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Micronutrient-based plant growth promotion for enhancing yield and profitability of wheat varieties in the Indo-Gangetic plains

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Abstract

Due to micronutrient deficiency, uneven physiological vigour, and rising input costs, wheat productivity in Indo-Gangetic Plains is constrained. A field experiment was carried out during rabi 2022-23 at Students' Instructional Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur to study micronutrient based plant growth promotion in two varieties of wheat. The two wheat cultivars: DBW-187 and PBW-723 were allotted to main plots and nine treatments comprising of plant growth promoters were allotted to the sub-plots. The treatments were control, nitrobenzene, gibberellic acid, solid and liquid seaweed extract, micronutrient mix Zn-Fe-Cu-B, fermented nutrient extract, humic+fulvic acid and amino acid solution. The treatment means, standard errors, critical difference values and exploratory correlation/regression were used to analyse growth, yield attributes, yield, derived physiological indices and economics. DBW-187 has produced greater grain yield (4601.8 kg/ha), straw yield (6982.1 kg/ha), HI (39.50%) and BCR (3.09) as compared to PBW-723. The micronutrient mixture Zn-Fe-Cu-B among the growth promoters produced the tallest plant (86.55 cm), maximum tillers (425.13/m²), grain yield (4572.17 kg/ha), straw yield (7072.20 kg/ha), harvest index (39.87%), net return (Rs. 104280.40/ha) and benefit-cost ratio (3.06). The treated plants achieved a grain yield of 3926.8 kg/ha and net return of Rs. 45704.19/ha. The findings show that application of micronutrient through foliar spray can enhance the yield and profitability of wheat, particularly DBW-187 so that it can be recommended for farmer's field.

Keywords: Benefit-cost ratio, DBW-187, harvest index, micronutrients, plant growth promoters, wheat

1. Introduction

Wheat is a major winter cereal in the Indo-Gangetic Plains of South Asia and is crucial to food security in this region. It is a substantial contributor to calorie and protein intake. With December 2024 announcement, third advance estimates for 2024-25 (Department of Agriculture and Farmers Welfare 2025) ^[3] for wheat output stood at 1175.07 lakh tonnes. India's wheat production pays due attention.

The intensively cultivated wheat systems are increasingly getting constrained for productivity improvement due to soil nutrients imbalance, heat and moisture stress during terminal stages, falling factor productivity and rising input costs. To meet these challenges, nutrient management strategies that enhance both biological efficiency and economic return rather than sole dependence on increased macronutrient inputs are necessary.

Micronutrients are required in small quantities, but exhibit large functional role in wheat. Zinc, iron, copper, and boron serve essential functions in chlorophyll biosynthesis, enzyme activation, the functioning of pollen, the metabolism of carbohydrates, and cell-wall formation and filling of the grain. The restricted tillering and dry matter accumulation and spike fertility and grain weight found when nitrogen, phosphorus and potassium are applied in recommended doses may be linked to deficiency of these elements. Wheat studies have revealed that iron and zinc application can enhance yield attributes, grain yield and benefit-cost ratio (Choudhary *et al.* 2021) ^[2] while foliar zinc application has also been shown to enhance grain zinc concentration and bioavailability in wheat cultivars and landraces (Hao *et al.* 2021) ^[6].

Farmers are also using growth promoters such as gibberellic acid, seaweed extract, humic and

fulvic acids, amino acid formulations and fermented nutrient extracts. The physiological processes may be changed, photosynthate transport enhanced, stress injury delayed, root growth improved and nutrient uptake increased. Seaweed-based inputs have received attention as a biostimulant for plant development. The reason for this is that seaweed contains mineral nutrients, organic compounds and hormone-like substances (El Boukhari *et al.* 2020) [4]. In this regard, two-season wheat experiments linked seaweed and microbial consortia with improved physiological status and yield under water-limited environments. (Vafa *et al.* 2022; Vafa *et al.* 2024) [12, 13].

