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Influence of PGPR on Growth and Yield of Oat (*Avena sativa* L.) under Field Conditions

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***Abstract*:** India has 15% of the world's livestock population. Currently, livestock rearing for animal goods such as dairy products, meat, eggs, wool and their byproducts, which have become a huge source for livelihood. But insufficient availability of quality fodder affects animal health and productivity. Oat is a unique cereal fodder crop, which is utilized for animal fodder as well as for the human diet. Despite having such potential of the crop, the area and yield are still not much more increasing in India. Concerning this problem, the present investigation was performed in search of potential plant growth-promoting rhizobacteria to enhance the crop growth and productivity of forage oat. During the study, the bacterial isolates were screened for plant growth-promoting properties such as siderophore production, zinc, potassium and phosphate solubilization. Afterward, a field trial was conducted with selected potential bacterial isolates. The results of the study demonstrated that among all bacterial isolates PAU 12 and CHM 7 were performed superior as they improved the green forage, dry matter yield, plant height, grain yield and weight of oat grains. The correlation coefficient analysis also showed that the plant growth-promoting properties proportionally enhanced fodder productivity, seeds yield and other agronomical parameters. Moreover, cluster and principal component analysis also confirmed that among all PGPR, the performance of PAU 12 and CHM 7 was remarkable. The present investigation confirmed the potential of bacterial isolate PAU 12 and CHM 7 and could be utilized with oat as potential bioinoculants to enhance its productivity in an eco-friendly manner.

***Keywords*:** Forage oat, PGPR, Growth and yield, Animal nutrition

Fodder production has attained significance in recent years. The sustainability and survival of our livestock depend upon the quality of feed and fodder resources available to the livestock. The production of livestock in India has taken a new leap by venturing itself on a commercial basis. Oat (*Avena sativa* L.) ranks sixth in world cereal production, following wheat, maize, rice, barley and sorghum. Oat is an important forage crop as it is grown in winters and is used for animal feed, human nutrition as well as industrial purposes. Oat has multiple uses as it is grown for grains, which is a source of high protein and is also widely used for haymaking. It is considered good fodder as its straw is soft and palatable. Moreover, its grains have high value for nutritional and medicinal purposes. Animals use forage as green fodder but it is also preserved in the form of hay and silage and is known as dry fodder. Day to day rising population of the world simultaneously increasing the demand of milk, butter, meat and their derivates products. India has one of the world's largest livestock populations and is known as a billion-dollar industry but the demand for animal goods is still unable to fulfill. As the worth of animals and their goods are associated with their genetics, nutrition and environment, hence adequate fodder with sufficient nutrients is obligatory. But currently cultivating fodder is unable to accomplish the rising fodder demand because crops residues are burned by the farmers and among all cropping areas, only a small fraction (4.4%) of land is devoted for forage production, moreover, their fodder and seed yield is also low, which is fails to fulfill the forage demand (Dikshit and Birthal 2010). The low nutrient content in forage crops is a major reason cause weight loss, low milk production, the occurrence of disease in animals. Yadav et al (2017) estimated that approximately an additional 219.2 MT of green fodder and 226.53 MT of dry fodder is required, which is beyond the production of fodder currently cultivated in India. Inspite of the requirement and importance of fodder and grain, research is being more focused on the improvement of wheat, rice and maize cultivation. Hence, to cope with this problem, efficient alternative strategies and government policies should be devised and formulated to augment fodder production and their grain yield.

Chemical fertilizer application is an easy approach to improve forage oat production but their extensive use causes soil infertility, soil water pollution, destroys native microflora

and ultimately makes the land barren. The root rhizosphere is the junction between bacteria and plant which support the growth and developmental activity of both plant and bacteria (Singh et al 2017, Joshi et al 2018). Plant growth-promoting rhizobacteria (PGPR) are classified as bacteria, closely associated with the root zone and are capable to improve plant growth, physiology and ultimately crop yield by facilitating nutrient availability and soil moisture without affecting environmental geochemical cycles (Khan et al 2020). Hence, exploitation of plant growth-promoting rhizobacteria (PGPR) could be efficient, eco-friendly, cost-effective and safer approach to augment the production of oat crops. PGPR possesses several incredible mechanisms such as atmospheric nitrogen fixation, phosphorous, zinc and potassium solubilization, iron chelation, exopolysaccharide and phytohormones production to preserve the soil health, which is the core quality and yield determination factor for crops (Khan et al 2019). Considering the importance of oat, the present investigation was carried out to find a potential PGPR to augment the oat productivity sustainably.

