore the average annual minimum and maximum temperatures are 12^{o}C and 27.4^{o}C, respectively [4]. The experimental field at this site characterized by heavy black soil (vertisols)

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 PGPR strains and chemical fertilizers (Urea and DAP) were used as a treatment.

PGP bacterial strains compatibility test

Compatibility of the three-selected PGPR was carried out to formulate bacterial consortia used as inoculants. The method described by Nikam et al.[13] with slight modifications was used for in-vitro bacterial compatibility testing. PGPR cultures were streaked on nutrient agar plates in such a way that for every single bacterial culture in the center of the plate, other cultures are streaked radiating from the center. The plates were incubated at 30°C for 48 hours and the zone of inhibition was observed and PGPR strains that do not show a clear zone between each other were selected for bacterial consortium formulation.

Bacterial inoculant preparation

Nutrient broth medium amended with 1% carboxyl methylcellulose (CMC) was prepared and inoculated with the selected potential PGPR strains and shaken for 48hrs in a rotary shaker. After shaking, the density of the culture was measured using a turbidimeter, bacterial cell concentration of 10^6 to 10^8cfu mL^{-1}.

Seed surface sterilization and seed inoculation

Teff seeds were surface sterilized with 70% alcohol for 3 minutes, followed with 1% hypochlorite for 5 minutes, and rinsed 5 times with sterile distilled water. Seed inoculation was carried out by using bacterial seed coating methods. Seed coating is a technique in which an active ingredient (e.g., bacterial inoculant) is applied to the surface of the seed with the help of a binder (adhesive) substance. For this nutrient broth medium amended with 1% carboxyl methylcellulose (CMC) was prepared. Either individual or consortium of PGPR was transferred into the prepared medium. Surface sterilized seeds of two teff varieties were immersed in a medium containing PGPR suspensions of either alone (10^{-8} CFU/ml) or consortium (10^{-8} CFU/ml) and incubated for one hour using a shaker incubator. The inoculated seeds transferred onto sterilized filter paper and allowed to air-dry in a laminar flow hood. Then the bacterial seed coating was completed.

Experimental procedure and treatment 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 PGPR strains either alone or in a consortium and two chemical fertilizers. The experiment was laid out as a random complete block design (RCBD) in a 4×2 factorial arrangement with three replications and 14 treatments. Two teff varieties were sown in a plot size of 2 m x 2 m each (4 m^2) with 20 cm row spacing and a total of 5 rows and 42 plots were used. Adjacent plots and blocks were spaced 0.5 and 1 m apart, respectively. Seeds sowing were made as per treatment at the rates of 5kg per hectare (2g/plot). Treatments were assigned to each plot randomly. Phosphate fertilizer was applied at a rate of 46kg ha^{-1} (18.4g/plot) during planting based on the treatment, and nitrogen was applied (side dressing) at a rate of 60kg ha^{-1} (24g/plot); in which 1/2(12g/plot) at planting and ½ (12g/plot) at tillering times in the form of Urea [20]. Fifteen days after teff seedling emergence, a second bacterial inoculation was performed, in which 5 mL of bacterial inoculums (10^{-8} CFU/ml) was added per plot. In addition, thirty days after teff seedling emergence, a third bacterial inoculation was performed at the same concentration as used previously. Plots were kept free of weed by hand weeding. Harvesting was done manually using hand sickle from an area of 1.8m x 1.8 m (3.24 m^2) to measure agronomic traits and other parameters. The details of treatments used in this study are presented in (Table 1).

***Table. 1**. Different treatments used for field experimental trial*

T24 (Dz-01-196[1])	T24 (Dz-01-974[1])	HDCF (Dz-01-196)	NI1 (Dz-01-196)
T36 (Dz-01-196[1])	T36 (Dz-01-974[1])	HDCF (Dz-01-974)	NI2 (Dz-01-974
T53 (Dz-01-196[1])	T53 (Dz-01-974[1])	FDCF (Dz-01-196)	
TBCS (Dz-01-196[1])	TBCS (Dz-01-974[1])	FDCF (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 [21].