The varietal responses of a micronutrient mixture need to be evaluated against other plant growth promoters conducted under the same field condition with yield and profitability analysed together. The present study therefore re-analysed the comparative effect of a Zn-Fe-Cu-B micronutrient mixture and other growth promoters on growth, yield attributes, yield, harvest index and economics of DBW-187 and PBW-723 wheat varieties under the conditions of central Indo-Gangetic Plain of Uttar Pradesh.

2. Materials and Methods

The experiment was conducted in Rabi 2022-23 at the Students' Instructional Farm of Chandra Shekhar Azad University of Agriculture and Technology (CSAUAT) Kanpur, Uttar Pradesh, India. The experimental farm is located at an elevation of 125.9 m above the mean sea level in the Indo-Gangetic alluvial tract of central Uttar Pradesh at about lat. 26°29'35" N and long. 80°16'25" E. The location has a semi-arid subtropical climate. Throughout the growing season, the temperature ranged from cool winter conditions to high temperatures in April and the rainfall during the growing season was low and there was thus supply of irrigation at critical stages.

Originally, the soil of the experimental field was sandy-loam in texture, slightly alkaline in reaction and low in available nitrogen. The organic carbon, available nitrogen, available phosphorus, available potassium and pH of the soil was found to be 0.48%, 148.20 kg/ha, 20.60 kg/ha, 215.50 kg/ha and 7.7, respectively. The trial was set up in a split-plot design and replicated three times. The main plots had wheat varieties and the sub-plots had plant growth promoter treatments. The gross plot size of the experiment was 5 m × 4 m, net plot size was 4 m × 3 m and spacing was 20 cm × 10 cm. The sowing of wheat took place on 5 December 2022. Moreover, and the recommended fertilizer dose of wheat crop was 120:60:40 kg N:P₂O₅:K₂O/ha.

The main plot factor included two varieties of wheat: DBW-187 and PBW-723. The nine treatments that were classified under the sub-plot TGP factor were control; nitrobenzene @ 3 ml/L; gibberellic acid (GA3) @ 2000 ppm; solid seaweed extract (SWE) @ 25 kg/ha; liquid SWE @ 625 ml/ha; micronutrient mixture comprising of Zn, Fe, Cu and B @ 0.5% (MI); UPL Macarena fermented nutrient extract @ 625 ml/ha; Humesol containing humic acid and fulvic acid @ 1250 ml/ha, and Amino Booster G containing 30% amino acid solution @ 5 ml/L.

The cultural practices were standard and uniformly followed. Watering was done before seeding and at four critical stages on December 26, 2022, January 20, 2023, February 14, 2023 and March 11, 2023. Weeds were controlled with clodinafop-propargyl and metsulfuron methyl at 30-35 DAS. The crop matured on 11 April 2023 and harvested on 21 April 2023. Data collection in the research, investigation was carried out for growth observations of plant population, plant height, tillers/m²,

fresh weight, dry weight and crop growth rate. The plant height was measured at 45 days after sowing (DAS), 90 DAS and at maturity. The 1 m x 1 m quadrat was used for counting the tillers that are expressed as tillers/m². The fresh and dry weights per plant were recorded at 45 DAS, 90 DAS and maturity. The recording of crop growth rate was done for 0-45 DAS, 45-90 DAS and 90 DAS to harvest.

The attributes that were utilized to measure the performance of an ear are as follows: number of ears/m², ear length, number of seeds/ear, seed weight/ear and test weight. The measurement of grain and straw yield from each plot was done in kilograms per hectare. The total between the straw and the grain taken together. The calculation of harvest index is a percentage ratio of the grain yield to biological yield. The costs to the government are analyzed through the benefit-cost ratio in the economic analysis. Estimation of Gross Return and Benefit-Cost Ratio. Gross returns were calculated based on prices prevailing during the study period, net returns were calculated by deducting cost of cultivation from gross returns and benefit-cost ratio was calculated by dividing gross return by cost of cultivation.

The data contained fresh weight, dry weight as well as harvest index. Relative growth rate and absolute growth rate were computed as derived indices using mean dry-weight data. The AGR and RGR are interpreted as secondary physiological measure rather than independently tested primary endpoints.