MATERIAL AND METHODS

Bacterial cultures and growth conditions: A total of twenty bacterial isolates were obtained from the Department of Microbiology culture collection, College of Basic Sciences and Humanities, GBPUA&T, Pantnagar, India. Bacterial cultures were grown on a nutrient agar medium at 28°C and purity was confirmed through Gram's staining followed with microscopic analysis. All the bacterial isolates were preserved in slants at 4°Cand in glycerol stocks at -20°C for for further use.

Plant growth-promoting traits assessment: The plant growth-promoting properties of the bacterial isolates were assessed through siderophores production, solubilization of potassium, and zinc as well as by nitrogen fixation.

Siderophore production: Siderophore production was determined on chrome azurol S test as described by Schwyn and Neilands (1987). In brief, actively grown bacterial culture was spot inoculated on Petri plate containing nutrient agar medium amended with CAS dye then plates were incubated at 28±2°C for 48 to 72 hours. The appearance of the yellow zone around the bacterial colony indicating the positive results for siderophore production and its efficiency was calculated by the following formula.

Siderophore production efficiency%= (Diameter of halo zone/diameter of colony) x 100

Zinc and potassium solubilization potential: The zinc solubilization potential of bacterial isolates was tested on minimal agar medium supplemented with 0.1 % ZnO and $ZnCO_3$(Ramesh et al 2014) and potassium solubilization was determined through Aleksandrow agar medium (Parmar and Sindhu 2013). Actively grown bacterial cultures were spot inoculated on respective medium and plates were incubated at 28±2°C for 48-96 hours. The appearance of halo zone around the bacterial colony was designated as zinc and potassium solubilization and solubilization efficiency were calculated by the following formula.

Solubilization efficiency %= (Diameter of halo zone/diameter of colony) x 100

Nitrogen fixation: The nitrogen fixation ability of bacterial isolates was tested by spot inoculation on Burk medium. The appearance of bacterial growth on Burk's medium was considered for positive results.

Field study: A field trial was conducted to compare plant growth promotory potential of selected six bacterial isolates on the growth of forage oat (*Avena sativa* cv. UPO 10-2) at an instructional dairy farm, Nagla, Pantnagar. For effective delivery of bacterial isolates, the bioformulation of each bacterial isolate was prepared with activated charcoal as an inert carrier material. The oat seeds were bacterized by each bacterial bioformulation separately and allowed to adhere to seeds by drying under shade for 1 hour. Subsequently, seeds were sown in the respective field plot. The whole experiment was performed in randomized block design with three replications.

Plant growth promotion assessment: At about 50% of the flowering stage of the crop five representative plant samples were taken for estimation of green forage yield and samples were dried in an oven at 80°C for 48h and their dry weight was measured. Moreover, at the time of maturity, plant height was measured. After crop harvesting, spike length, number of grains/spike, 1000grain weight, biological and grain yield, and harvest index were calculated.

Statistical analysis: To determine the significance and variance between the treatments one-way ANOVA followed by Duncan was performed at P<5%. Pearson's correlation coefficient analysis was performed to determine the link among the PGP traits, grain, biological yield and harvest index. Further, to confirm the effect of relative bacterial isolates on the plant's agronomical parameters, principal component analysis and cluster analysis were performed.