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.

The number of total spikelets (NTS): The number of total spikelets 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.

Shoot dry weight (SDW): above ground total (shoot plus grain) biomass kilogram for the entire plot.

Grain yield (GY): Grain yield is measured by harvesting the crop from each pot.

Straw yield (SY): After threshing and recording the grain yield, the straw yield was measured by drying the straw to a constant weight.

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

Lodging index (LI): 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 [22]. The degree was determined lodging 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 arc sign transformation described for percentage data by Gomez and Gomez [23].

Teff grain nutrient analysis

The following macro and micronutrients such as nitrogen (N), phosphorus (P), sulfur (S), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe) were determined using standard procedure. Teff seeds were oven-dried at 60°C for 48 hours and milled. For each treatment, 1,000 mg of milled grain was used to determine grain nutrient contents. The N concentration was determined through complete digestion in concentrated H_2SO4 and subsequent distillation using the micro-Kjeldahl method. Total K and P were determined by using a flame photometer and metavanadate colorimetric, respectively. Total Ca, Mg, and Zn contents in grain were determined using an inductively coupled plasma–atomic emission spectrometer. The protein content was quantified by Kjeldahl's method and the samples were read on a UV-VIS spectrophotometer. The analysis was developed according to the methodology described by Miyazawa et al. [19]

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 in a factorial experiment. Two-way ANOVA was conducted to test the significance level of factors (treatment & variety) at $p \leq 0.05$. A comparison of means was performed using the least significant difference (LSD).

RESULT

Effect of PGPR and chemical fertilizer application on teff agronomic traits

Two-way ANOVA results showed that in Table.2. The treatments were significantly influenced all teff agronomic traits at 0.1% probability level except the number of fertile tillers significantly affected by treatment at 5% probability level. Furthermore, panicle length, shoot dry biomass, and straw yield was significantly affected by variety at 0.1% probability level, while plant height and lodging index were significantly affected by variety at 5% probability. Whereas, no significant differences were observed by the interaction effect of variety*treatment on different teff agronomic traits.

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

S.O.V	DF	Teff agronomic traits								
		PH	PL	NTS	NFT	SDW	GY	SY	HI	LI
TM	6	1936^{***}	252^{***}	92.3^{***}	20^{*}	130^{***}	3.4^{***}	45^{***}	0.01^{***}	1335^{***}
VT	1	220^{*}	334^{***}	25.3^{NS}	1.5^{NS}	56^{***}	2.04^{NS}	26^{***}	0.01^{NS}	46^{*}
TM*VT	6	41.6^{NS}	8.0^{NS}	4.6^{NS}	4.9^{NS}	3^{NS}	0.28^{NS}	1.7^{NS}	0.001^{NS}	5.9^{NS}
Error	28	45.6	9.9	9.1	7.7	2.9	0.13	1.80	0.001	6.50

Note: S.O.V= source of variation, TM=treatment, VT=variety, DF=degree of freedom, PH=plant height, PL=panicle length, NTS=number of the total spikelet, NFT=number of the fertile tiller, SDW=shoot dry weight, GY=grin yield, SY=straw yield, HI=harvest index, LI=lodging index, *, **, ***: statistically significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$ probability level, respectively and NS: not significant.

Effect of PGPR and chemical fertilizer application on teff variety growth and growth-related traits

Plant height (PH)

Individual treatments mean result presented in Table. 3 showed that the application of either individual or combined PGPR along with a half dose of chemical fertilizers was significantly ($P \leq 0.01$) increased plant height of both varieties over the control. The longest PH (133.5 cm) was observed on Dz-01-974 inoculated with PGPR consortium and half dose of chemical fertilizer. Moreover, Dz-01-196 received a full dose of the recommended chemical fertilizer was highly and significantly increased plant height (143.6 cm), which increases 1.2 folds over the same variety inoculated with PGPR consortium and half dose of chemical fertilizer.