Equations utilized for derived quantities

- Biological yield is the weight of total biomass produced per unit land together with the harvestable yield of a crop.
- The Harvest index is defined as the ratio of grain yield to biological yield; the gross return is the sum of the value of grain yield and straw yield.
- The formula for computing net return is gross return less cost of cultivation.
- Benefit-cost ratio equals gross return, divided by cost of cultivation.
- The formula used for calculating the absolute growth rate is $W_2 - W_1 / T_2 - T_1$.
- The relative growth rate is calculated as the product of the change in natural logarithm over a time interval by 1/t.
- Crop growth rate, expressed in g/m²/day, refers to the increase in dry matter occurring per unit land area per unit time.

In the AGR and RGR formulae, W1 and W2 stand for dry weight at two consecutive observations and T₁ and T₂ stand for the corresponding dates. The AGR and RGR are calculated for 45-90 DAS and 90 DAS-maturity intervals.

Analysis of variance for a split-plot design was used to assess the original experiment, which used variety as the main-plot factor and plant growth promoter as the sub-plot factor. The relevant error terms were used to estimate the main effects of the variety, the main effects of the plant growth promoters and the variety × growth promoter interactions. Mean comparisons were interpreted according to the critical difference at 5% probability. Treatment-mean-based exploratory correlation and regression were conducted in Microsoft Excel/R-equivalent workflow to bolster the research. Pearson correlation among crop yield attributes was calculated (plant height, tillers, dry weight, crop growth rate, ears/m², test weight, grain yield, straw yield, harvest index, net return and benefit-cost ratio). Simple regression techniques were employed to investigate the relationships between test weight, dry weight at maturity, crop

growth rate (CGR) and grain yield of wheat. The analyses discussed earlier are labelled exploratory because they employ treatment means instead of raw experimental units.

3. Results and Discussion

3.1 Response of wheat varieties to plant growth promoters

DBW-187 had a better vegetative expression than PBW-723. The plant features of DBW-187 was better than PBW-723 at maturity or harvest stage as it recorded higher plant height of 87.04 cm, tillers of 427.93/m², fresh weight of 24.82 g/plant and dry weight of 22.77 g/plant. As per the report, PBW-723 recorded slightly lower plant height of 83.99 cm, 417.89 tillers/m², 22.76 g fresh weight/plant and 20.83 g dry weight/plant. The DBW-187 has higher dry-matter accumulation which indicates a superior source development which later translated into greater grain and straw yield.

Among the plant growth promoters, application of the micronutrient mixture Zn-Fe-Cu-B recorded maximum maturity plant height (86.55 cm), tillers (425.13/m²), fresh weight (25.10 g/plant), dry weight (23.05 g/plant) and CGR during 45-90 DAS (0.243 g/m²/day) growth parameters. The application of gibberellic acid enhanced the overall plant growth which lead to final plant height of 86.38 cm, tillers of 424.62/m², dry weight of 22.78 g/plant and crop growth rate (CGR) of 0.238 g/m²/day. Control plots exhibited significantly lower values for plant height, dry matter (DM) and CGR. The results indicate improved vegetative vigour that may be due to higher enzyme activity, enhanced chlorophyll formation and better utilization of applied macronutrients. Choudhary *et al.* (2021) [2] stated that iron and zinc had similar positive effects on the growth and economic yield of wheat. Further, micronutrient application through foliage was found to be essential for the improvement of grain minerals according to Hao *et al.* (2021) [6].

3.2 Physiological indices that were derived

According to the derived AGR values, during the periods of 45-90 DAS (0.256 g/plant/day) and 90 DAS-maturity (0.217 g/plant/day), the micronutrient mixture recorded the highest dry-matter increment. Gibberellic acid coming second at 45-90 DAS (0.254 g/plant/day). RGR fell after 90 DAS for the treatments because the accumulation of dry matter becomes slower in proportion to the development of the plant. The impressive RGR of the control, which occurred during the early growth phase, should not be interpreted without consideration of lower absolute biomass, since it began from a very low dry weight base.