RESULTS AND DISCUSSION

PGP potential of bacterial isolates: Among all bacterial isolates, PAU 12 followed by CHM 7 and HRC 23 showed the highest siderophore production efficiency (Table 1). Further, maximum efficacy of zinc solubilization exhibited by CHM4 and CHM7 i.e 333.33% (Table 1). Parveen et al (2018) also observed the siderophore production and zinc solubilization

potential of bacterial isolates ranged from 72.7-250% and 150-600%, respectively. Moreover, Roshani et al (2020) also screen the PGPR for consortium preparation by investigating their siderophore and zinc solubilization potential ranging 66.66 – 70.66 % and 260-325%, respectively and further assessed them for plant growth promotion on wheat and found. In addition, among all bacterial isolates, PAU 12 showed the highest potassium solubilization efficiency i.e. 225% followed by CHM7 (i.e. 200%). All the bacterial isolates except CHC 4, BW 12, and DHB 8 were able to grow on nitrogen-deficient Burk's Medium and confirmed their nitrogen fixation ability (Table 1) Parmar and Sindhu (2013) and Ahemad and Kibret (2014) documented that potassium solubilization and nitrogen fixation ability are the crucial mechanisms of PGPR to support plant growth and productivity.

Yield and growth performance: The current investigation demonstrated the remarkable influence of all bacterial isolates on the growth promotion and yield attributing parameters of oat crop over control. Green forage and dry matter yield are the important attributes for oat production. The highest green forage (621.33 and 624.00 q/ha) and dry matter yield (98.27 and 95.10 q/ha) were observed under treatment of PAU 12 and CHC 4 bacterial isolates, respectively. Likewise, Deva et al (2014) also reported the enhancement in fodder yield when oat seeds were treated with potential PGPR. In a present study when concerning the plant height, seeds primed with PAU 12 exhibited maximum plant height i.e. 129.00 cm followed by CHM7 and CHC 4 (Table 2). Almaghrabi et al (2013) also reported 60% increment in tomato plant height when primed with potential PGPR over uninoculated control. Among all treatments, the utmost spike length (37.97 and 37.13 cm) and the number of grains per spike (50.33 and 49.33) were observed in PAU 12 and CHM 7 treated plants, respectively (Table 2). Naeem et al (2018) also observed 22 and 20% increase in spike length and the number of grains per spike, respectively over un-inoculated control, when wheat seeds were primed with PGPR. The present study results confirmed the grain weight enhancement upon priming of each PGPR over control, but a

Table 1. Plant growth-promoting traits of bacterial isolates

Bacterial Isolates	Siderophore production efficiency%	Potassium solubilization efficiency%	Zinc solubilization efficiency%	Nitrogen fixation
PAU 12	133.33	225.00	185.71	+
CHC 4	-	175.00	333.33	-
CHM 7	116.66	200.00	333.33	+
HRM 29	112.50	-	166.66	+
BH 7	110.00	180.00	200.00	+
PIT 4	100.00	150.00	260.00	+
J 28	100.00	180.00	160.00	+
HRC 23	116.66	140.00	150.00	+
BW 12	-	-	-	-
DHB 8	-	-	-	-

Table 2. Influence of PGPR on plant growth promotion and yield attributing traits of oat

