RESEARCH ARTICLE

Enhancing wheat (*Triticum aestivum*) growth and productivity through bio-fertilizers: A comprehensive study

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This study investigates the impact of various bio-fertilizers on the growth and productivity of two wheat varieties, PBW 725 and PBW 343, during the rabi season. Seven different treatments, including *Azotobacter* (AZ), Phosphate Solubilizing Bacteria (PSB), *Trichoderma* (TR), and their combinations, along with a control group, were applied in a factorial randomized block design. The experiment evaluated plant growth, yield, and related characteristics. The results demonstrated a significant positive response to bio-fertilizers, with PBW 725 outperforming PBW 343. Combined application of bio-fertilizers, particularly AZ+PSB, showed a substantial increase in plant height, tillering, and yield components. The highest grain yield was observed in variety PBW 725 when treated with combined bio-fertilizers.

Key Words: *Wheat; Bio-fertilizers; Plant; Spike; Productivity*

INTRODUCTION

The most significant staple food that the people of India eat is wheat. About one-third of the world's population mostly gets their food from it. Wheat is used as flour for leavened flat and steamed breads, biscuits, cookies, cakes, morning cereal, pasta, noodles, and fermentation to generate beer and other alcoholic drinks or biofuel. Wheat is also rich in vitamins, minerals, proteins, and carbohydrates. The two primary components of wheat are protein and carbohydrates. It has 70% carbs, 12% protein, 2.2% crude fibre, 2% fat, and 1.8% minerals [1]. Fertilizers are one type of agricultural input that is essential to helping India achieve food security. However, after achieving food security, attention has recently shifted from productivity enhancement-based agricultural research to nutritional security and sustainability issues. This is because we now need to supplement chemical fertilizers with inexpensive organic and bio sources of plant nutrients to address the deteriorating soil health brought on by the global energy crisis and the rising cost of fertilizers [2]. "A substance that contains living microorganisms that is applied to soil, plant surfaces, or seeds is known as bio-fertilizer. These microbes help plants grow by providing nutrients through organic processes like phosphorus solubilization, nitrogen fixation, and the creation of compounds that promote growth. The use of chemical pesticides and fertilizers may be lessened by applying biofertilizers. The microorganisms included in biofertilizers are essential for reestablishing the organic matter in the soil and the natural nutrient cycle. It is possible to grow healthy plants while advancing sustainability and soil health by utilizing bio-fertilizers. Furthermore, compared to chemical fertilizers, bio-fertilizers are frequently more affordable and regarded as environmentally beneficial organic agro-inputs [3].

The use of pesticides and fertilizers has been used to increase the quantity of wheat in order to meet the growing demand; however this strategy has a negative impact on the quality of the crop as well as the overall cultivation environment. Evaluating wheat quality entails looking at the nutritional makeup of wheat flour as well as its useful qualities for baking bread [4]. In comparison to chemical fertilizers, biofertilizers are more affordable and have reduced manufacturing costs, especially when it comes to the use of nitrogen and phosphate. Chemical fertilizer use causes eutrophication in aquatic bodies, which pollutes the air and groundwater [5].

MATERIALS AND METHODS

Field experiment was conducted during the Rabi season. The field experiment with seven treatments of two verities of different combinations of bio-fertilizers was conducted on wheat at the experimental farm. PBW 343 and PBW 725 varieties were sown manually with single plot hand drill at the depth of 5 cm.

Treatment details:

T_1: Control

T_2: *Azotobacter*

T_3: Phosphate Solubilizing bacteria (PSB)

T_4: *Trichoderma*

T_5: *Azotobacter*+PSB

T_6: PSB+*Trichoderma*

T_7: *Azotobacter*+PSB+*Trichoderma*

Days to 50% field emergence

Field emergence was recorded after 15 days of sowing when the entire seedling emerged out from the soil, in each row.

Days to maturity

Number of days taken from crop maturity was taken as the number of days from sowing to the maturity of crop.

Plant height (cm)

Five plants per plot were selected at random and their height was recorded periodically from ground level up to base of last fully opened leaf at 30 and 60 Days after Sowing (DAS), up to the base of flag leaf at (DAS) and up to the base of spike at 120 days. Final plant height was recorded by adding ear length and average value of the plant height was expressed in cm.