As this pattern indicates, improvements in micronutrient application improve the absolute capacity of the crop canopy to accumulate dry matter rather than simply increasing the proportional growth. The dry weight improvement in seaweed extract and humic/fulvic-acids treatment was significantly less than that of Zn-Fe-Cu-B mixture. The physiological role of biostimulants in increasing the photosynthetic status and tolerance to stress has been established through studies conducted on wheat and other crops (El Boukhari *et al.* 2020; Vafa *et al.* 2022; Alsudays *et al.* 2024) [4, 12, 1].

The traits of yield that is caused by the plant growth promotion of micronutrient-based type.

DBW-187 exhibited superiority over PBW-723 in terms of the number of ears per square meter, ear length, seeds per ear, weight of seeds per ear, and test weight of the grain. This indicates that varietal variations in vegetative growth persisted into reproductive development. The significance of seed weight/ear and test weight variability is particularly crucial

because grain yield in wheat is strongly influenced by grain number and grain size.

The micronutrient blend generated the most robust enhancement in yield attributes, resulting in 420.53 ears per square meter, an ear length of 11.05 cm, 67.55 seeds per ear, a seed weight of 2.64 grams per ear, and a test weight of 39.82 grams. Gibberellic acid was the second most effective treatment for most traits. The treated plants produced ears which were longer (20.54%), contained more seeds (seeds/ear increase of 8.33%), produced heavier seeds (seed weight/ear up by 46.96%) and were heavier (test weight increase of 7.78%) compared with control. The biological explanation is that Zn, Fe, Cu and B work together to strengthen pollen viability, influence carbohydrate movement, stimulate enzymatic respiration and enhance grain filling. A wheat research from Rajasthan likewise indicated that the fertilization of zinc and iron increased effective tillers, grains/spike, spike length and grain yield.

3.3 Yield associated with straw and grain crop

DBW-187 showed a visible yield benefit. The cultivar had a grain yield of 4601.8 kg/ha, a straw yield of 6982.1 kg/ha and a biological yield of 11583.3 kg/ha compared to 3852.5, 6204.3 and 10062.3 kg/ha in PBW-723. The enhancement in grain yield, straw yield, and biological yield of DBW-187 over PBW-723 was 16.28, 11.73 and 13.13%, respectively. This success of a variety may be attributed to a higher tillering ability, stronger biomass production and better spike traits under timely sown conditions.

The highest grain yield, straw yield and biological yield were recorded for Zn-Fe-Cu-B micronutrient treatment (4572.17 kg/ha). The micronutrient mixture achieved grain yield increase by 31.16% compared to control, increased straw yield by 17.32% and biological yield by 22.92%. Grain yield was reported to be the second best using gibberellic acid (4545.80 kg/ha), then using seaweed liquid (4465.23 kg/ha) and seaweed solid (4405.50 kg/ha). The similar performance of gibberellic acid and seaweed extract indicates that agricultural hormones or biostimulants may enhance wheat productivity. However, the micronutrient mixture produced the highest combined growth-yield-economic response. Wheat experiments utilizing biofertilizer and seaweed extract indicated improvement in grain and straw yield (Kewat *et al.* 2022; Vafa *et al.* 2024) [8, 13].

3.4 Physiological efficiency and harvest index

DBW-187 had a harvest index of 39.50% whereas PBW-723 recorded 38.30%. The micronutrient mixture possessed the highest harvest index (39.87%) among plant growth promoters, gibberellic acid (39.65%), seaweed liquid (39.48%) and seaweed solid (39.37%). Only 35.82% of the control was recorded. Improvements in harvest index under micronutrients indicate that the yield increase was not merely due to the accumulation of vegetative biomass; a greater portion of biological yield was partitioned into the grain.

The enhanced harvest index may be due to the impact of boron on reproductive development, zinc on enzyme and auxin metabolism, iron on chlorophyll-linked electron transport and copper on oxidative enzyme systems. These processes all enhance the movement from source to sink during the development of grain. Nonetheless, the validation of harvest index values over subsequent years is essential, as terminal weather has a profound impact on wheat grain filling.