Treatment	Forage yield (q ha^{-1})	Dry matter yield (q ha^{-1})	Plant height (cm)	Spike length (in cm)	Number of grain per spike	1000 grain weight (in g)	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Biological yield (q ha^{-1})	% Harvest index
Control	566.40±3.33^{a}	86.76±0.77^{a}	119.33±0.88^{a}	32.00±0.94^{a}	43.00±1.52^{a}	45.21±0.55^{a}	15.93±0.37^{a}	179.63±2.33^{a}	195.56±4.09^{a}	8.15±0.22^{a}
PAU 12	621.33±2.66^{c}	98.27±0.48^{d}	129.00±1.15^{d}	37.97±0.61^{c}	50.33±0.88^{c}	50.73±1.23^{b}	19.31±0.08^{e}	207.87±1.92^{C}	227.18±3.39^{c}	8.50±0.10^{a}
BH7	581.33±11.6^{a}	91.38±0.77^{b}	125.00±0.85^{c}	35.57±0.97^{c}	47.00±0.57^{b}	49.99±1.11^{b}	18.15±0.16^{c}	196.76±0.96^{b}	214.91±1.59^{b}	8.45±0.11^{a}
PIT 4	589.33±2.66^{b}	89.53±0.43^{b}	124.67±2.02^{c}	35.15±0.20^{b}	47.00±1.00^{b}	48.74±0.36^{b}	17.64±0.13^{c}	193.52±0.26^{b}	211.16±0.54^{b}	8.35±0.05^{a}
J2 8	576.00±9.23^{a}	88.48±0.66^{a}	123.33±2.18^{c}	35.20±0.43^{b}	46.33±1.45^{a}	48.19±1.47^{a}	17.27±0.12^{b}	193.06±6.07^{a}	210.32±10.3^{b}	8.26±0.47^{a}
HRC23	581.33±11.6^{a}	88.90±1.33^{a}	121.67±1.20^{b}	34.80±1.08^{a}	46.00±0.57^{a}	46.75±0.36^{a}	17.08±0.08^{b}	187.96±2.79^{a}	205.05±4.86^{a}	8.34±0.18^{a}
HRM29	584.00±4.61^{a}	93.91±0.78^{C}	126.67±0.33^{c}	35.43±0.28^{b}	47.33±1.85^{b}	47.15±0.62^{a}	18.24±0.12^{d}	198.15±0.70^{b}	216.39±1.10^{b}	8.43±0.09^{a}
CHM7	598.93±3.73^{b}	94.57±0.82^{C}	127.00±1.15^{d}	37.33±0.95^{b}	48.00±0.57^{b}	50.06±1.20^{b}	18.59±0.30^{d}	201.39±0.92^{b}	219.98±1.70^{b}	8.45±0.12^{a}
CHC4	624.00±923^{c}	95.10±0.54^{C}	127.67±0.88^{d}	37.13±0.72^{b}	49.33±1.20^{b}	49.62±1.91^{b}	18.56±012^{d}	200.93±0.53^{b}	219.49±0.81^{b}	8.46±0.08^{a}

Data were analyzed at P<0.05 level of significance. Mean±SE is shown in the table; each value is the mean of three replicates

Table 3. Correlation between PGP traits of bacterial isolates and oat agronomical parameters

Characters	Dry matter yield	Plant height	Straw yield	Biological yield	Forage yield	Harvest index	Grain yield	Number of grain per spike	Spike length	Weight of 1000 grain weight	Siderophore production efficiency	potassium solubilization efficiency	Zinc solubilization efficiency
Dry matter yield		0.000296	0.000258	0.0002	0.01119	0.002918	5.22E-05	0.000717	0.001869	0.095258	0.1089	0.28022	0.39202
Plant height	0.95029		6.69E-05	5.70E-05	0.01590	0.009339	6.91E-05	0.001111	0.004364	0.054586	0.33731	0.30049	0.2364
Straw yield	0.95254	0.96987		2.37E-11	0.02070	0.012726	1.21E-05	0.000786	0.000975	0.022173	0.18701	0.12301	0.35363
Biological yield	0.95643	0.97144	0.99979		0.02005	0.010548	5.95E-06	0.00075	0.000973	0.022243	0.18197	0.12778	0.34872
Forage yield	0.82767	0.80512	0.7861	0.78851		0.052772	0.018444	0.000337	0.003928	0.083933	0.43811	0.17404	0.14548
Harvest index	0.89177	0.83824	0.81978	0.83123	0.70093		0.001725	0.019877	0.027912	0.084685	0.15227	0.42246	0.3293
Grain yield	0.97227	0.96954	0.98304	0.9866	0.79468	0.90958		0.000966	0.00164	0.026174	0.15343	0.17825	0.31748
Number of grain per spike	0.93293	0.92218	0.93079	0.93188	0.94807	0.78918	0.92577		0.000871	0.040906	0.24595	0.13343	0.29227
Spike length	0.90708	0.8757	0.92555	0.92559	0.88014	0.76219	0.91113	0.92834		0.017006	0.19342	0.042068	0.1659
Weight of 1000 grain weight	0.6283	0.69723	0.78086	0.78062	0.64539	0.64421	0.76757	0.72727	0.80047		0.49405	0.006559	0.17328
Siderophore production efficiency	0.60919	0.39164	0.51949	0.52458	0.32105	0.55618	0.55488	0.46474	0.51314	0.28488		0.35662	0.5275
Potassium solubilization efficiency	0.43598	0.41978	0.59082	0.58489	0.53271	0.33151	0.52837	0.578	0.7245	0.85692	0.37746		0.452
Zinc solubilization efficiency	0.35233	0.47311	0.37962	0.38321	0.56386	0.39764	0.4066	0.42628	0.54129	0.5335	-0.26401	0.31191	