Number of tillers per plant

To record the number of tillers per plant, five plants were selected randomly from every plot from the marked row at harvest. Their tillers were counted

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and averaged to express the number of tillers per plant. At maturity number of effective tillers was counted and data were analyzed statistically.

Spike length (cm)

Ear length was measured from the base to the end of the tip of the head and was averaged for five randomly selected ears.

Number of spikelets per spike

Numbers of spikelets were counted in five spikes selected at random from each plot and average was calculated.

Number of grains per spike

Total number of grains from randomly selected five spikes from each plot was counted after manually threshing and average number of grains per spike was recorded.

Test weight (1000 grains) g

Test weight was recorded by taking random samples of grains from the produce of each plot and 1000 grains were counted and weighed.

Grain yield (q/ha)

Grain yield from each net plot harvested were recorded in grammes after threshing and winnowing. The plot yield was later on converted into q/ha.

Straw yield (q/ha)

At the time of harvest, the bundle weight of produce was taken. Later on weight of straw was calculated after deducting grain weight from the bundle weight. The straw yield was expressed as qha^{-1}.

Harvest Index (HI)

Harvest index was calculated by dividing economic yield (grain) yield by the total biological (grain+straw) yield and then multiplied by 100 to express as percentage.

Statistical analysis of the data was recorded was done through randomized block design. It was determined by applied two-factor ANOVA. Test of significance were recorded on the basis of CD differences at 5%.

RESULTS AND DISCUSSION

Field emergence %

Plant emergence count constitutes the very bases of optimum plant population stand which ultimately counts for crop yield. Emergence count is presented in Table 1. Variety PBW-725 showed the maximum mean value of the field emergence (59.88%) followed by PBW-343 (51.63%). The interaction due to variety and treatment had significant difference for field emergence. Emergence count for all treatments was maximum in PBW-725 (67.35%) with T_5 in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$ followed by PBW-343 (62.30%) with T_5 in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. AT T_1 minimum reduction in the field emergence was observed in PBW-343 (42.23%) followed by PBW-725 (48.36%). Free-living N_2-fixing bacteria called *Rhizobium* and *Azotobacter* are employed; these bacteria can generate and secrete certain physiologically active compounds that promote seed germination and increase the vigour of the seedlings that are produced [6]. Furthermore, organic fertilizer increased wheat seed germination. The importance of organic matter in preserving high levels of soil fertility is widely accepted [7]. Applying humic acid has been found to be a substantial organic matter in the soil that enhances seedling growth and germination. When it comes to *Plantago ovata* germination, organic fertilizer has a greater effect than chemical fertilizer [8].

TABLE 1
Effect of different treatments of bio-fertilizers on 50% field emergence in wheat varieties

Verities	Treatments						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	42.23	52.63	48.32	47.63	62.30	51.67	56.67	51.63
PssBW725	48.36	65.07	57.83	51.67	67.35	62.22	66.65	59.88
Mean	45.29	58.85	53.07	49.65	64.83	56.95	61.66	55.76
	Variety	Treatment	V x T					
SE ±	0.10	0.20	0.29					
CD (5%)	0.31	0.59	0.84					

Plant height

The final plant height recorded at the time of harvesting. There was significant difference due to various treatments. The data show that plant height in all treatments was higher than that of the control (Table 2). Highest plant height was recorded under treatment AZ+PSB (T_5) *i.e.,* application of *Azotobacter* with PSB followed by AZ+PSB+TR (T_7) by treatment *i.e.,* application of *Azotobacter* and PSB with *Trichoderma* in both verities. The data obtained on plant height indicated that at all stages of observation variety PBW-725 produced significantly higher plant height than PBW-343, which recorded the lowest plant height at all the stages of crop growth. At maturity, as usual PBW-725 (102.95%) was recorded maximum plant height and significantly superior to PBW-343 (93.36%). At 30, 60, 90 DAS of crop stage, maximum plant height was recorded with treatment T_5 than T_2, T_6, T_7 but all these treatments produced significantly taller plants than T_3, T_4, T_1. Treatment T_1 produced significantly dwarf plants than all other treatments in both these varities. Maximum mean plant height (102.28%) was recorded with treatment T5 at maturity and the trend was $T_5>T_7>T_2>T_6>T_3>T_4>T_1$.