3.5 Profitability and feasibility in economics

Yield Predictions Influenced Economic Results. Gross return of

DBW-187 was Rs. 154733.0/ha; net return Rs. 104774.90/ha; and benefit-cost ratio 3.09; while PBW-723 was Rs. 132036.4/ha; Rs. 82078.26/ha; and 2.64. Consequently, DBW-187 gave a net-return edge of Rs.22696.64/ha over PBW-723.

Among the various plant growth promoters, application of micronutrient mixture gave significantly maximum gross return (Rs. 154665.25/ha), net return (Rs. 104280.40/ha) and B: C ratio (3.06) over control and rest of the treatments. The net return rose to Rs. 39191.72/ha whereas B: C ratio was enhanced by 0.71 in comparison of control. The economic returns for gibberellic acid were close by, which gave Rs. 103458.20/ha. The B: C ratio was 3.05. The profitability of seaweed liquid and seaweed solid also improved, but their B: C ratios were still lower than those of micronutrients and gibberellic acid. The economic significance of micronutrients is relevant to wheat farmers since a yield enhancement can be supplied through low volume foliar input with no major increase in total cost of production. According to Choudhary *et al.* (2021)^[2], bolstering wheat's yield profitability is associated with micronutrient fertilization.

3.6 The effects of wheat varieties and nutrient management

The main-effect pattern allows us to make a pragmatic inference that DBW-187 was the superior variety while the micronutrient mixture was the best growth promoter. Thus, the joint recommendation should be regarded as encouraging.

3.7 Interpreting correlation and regression

The association of yield with maturity plant height ($r=0.996$), harvest index ($r=0.995$), net return ($r=0.993$), dry weight at maturity ($r=0.979$) and CGR during 45-90 DA ($r=0.977$) was found to be very strong in exploratory correlation based on treatment means. Evaluating Treatments in the Context of the Agronomic Response Gradient.

The test weight alone explained a large portion of the treatment-mean variation in grain yield ($R^2=0.986$). The dry weight at maturity ($R^2=0.958$) and the CGR between 45 and 90 DAS ($R^2=0.954$) were other good predictors. The regression model relies on nine treatment means, meaning the aforementioned results should not be taken as causal proof. The biological explanation is that improving grain yield enabled better biomass accumulation, spike development and grain filling that supported the pattern.

4. Conclusion

DBW-187 was found to be a better wheat variety and Zn-Fe-Cu-B micronutrient mixture was discovered to be the best plant growth promoter under one season field conditions of central Uttar Pradesh. According to the results, the treatment of micronutrients with wheat gave the highest grain yield, straw yield, harvest index, net return and benefit-cost ratio. The treatment may be recommended for timely sown wheat as a promising option provided finding is validated over more season and places before the advisory use at large scale.

Disclaimer (artificial intelligence)

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Competing interests

Authors have declared that no competing interests exist.

Tables

Table 1: Treatment structure and experimental details

Parameter	Details
Study type	Field experiment; thesis-derived manuscript draft
Location	Students' Instructional Farm, CSAUA&T, Kanpur, Uttar Pradesh
Season	Rabi 2022-23
Design	Split-plot design with three replications
Main plot	DBW-187 and PBW-723 wheat varieties
Sub-plot	eight plant growth promoter treatments
Plot size	Gross 5 m × 4 m; net 4 m × 3 m
Sowing and harvest	Sown 5 Dec 2022; harvested 21 Apr 2023
Fertilizer dose	120:60:40 kg N:P ₂ O ₅ :K ₂ O/ha

Treatments: G0 control; G1 nitrobenzene; G2 gibberellic acid; G3 seaweed extract solid; G4 seaweed extract liquid; G5 Zn-Fe-Cu-B micronutrient mixture; G6 fermented nutrient extract; G7 humic plus fulvic acid; G8 amino acid solution.