maximum 12.20% increment in 1000-grain weight was recorded for PAU 12 inoculated plants. The highest grain and straw yield was in PAU 12 and CHM 7 primed plants, respectively (Table 2). Akbar et al (2019) and Yadav et al (2014) also mentioned the increase in grain weight, grain yield and straw yield upon priming with potential PGPR. In addition to these findings, the present investigation demonstrated a significant harvest index (8.50) of oat in PAU 12 primed plants. The present study was also supported by numerous earlier studies conducted with potential PGPR and reported a remarkable increment in plant agronomical and yield attributes in many crops (Kalita et al 2015, Roychowdhury et al 2016, Nawaz et al 2020).

Correlation coefficient analysis: Statistical analysis between PGP properties and oat yield parameters demonstrated a highly positive correlation among them and illustrated that amplitude of PGPR activity significantly enhanced the yield and other agronomical parameters of oat (Table 3). The findings of Singh et al (2011) also supports the present study with a highly positive correlation among phosphate solubilizing bacteria, growth and yield attributes of lentil. TshibuyiKasu-Bandi et al (2019) also recorded the positive correlation of PGPR on agronomical parameters of soybean.

Cluster and Principal component analysis: The relative effect of PGPR on yield attributes of oat plants was performed through principal component and cluster analysis and results of these analyses revealed that PAU 12 and CHM 7 are fall on the right side which confirmed their maximum positive influence on plant yield attributes (Fig. 1). The cluster analysis also revealed that PGPR PAU 12, CHC4 and CHM 7 were the potential PGPR as they had clustered together on the left side (Fig. 2). Similarly, TshibuyiKasu-Bandi et al (2019) also determined the best PGPR that had maximum

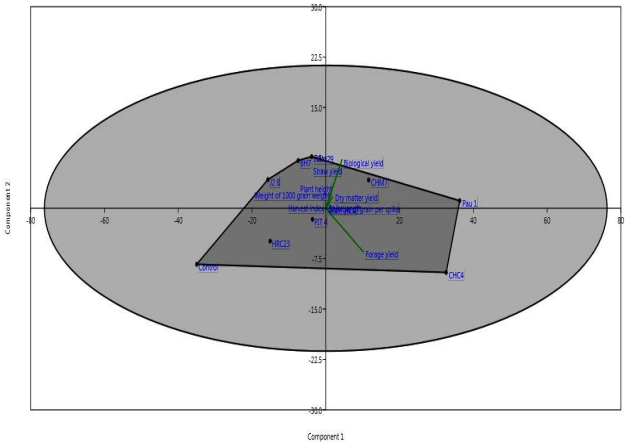

Fig. 1. Principal component analysis depicting the influence of PGPR on growth and yield attributes of forage oat

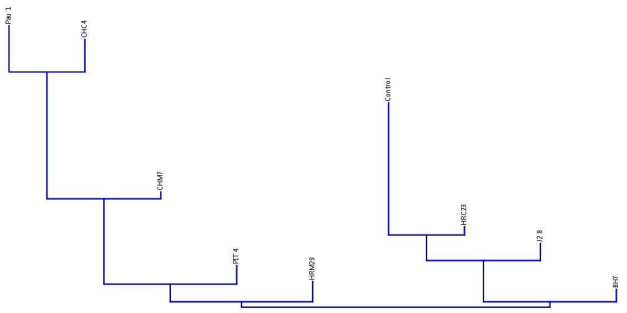

Fig. 2. Cluster analysis of treatments depicting grouping on the basis of their plant growth promotion potential

effect on agronomical parameters through principal component analysis (PCA).

CONCLUSION

PAU 12 and CHM 7 were exhibited utmost potential for plant growth promotion, as they significantly improved yield and other agronomical attributes of forage oat. Positive effects and their relative amplitude on yield were also supported by the correlation, principal component and cluster analysis. Hence, after further field evaluations, these PGPR could be utilized as plant probiotics to augment the forage and seed yield of oat to maintain sustainable, economical and eco-friendly agriculture.

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