Panicle length (PL)

Individual treatment means comparison result is presented in Table.3 revealed that either single or consortium PGPR co-inoculated with a half dose of chemical fertilizer was significantly (P<0.001) increased panicle length of both varieties. The longest PL (53.2cm) was observed on Dz-01-974, which increases 1.3 folds over the same variety treated with only 50% recommended dose of the chemical fertilizer respectively (Table 3).

Number of total spikelets (NTS)

Inoculation of either single or consortium PGPR with a half dose of chemical fertilizer shows a significant (P<0.001) difference in the number of the total spikelet of both varieties. The maximum number of total spikelets (30.9) was observed on Dz-01-974, which exceeds 1.3 folds over the same variety treated with only 50% of the recommended dose of chemical fertilizer respectively (Table 3).

Number of fertile tillers (NFT)

Both varieties' number of fertile tillers was significantly (P<0.05) affected by co-inoculation of *Pseudomonas fluorescens biotype G* with a half dose of chemical fertilizer. The maximum number of fertile tillers (13.3) was observed on Dz-01-974, which increases 2.2 folds over the same variety treated with only 50% and 100% chemical fertilizer respectively (Table 3).

***Table 3**. Means of PGPR and chemical fertilizer application inoculation effects on growth & related traits*

Treatment	Plant growth-promoting traits							
	PH		PL		NTS		N FT	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	magna	Dukem
50% NP	104.2^{c}	114.4^{c}	36.5^{b}	39.7^{b}	24.1^{a}	23^{bc}	6.6^{b}	6.1^{b}
100% NP	143.6^{a}	137.1^{a}	45.3^{a}	51.9^{a}	28.0^{a}	28.2^{ab}	8.5^{ab}	8.1^{b}
Serratia marcescens ss marcescens + 1/2 dose NP	122.5^{b}	128.9^{a}	44.3^{a}	50.1^{a}	27.9^{a}	27.9^{a}	8.0^{ab}	8.6^{b}
Pseudomonas fluorescens biotype G + 1/2 dose NP	124.8^{b}	129.6^{a}	43.6^{a}	51.5^{a}	26.1^{a}	30.73^{a}	12.0^{a}	13.3^{a}
Enterobacter cloacae ss dissolvens + 1/2 dose NP	125.5^{b}	133.1^{a}	43.0^{a}	50.9^{a}	27.7^{a}	29.6^{a}	9.7^{ab}	10.0^{ab}
Bacteria consortium + 1/2 dose NP	128.7^{b}	133.5^{a}	46.9^{a}	53.2^{a}	28.6^{a}	30.9^{a}	9.8^{ab}	10.3^{ab}
LSD (0.05) %	10.95	12.64	5.22	5.01	5.07	4.86	3.74	4.64

Note: NP=nitrogen and phosphorus, PH=plant height, PL=panicle length, NTS=number of total spikelet, NFT=number of fertile tillers, Different letters indicate significant differences at P≤0.05 according to the LSD test.

Effect of PGPR and chemical fertilizer application on teff yield and yield-related traits

Shoot dry weight (SDW)

Both varieties shoot dry weight significantly (P<0.001) affected by co-inoculation of either single or consortium PGPR with a half dose of chemical fertilizer. The maximum SDBM (18.0 t ha^{-1}) was recorded from Dz-01-974 inoculated with *Serratia marcescens ss marcescens* and half dose of chemical fertilizer, which exceeds 2.3 folds over the same variety, received only 50% recommended dose of the chemical fertilizer treatment respectively (Table 4).