Table 2a: Effect of wheat varieties on growth parameters

Variety	PH 45 DAS	PH 90 DAS	PH maturity	Tillers 45 DAS	Tillers 90 DAS	Tillers maturity	Dry wt 45 DAS	Dry wt 90 DAS	Dry wt maturity	CGR 45-90
DBW-187	38.74	78.97	87.04	382.66	453.01	427.93	3.56	14.9	22.77	0.226
PBW-723	36.94	75.84	83.99	362.89	442.65	417.89	2.51	12.99	20.83	0.212
SE(d) ±	0.53	0.61	0.42	0.502	3.211	0.75	0.112	0.397	0.092	0.003
CD at 5%	NS	2.825	1.947	2.326	NS	3.473	0.52	1.841	0.427	0.013

Table 2b: Effect of plant growth promoters on growth and derived physiological indices

Treatment	Plant height at maturity (cm)	Tillers at maturity (m-2)	Fresh weight at maturity (g/plant)	Dry weight at maturity (g/plant)	CGR 45-90 DAS (g/m ² /day)	AGR 45-90 (g/plant/day)	RGR 45-90 (g/g/day)
Control	82.75	418.07	20.55	19.18	0.113	0.214	0.038
Nitrobenzene @ 3 ml/L	85.78	423.62	24.02	22.00	0.230	0.247	0.034
Gibberellic acid @ 2000 ppm	86.38	424.62	24.82	22.78	0.238	0.254	0.033
Seaweed extract solid @ 25 kg/ha	86.00	423.93	24.25	22.30	0.232	0.249	0.034
Seaweed extract liquid @ 625 ml/ha	86.17	424.22	24.55	22.53	0.236	0.252	0.033
Micronutrients (Zn, Fe, Cu, B) @ 0.5%	86.55	425.13	25.10	23.05	0.243	0.256	0.032
UPL Macarena @ 625 ml/ha	85.10	421.12	23.33	21.18	0.224	0.231	0.034
Humesol @ 1250 ml/ha	85.65	423.20	23.85	21.73	0.229	0.242	0.034
Amino Booster G @ 5 ml/L	85.28	422.32	23.63	21.43	0.226	0.237	0.034
SE(d) ±	0.180	1.165	0.215	0.301	0.004		
CD at 5%	0.367	2.383	0.441	0.616	0.008		

PH, plant height; CGR, crop growth rate; AGR and RGR are derived from dry-weight means.

Table 3: Effect of plant growth promoters on yield attributes of wheat

Treatment	Ears/m ²	Ear length (cm)	Seeds/ear	Seed weight/ear (g)	Test weight (g)
Control	411.72	8.78	61.92	1.40	36.72
Nitrobenzene @ 3 ml/L	417.42	10.52	65.95	2.40	38.98
Gibberellic acid @ 2000 ppm	419.90	10.95	67.28	2.58	39.53
Seaweed extract solid @ 25 kg/ha	418.07	10.67	66.40	2.46	39.15
Seaweed extract liquid @ 625 ml/ha	419.05	10.80	66.83	2.52	39.33
Micronutrients (Zn, Fe, Cu, B) @ 0.5%	420.53	11.05	67.55	2.64	39.82
UPL Macarena @ 625 ml/ha	414.77	10.22	64.23	2.16	38.60
Humesol @ 1250 ml/ha	416.20	10.43	65.47	2.33	38.88
Amino Booster G @ 5 ml/L	415.43	10.28	64.87	2.26	38.80
SE(d) ±	0.599	0.187	0.261	0.033	0.505
CD at 5%	1.225	0.383	0.534	0.067	1.033

Table 4a: Variety-wise yield and economics of wheat

Variety	Biological yield	Grain yield	Straw yield	Harvest index	Gross return	Net return	B:C
DBW-187	11583.30	4601.80	6982.10	39.50	154733.00	104774.90	3.09
PBW-723	10062.30	3852.50	6204.30	38.30	132036.40	82078.26	2.64
SE(d) ±	14.776	30.446	27.709	0.120	533.24	522.79	0.010
CD at 5%	68.447	141.038	128.360	0.557	2470.17	2421.78	0.020