This might be as a result of the function that biofertilizers play in enhancing the qualities of the soil, making nutrients more accessible, and encouraging plant absorption of nutrients. Plant height increased when bio-fertilizer was added [9,10].

TABLE 2
Effect of different treatments of bio-fertilizers on plant height (cm) in wheat verities at harvest

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	79.56	98.76	90.73	87.23	99.66	98.36	99.19	93.36
PBW725	99.83	102.80	101.06	100.76	104.90	101.80	103.70	102.12
Mean	89.70	100.78	95.90	94.00	102.28	100.08	101.45	97.74
	Variety	Treatment	V x T					
SE ±	0.35	0.66	0.93					
CD (5%)	0.10	0.19	0.27					

Effective tillers

It is one of the most important yields contributing character which serve as a direct index for determining the actual yield of the crop. The data on number of tillers plant-1 as affected by different treatments was recorded at maturity are presented in Table 3. It is apparent from the data the maximum number of tillers plant-1 was recorded at maturity irrespective of treatments.

The number of tillers plant-1 differed significantly among varities and it was recorded highest in variety PBW 725, which was significantly superior to variety PBW 343 at all stages of crop growth. Variety PBW 725 showed the maximum mean value of number of tillers (15.45) which is statistically at par with PBW 343 (14.43) at maturity stage. T_1 produced less number of effective tillers and T_5 produced more number of effective tillers all stages of crop growth in both the varities. In general, the order of effective tillers in both the varities was $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. Grain yield, number of spikes/plant, harvest index, 1000 grain weight, and number of tillers/plant were all increased by applying organic manure and biofertilizer (*Azotobacter chroococcum*); nevertheless, at control, the maximum amounts were found in the harvest index and grain protein content [11].

TABLE 3
Effect of different treatments of bio-fertilizers on no. of tillers in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	14.23	14.50	14.37	14.29	14.67	14.44	14.56	14.43
PBW725	15.25	15.51	15.39	15.32	15.65	15.44	15.61	15.45
Mean	14.74	15.00	14.88	14.80	15.16	14.94	15.08	14.94
	Variety	Treatment	V x T					
SE ±	0.44	0.82	0.11					
CD (5%)	0.12	0.24	0.34					

Length of spike

Variety PBW 725 showed largest mean value of ear length (9.09 cm) which is statistically at par with PBW 343 (8.76 cm). The interaction due to variety and treatment had significant difference for spike length. The maximum spike length was measured under T_5 treatment in PBW-725 (11.00 cm) in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$ followed by PBW-343 (10.20 cm) with T_5 in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. AT T_1 minimum reduction in the spike length was observed in PBW-343 (7.90 cm) followed by PBW-725 (8.13 cm) (Table 4). In variety PBW 725, spike length was 11.00, 9.70, 9.30, 9.00, 8.26, 8.26, 8.13 and in variety PBW 343, spike length was 10.20, 9.33, 9.20, 8.53, 8.20, 8.00, 7.90 followed by this order $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. Grain yield, number of spikes/plant, harvest index, 1000 grain weight, and number of tillers/plant were all increased by applying organic manure and biofertilizer (*Azotobacter chroococcum*); nevertheless, at control, the maximum amounts were found in the harvest index and grain protein content [12].

TABLE 4
Effect of different treatments of bio-fertilizers on length of spike (cm) in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	7.90	9.20	8.20	8.00	10.20	8.53	9.33	8.76
PBW725	8.13	9.30	8.26	8.26	11.00	9.00	9.70	9.09
Mean	8.01	9.25	8.23	8.13	10.60	8.76	9.51	8.93
	Variety	Treatment	V x T					
SE ±	0.23	0.44	0.62					
CD (5%)	0.69	0.12	0.18					