Grain yield (GY)

The grain yield of both varieties was highly and significantly (P<0.001) influenced by the combined application of either individual or consortium PGPR with a half dose of chemical fertilizer. The highest GY (3.6 t/ ha^{-1}) were obtained from Dz-01-974 inoculated with PGPR consortium and half dose of chemical fertilizer, which increases yield 5.3 folds over the same variety, received only 50% recommended dose of the chemical fertilizer treatment respectively (Table 4)

Straw yield (SY)

Both varieties straw yield significantly (P<0.001) influenced by the combined application of either single or consortium PGPR with a half dose of chemical fertilizer. The maximum SY (10.6tha^{-1}) was obtained from Dz-01-974 inoculated with *Serratiamarcescen ss smarcescens* and half dose of chemical fertilizer, which increases 2.5 folds over the same variety, received only 50% and 100% recommended dose of the chemical fertilizer respectively (Table 4).

Harvest index (HI)

The harvest index of both varieties was significantly (P<0.05) affected by the combined application of either single or consortium PGPR with a half dose of chemical fertilizer. The highest HI (32 %) was observed on Dz-01-974 inoculated with *Enterobacter cloacae ss dissolvens*, which exceeds 1.7 folds over some variety, received only 50% recommended dose of the chemical fertilizer respectively (Table 4)

Lodging index (LI)

The lodging index of both varieties had not been significantly affected by inoculation of either individual or consortium PGPR along with a half dose of chemical fertilizer, however, the varieties treated with 100% recommended dose of the chemical fertilizer significantly increases the lodging index. The largest LI (75%) was observed on Dz-01-196, followed by LI (50%) was observed on Dz-01-974, while the lowest LI (20%) was observed on both varieties treated with a half dose of chemical fertilizer, which increases 2.8 folds over the same variety inoculated with PGPR consortium and individual PGPR inoculants respectively (Table 4).

***Table 4**. Means of PGPR and chemical fertilizer application on teff growth, yield, and related traits*

Treatment	SDW t ha^{-1}		GY t ha^{-1}		SY t ha^{-1}		HI%		LI%	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem
50% NP	7.4^{b}	7.9^{b}	0.66^{c}	0.68^{d}	3.9^{b}	4.2^{b}	17^{c}	18^{b}	20^{cd}	20^{cd}
100% NP	14.3^{a}	16.7^{a}	1.9^{b}	3.0^{bc}	8.1^{a}	9.6^{a}	20^{bc}	20^{b}	55^{a}	45^{b}
Serratia marcescens ss marcescens + ½ dose NP	14.9^{a}	18.0^{a}	2.5^{a}	3.2^{b}	8.6^{a}	10.6^{a}	26^{ab}	25^{ab}	30^{c}	25^{cd}
Pseudomonas fluorescens biotype G + ½ dose NP	15.5^{a}	16.1^{a}	2.4^{a}	3.1^{b}	8.7a	8.6^{a}	25^{ab}	28^{a}	28^{c}	25^{cd}
Enterobacter cloacae ss dissolvens + ½ dose NP	14.1^{a}	17.2^{a}	1.9^{b}	2.6^{c}	8.3^{a}	10.2^{a}	21^{bc}	32^{a}	30^{c}	30^{c}
Bacteria consortium + ½ dose NP	15.4^{a}	16.8^{a}	2.7^{a}	3.6^{a}	8.9^{a}	9.3^{a}	27^{a}	30^{a}	25^{cd}	25^{cd}
LSD (0.05) %	1.02	1.08	0.13	0.13	0.95	0.98	0.05	0.05	4.47	5.10

Note: NP=nitrogen and phosphorus, SDBM=shoot dry biomass, GY=grain yield, SY=straw yield, HI=harvest index, LI=lodging index, LSD=least significant difference, Different letters indicate significant differences at P≤0.05 according to the LSD test.

Effects of PGPR and chemical fertilizer application on teff grain nutrient uptake

The result of the two way ANOVA is presented in Table 5 showed that the teff grain phosphorus (P) and iron (Fe) uptake significantly affected by treatment at 0.1% probability level, however grain nitrogen (N) and calcium (Ca) uptake was significantly influenced by treatment at 1% probability, although grain magnesium (Mg) uptake significantly affected by treatment at 5% probability level. Only grain magnesium (Mg) uptake is also significantly affected by variety at 1% probability level.