Table 4b: Effect of plant growth promoters on yield and economics of wheat

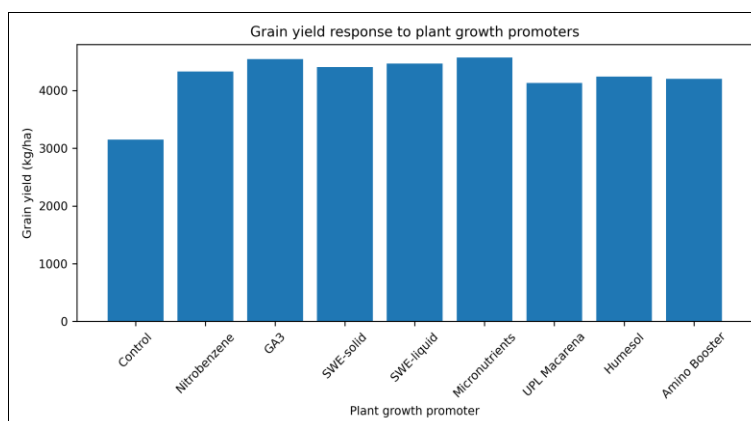
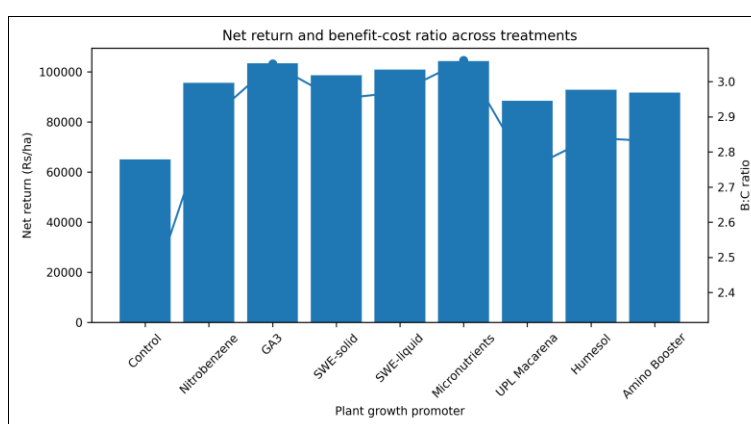
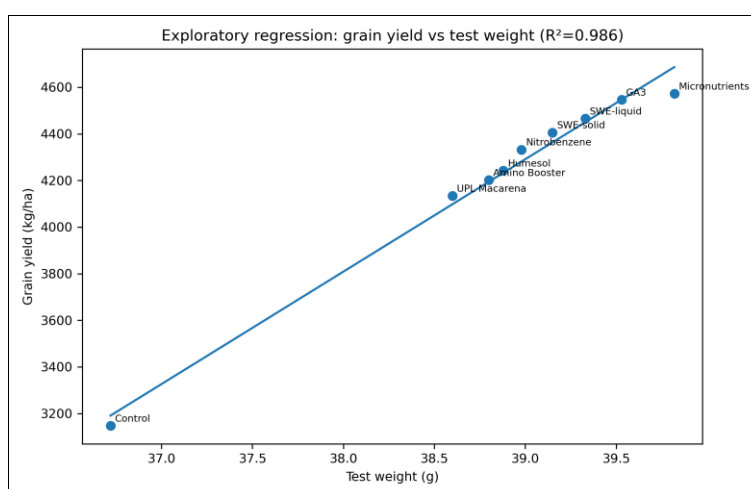
Treatment	Biological yield (kg/ha)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
Control	8994.43	3147.18	5847.18	35.82	113315.50	65088.68	2.35
Nitrobenzene @ 3 ml/L	10980.52	4332.02	6648.57	39.32	146176.35	95589.53	2.89
Gibberellic acid @ 2000 ppm	11506.92	4545.80	6961.08	39.65	153280.95	103458.20	3.05
Seaweed extract solid @ 25 kg/ha	11166.54	4405.50	6761.08	39.37	148654.10	98629.26	2.95
Seaweed extract liquid @ 625 ml/ha	11345.82	4465.23	6883.30	39.48	150958.35	100921.50	2.97
Micronutrients (Zn, Fe, Cu, B) @ 0.5%	11669.40	4572.17	7072.20	39.87	154665.25	104280.40	3.06
UPL Macarena @ 625 ml/ha	10381.92	4133.30	6248.60	38.80	138806.10	88379.28	2.75
Humesol @ 1250 ml/ha	10748.57	4241.68	6506.92	39.05	143107.15	92774.31	2.84
Amino Booster G @ 5 ml/L	10611.08	4201.35	6409.67	39.00	141498.70	91717.90	2.83
SE(d) ±	46.884	44.067	27.842	0.310	986.635	986.930	0.020
CD at 5%	95.935	90.169	56.971	0.635	2018.86	2019.46	0.042
Interaction SE(d) ±	66.305	62.320	39.375	0.439	1395.31	1395.73	0.029
Interaction CD at 5%	144.746	161.635	117.003	0.987	3364.33	3348.01	0.059