Number of spikelets/spike

Number of spikelets per spike is an important index of grain yield and it is generally accepted that the number of grains directly related to the number of spikelets per spike. It is clear from the the average number of spikelets per spike significantly affected by different treatment Table 5. Variety PBW 725 showed largest mean value of number of spikelets per spike (17.04) which is statistically at par with PBW 343 (16.76). The interaction due to variety and treatment had significant difference for spike length. The maximum number of spikelets per spike was measured under T_5 treatment in PBW-725 (19.13) in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$ followed by PBW-343 (19.00) with T_5 in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. AT T_1 minimum reduction in the number of spikelets per spike was observed in PBW-343 (13.70) followed by PBW-725 (14.30). In variety PBW 725, spike length was 19.13, 18.10, 18.00, 17.13, 16.73, 15.90, 14.30 and in variety PBW 343, spike length was 19.00, 17.90, 17.63, 17.00, 16.50, 15.63, 13.70 followed by this order $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. A regular delivery of plant nutrients to the plants and an increased soil buffering capacity are the results of adding FYM to the soil, which may be the cause of the increased spikelets/spike with integrated nutrition management. The function of biofertilizer in boosting the build-up of dry matter, leading to an elevation in grain starch, which was mirrored in the plant's development of more grains. Increased grain yield as a result of the application of biofertilizer, nutrient buildup, and dry matter processing, all of which contribute to a higher rate of seed fertilization [13-15].

TABLE 5
Effect of different treatments of bio-fertilizers on no. of spikelet/spike in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	13.70	17.63	16.50	15.63	19.00	17.00	17.90	16.76
PBW725	14.30	18.00	16.73	15.90	19.13	17.13	18.10	17.04
Mean	14.00	17.81	16.61	15.76	19.06	17.06	18.00	16.90
	Variety	Treatment	V x T					
SE ±	0.30	0.57	0.81					
CD (5%)	0.89	0.16	0.23					

Test weight

The test weight is important and reliable index of grain yield. Test weight indicates the development of grain and has direct relation to grain yield and quality of crop. The data pertaining to test weight as affected by different treatments have been summarized in Table 6. The data clearly showed significant difference in test weight of verities. Variety PBW 725 showed maximum mean value of 1000 seed weight (37.56 g) followed by PBW 343. The interaction due to variety and treatment showed significant difference for 1000 seed weight. The treatment T_5 showed higher values of test weight than T_6, T_3, T_4, T_1 and non-significant with T_5, T_7, T_2. T_6 was statistically at par with T_3 and but differ with T_4, T_1 in both verities. Treatments T_4, T_1 differ significantly with each other. At treatment T_1, minimum reduction in test weight was observed in PBW-343 (33.46 g) followed by PBW-725 (36.20 g). In variety PBW 725, test weight was 38.70, 38.13, 38.00, 37.60, 37.33, 37.00, 36.20 and in variety PBW 343, test weight was 35.20, 35.00, 34.96, 34.46, 34.13, 33.90, 33.46 followed by this order $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. This may be due to the role of bio-fertilizer in increasing the accumulation of dry matter in the plant, which was reflected in an increase in the use of manufactured materials from source to downstream (grains) and an increase in the weight of grains, [16]. When organic manure and biofertilizer were applied, there was an increase in grain production, biological yield, harvest index, 1000-grain weight, and chlorophyll content; however, at the control point, the largest amounts of grain protein content and spikes per spike were seen.

TABLE 6
Effect of different treatments of bio-fertilizers on test weight (gm) 1000 grains in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	33.46	34.96	34.13	33.90	35.20	34.46	35.00	34.44
PBW725	36.20	38.00	37.33	37.00	38.70	37.60	38.13	37.56
Mean	34.83	36.48	35.73	35.45	36.95	36.03	36.56	36.00
	Variety	Treatment	V x T					
SE ±	0.32	0.60	0.86					
CD (5%)	0.94	0.17	0.25					

Grain yield (qha^{-1})