***Table 5**. Mean square of treatment and variety effects on grain nutrient uptake*

S .O.V	D.F	N%	P%	K%	Mg%	Ca%	Zn%	Fe%
TM	6	0.07**	3.03***	0.001^{NS}	0.0004*	0.06**	0.00001^{NS}	0.011***
VT	1	0.02^{NS}	0.17 ^{NS}	0.01^{NS}	0.002**	0.001^{NS}	0.0001^{NS}	0.004^{NS}
Error	6	0.004	0.17	0.004	0.0001	0.001	0.00001	0.001

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

Effect of PGPR and chemical fertilizer application on teff grain N, P, S, K, Mg, Ca, Zn, and Fe uptake

The result of the individual treatment means is presented in Table 6. Application of either individual or consortium PGPR inoculants along with a half dose of the chemical fertilizer was significantly improved teff grains N, P, S, and Ca uptake. The highest grain nitrogen (1.87%), P (3.83%), S (1.70%), and Ca (0.18%) uptake was recorded on a variety treated with the PGPR consortium. Therefore, grain potassium, magnesium, zinc, and iron uptake was not significantly affected by the application of single or consortium PGPR inoculants together with a half dose of the chemical fertilizer.

***Table 6**. Means of PGPR and chemical fertilizer co-inoculation on teff grain nutrients content improvement*

Treatment	N%	P%	S%	K%	Mg%	Ca%	Zn%	Fe%
50%	1.53cd	1.83b	0.45d	0.41a	0.07a	0.10b	0.00a	0.01a
100 % NP	1.68bc	0.33c	0.64d	0.39a	0.10a	0.05b	0.00a	0.01a
Serratia marcescens ss marcescens + ½ dose NP	1.82ab	2.44b	1.34b	0.36a	0.10a	0.04b	0.00a	0.02a
Pseudomonas fluorescens biotype G + ½ dose NP	1.89a	2.78b	1.35b	0.38a	0.10a	0.06b	0.05a	0.05a
Enterobacter cloacae ss dissolvens + ½ dose NP	1.80ab	2.63b	0.98c	0.43a	0.12a	0.07b	0.05a	0.05a
Bacteria consortium + ½ dose NP	1.87 a	3.83a	1.70a	0.47a	0.10a	0.18a	0.05a	0.05a
LSD (0.05)	0.17	0.96	0.29	0.16	0.04	0.07	0.01	0. 10

Note: NP=nitrogen and phosphorus, N=nitrogen, P=phosphorus, S=Sulphur, K=potassium, Mg=magnesium, Ca=calcium, Zn=zinc, Fe=iron, Different letters indicate significant differences at $P \leq 0.05$ according to the LSD test.

DISCUSSION

The present study result showed that inoculation of either individual or consortium of PGPR with a half dose of chemical fertilizer significantly ($P \leq 0.05$) affected teff varieties agronomic traits and grain nutrient uptake over the control. These results are supported by Abbas *et al.*, [24] report, integrated effect of PGPR, PSB, and NPK chemical fertilizer significantly increased plant growth of maize as compared to control. In the present study, the result revealed that the application of chemical fertilizer was significantly increased the plant height of the two-teff varieties over control. The maximum height observed on Dz-o1-196 received 100% recommended chemical fertilizer, which increases 1.03 fold over the same variety inoculated with PGPR consortium. The highest plant height obtained at the higher dose of chemical fertilizer might be due to the vital role of fertilizer applied for elongation and vegetative growth. Okubay et al., [25] reported that the maximum teff plant height was obtained from the application of the highest rate of chemical fertilizer whereas the lowest plant height was obtained from the control. Moreover, Wakene et al., [26] stated that the plant height of barley increased with increasing rates of nitrogen fertilizer.