Table 5: Exploratory correlation matrix based on plant growth promoter treatment means

Response variable	Plant height	Dry weight	CGR 45-90	Ears/m ²	Test weight	Harvest index
Grain yield (kg/ha)	0.996	0.979	0.977	0.912	0.993	0.995
Net return (Rs/ha)	0.997	0.995	0.946	0.951	0.994	0.979
B:C ratio	0.994	0.995	0.938	0.956	0.993	0.974

Table 6: Exploratory simple regression summary for grain yield

Predictor of grain yield	Slope	Intercept	R2	Interpretation note
Test weight (g)	482.34	-14520.29	0.986	Treatment means only
Dry weight at maturity (g/plant)	365.46	-3739.14	0.958	Treatment means only
CGR 45-90 DAS (g/m ² /day)	10508.01	1925.88	0.954	Treatment means only

**Fig 1:** Grain yield response of wheat to plant growth promoter treatments. The Zn-Fe-Cu-B micronutrient mixture recorded the highest grain yield**Fig 2:** Net return and benefit-cost ratio across plant growth promoter treatments. The micronutrient mixture showed the highest net return and B:C ratio**Fig 3:** Exploratory relationship between test weight and grain yield using plant growth promoter treatment means

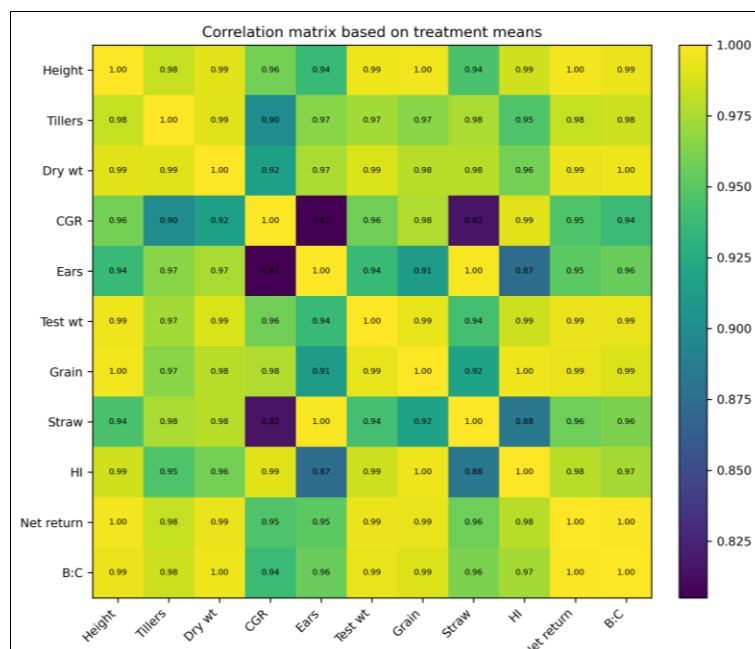


Fig 4: Correlation heatmap for selected growth, yield and economic variables based on treatment means

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