The grain yield constitutes the most important component concerning the economic yield of wheat crop. Grain yield is the end product and is net result of various inputs, influencing growth and yield contributing character. It is the most important character regarding economic values of the crop for comparing efficiency of different treatments. The resultant impact of all the growth and yield parameters as influenced by various treatments is reflected in grain yield. The grain yield per plot was recorded and converted into quintals per hectare. The data with respect to grain yield is presented in Table 7. The grain yield was significantly influenced by two verities and these two verities were noticed significant difference to each other. The highest grain yield was produced by PBW 725 (7.74 qha^{-1}) followed by PBW 343 (5.02 qha^{-1}), respectively. The treatment T_5 showed higher values of grain yield than other treatments T_6, T_3, T_4, T_1 and non-significant with T_5, T_7, T_2. T_6 was statistically at par with T_3 and but differ with T_4, T_1 in both verities. Treatments T_4, T_1 differ significantly with each other. At treatment T_1, minimum reduction in grain yield was observed in PBW-343 (4.48 qha^{-1}) followed by PBW-725 (6.75 qha^{-1}). In variety PBW 725, grain yield was 8.22, 8.14, 7.97, 7.85, 7.68, 7.58, 6.75 and in variety PBW 343, grain yield was 5.36, 5.24, 5.15, 5.11, 4.97, 4.85, 4.48 followed by this order $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. This is because biofertilizer helps the plant get more nutrients, and the two cultivars that excelled in terms of panicle number of grains and grain weight, which showed up in grain yield, are responsible for this level of excellence. More grain was produced by the bio-fertilizer than by an increase in its constituent parts. The same table also shows that the grown cultivars differ significantly from one another [17].

TABLE 7
Effect of different treatments of bio-fertilizers on grain yield (qha^{-1}) in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	4.48	5.15	4.97	4.85	5.36	5.11	5.24	5.02
PBW725	6.75	7.97	7.68	7.58	8.22	7.85	8.14	7.74
Mean	5.62	6.56	6.33	6.22	6.79	6.48	6.69	6.38
	Variety	**Treatment**	**V x T**					
SE ±	0.10	0.19	0.27					
CD (5%)	0.29	0.56	0.79					

Straw yield (qha^{-1})

Straw yield is an important parameter of biological yield for judging the ultimate performance of a crop. Thus, wheat straw makes a major contribution to the efficiency of various treatments tested in an experiment. The data on straw yield as affected by different treatments have been presented in Table 8. Difference in straw yield (qha^{-1}) of verities was non-significant. Although maximum straw yield was recorded in PBW 725 (7.97 qha^{-1}) followed by PBW 343 (5.24 qha^{-1}), respectively. The highest straw yield was recorded under T_5 treatment in PBW-725 (8.44 qha^{-1}) in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$ followed by PBW-343 (5.59 qha^{-1}) with T_5 in order of $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. AT T_1 minimum reduction in the straw yield was observed in PBW-343 (4.79 qha^{-1}) followed by PBW-725 (6.98 qha^{-1}). In variety PBW 725, straw yield was 8.44, 8.37, 8.19, 8.10, 7.90, 7.80, 6.98 and in variety PBW 343, straw yield was 5.59, 5.46, 5.32, 5.33, 5.12, 5.08, 4.79 followed by this order $T_5>T_7>T_2>T_6>T_3>T_4>T_1$. This might be because the biological yield showed evidence of the exceptional yield and components of this treatment. The results of Table 8 also show a significant difference in the biological yield according to the different cultivars; this is because the cultivar with the highest average plant height had a higher biological yield, which was reflected in the increase in bio-fertilizer levels [18]. Because the cultivars differ in the growth features they yield, there are variances in the biological yield between them [19,20].

TABLE 8
Effect of different treatments of bio-fertilizers on straw yield (qha^{-1}) in wheat verities

Verities	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Mean
PBW343	4.79	5.32	5.12	5.08	5.59	5.33	5.46	5.24
PBW725	6.98	8.19	7.90	7.80	8.44	8.10	8.37	7.97
Mean	5.89	6.76	6.51	6.44	7.01	6.72	6.91	6.60
	Variety	**Treatment**	**V x T**					
SE ±	0.15	0.28	0.39					
CD (5%)	0.43	0.82	0.11					

CONCLUSION

In conclusion, this study emphasizes the efficacy of bio-fertilizers, particularly *Azotobacter* and phosphate solubilizing bacteria, in enhancing wheat growth and productivity. Variety PBW 725 exhibited superior performance compared to PBW 343. The combined application of bio-fertilizers showed a synergistic effect, significantly increasing plant height, tillering, and yield components. This research contributes valuable insights into sustainable agricultural practices, emphasizing the potential of bio-fertilizers in ensuring food security while minimizing the environmental impact of traditional chemical fertilizers.

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