Panicle length and therefore the number of total spikelets are the most important traits which affect plant growth. In our study, panicle length was significantly ($P<0.001$) affected by inoculation of either single or consortium PGPR with a half dose of chemical fertilizer. Longer panicles allow more spikelets that contain higher plant height.

The present study result suggested that shoot dry weight of both varieties were significantly increased by inoculation of either individual or consortium PGPR inoculants with a half dose of chemical fertilizer. The maximum shoot dry weight (18.1 t ha^{-1}) obtained from Dz-01-974 inoculated with the *Serratia marcescens ss marcescens* and half dose of chemical fertilizer followed by bacterial consortium (18 t ha^{-1}) inoculation. Correspondingly, Zafar et al., [27] reported that the use of PGPR strains in combination with chemical fertilizers further improved shoot dry weight compared to the control. Inoculation of the PGPR and chemical fertilizer might have improved the availability and uptake of N, P, and K by the plants, which stimulated the performance of crops due to the production of plant growth regulators [28].

As well the study result revealed that teff grain and straw yield was significantly ($P<0.001$) increased by inoculation of the either single or consortium of PGPR in combination with a half dose of chemical fertilizer over the treatment received 100% chemical fertilizer. The highest grain yield (3.6 t/ ha^{-1}) and straw yield (10.6 t ha^{-1}) were obtained from Dz-01-974 inoculated with PGPR consortium and half dose of chemical fertilizer. This might be due to the synergistic effect of PGPR and chemical fertilizer that increases the grain and straw yield of the teff variety. Amalraj *et al.*, [29] compared the effect of single and combined treatments of PGPR with chemical fertilizer and reported better results for combined treatments. Saber et al., [30] reported that inoculation of PGPR and chemical fertilizer had a significant role in wheat yield and yield-related partners. Recent studies have shown the effect of the joint application of chemical fertilizer and microbial inoculants on grain yield improvement [19]. Similarly, Assainar et al., [31] reported that an adequate combination of microbial inoculants with rock-based fertilizer improved grain yield in maize. Moreover, several studies have demonstrated improved yield of various staple cereal crops in response to mineral fertilization and inoculation with some non-symbiotic NF bacteria that exhibit multiple PGPR traits [19].

In the present study, the individual treatments mean result revealed that the harvest index of the teff varieties was significantly ($P<0.05$) increased by inoculation of either single or consortium PGPR inoculants with a chemical fertilize over control. The maximum HI (32%) was observed on Dz-01-974 inoculated with *Enterobacter cloacae ss dissolvens* and half dose of chemical fertilizer. These results showed that the integrated effect of PGPR bacterial strain and reduced amounts of the chemical fertilizer could increase the availability of essential nutrients to the plant and improve plant productivity as well as increase HI.

In this study, the lodging index of teff varieties was highly significantly ($P \leq 0.05$) affected by the application of chemical fertilizer. The higher lodging index (55%) was observed under the plot that received 100% recommended dose of chemical fertilizer, and the lowest lodging index was observed in teff varieties inoculated with PGPR either alone or in a consortium. Increasing fertilizer rate enhanced lodging index of the varieties, which exceeds 1.8 to 2.2 folds over the same variety treated with 100% recommended dose of chemical fertilizer and PGPR consortium inoculation respectively. Teff lodging increment could be due to the profound effect of high dose N fertilizer supply and this enhancing vegetative growth of crop thereby leading to bending of the weak stem due to the sheer load of the canopy. Seyfu [20] reported that lodging in cereals is considered to be caused by the high rate of nitrogen fertilizer application.

CONCLUSION

The results of this study indicated that inoculation of individual or a consortium of native PGPR along with a half dose of the chemical fertilizer significantly increased plant height, panicle length, shoot dry weight, grain yield, and straw yield, N, P, S, Ca, and Fe contents of the teff grain. This study suggested that the application of either single or a consortium of PGPR along with a half dose of chemical fertilizer as treatments could be an efficient approach to enhance teff crop production and productivity and improve grain quality without affecting human health, environment and biodiversity.

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