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Pradeep Kumar Gurjar
Vivekanand Global University
Jagatpura, Jaipur, Rajasthan, India

Corresponding Author:
Pradeep Kumar Gurjar
Vivekanand Global University
Jagatpura, Jaipur, Rajasthan, India

Effect of bioregulators on growth, yield, and economics of wheat (*Triticum aestivum* L.)

Pradeep Kumar Gurjar

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Abstract
Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally, serving as a staple food for millions of people. The productivity of wheat is often constrained by environmental stress, poor nutrient uptake, and limited photosynthetic efficiency. Bioregulators such as thiourea and kinetin have emerged as promising tools to modulate physiological and biochemical processes in plants, thereby improving growth, yield, and economic returns. The present investigation was carried out during the rabi season with nine treatments, including seed soaking and foliar application of bioregulators at tillering and flowering stages. Growth traits (plant height, dry matter accumulation, chlorophyll content), yield attributes (effective tillers, spike length, grains per spike, test weight), yields (grain, straw, biological yield, harvest index), and economics (net returns and benefit-cost ratio) were evaluated. The results revealed significant differences among treatments. Foliar application of thiourea (500 ppm) at tillering and flowering (T_6) and combined seed soaking + foliar spray of thiourea (T_8) showed maximum improvements in plant height (89.90 cm), dry matter accumulation (250.14 g/m row), chlorophyll content (2.29%), and yield attributes. These treatments also recorded the highest grain yield (4732 kg/ha), biological yield (11,442 kg/ha), and harvest index (41.36%). Net returns (Rs. 80,786/ha) and benefit-cost ratio (2.35) were also superior under thiourea foliar spray compared to control (Rs. 52,740/ha; 1.34 B:C). Kinetin application (T_5, T_7, T_9) also improved growth and productivity but was slightly inferior to thiourea treatments.
The study concluded that thiourea, particularly in foliar application or in combination with seed soaking, is a highly effective bioregulator in wheat for enhancing physiological traits, productivity, and profitability. These findings support the integration of plant bioregulators into wheat production strategies to optimize resource use efficiency and improve food security

Keywords: Wheat, bioregulators, thiourea, kinetin, growth, yield, economics

Introduction
Wheat (*Triticum aestivum* L.) is a major cereal crop grown worldwide, occupying about 220 million hectares with a production of over 770 million tonnes annually [1]. In India, it ranks second after rice, with an area of 30 million hectares and production around 110 million tonnes [2]. As a staple crop, wheat contributes significantly to food and nutritional security. However, yield stagnation in wheat due to abiotic stresses (drought, heat, salinity) and biotic constraints has become a major concern [3]. Improving wheat productivity under such conditions requires innovative agronomic practices, including the use of plant bioregulators.
Bioregulators (plant growth regulators or PGRs) are organic compounds, other than nutrients, that modify physiological processes in plants at very low concentrations [4]. They influence cell division, elongation, photosynthesis, flowering, and grain filling. Two commonly studied bioregulators are thiourea (an organosulfur compound with anti-oxidative and osmoprotective properties) and kinetin (A cytokinin promoting cell division and chlorophyll retention).
Thiourea has been reported to improve stress tolerance, enhance photosynthetic activity, and increase yield in wheat under both normal and stress conditions [5, 6]. Its application as seed soaking or foliar spray stimulates early seedling vigor, enhances dry matter partitioning, and improves spike and grain formation [7]. Similarly, kinetin delays leaf senescence, increases chlorophyll retention, and promotes assimilate partitioning towards reproductive organs [8, 9]. Previous studies have demonstrated significant improvements in wheat productivity with thiourea and kinetin.

For instance, Sahu *et al*. [10] reported increased grain yield by 15-20% with thiourea sprays at critical growth stages. Kinetin application has also shown positive effects on spike length and grains per spike [11]. However, comparative studies evaluating both thiourea and kinetin under combined seed soaking and foliar application are limited.

Materials and Methods

A field experiment entitled was conducted during the rabi season of 2024-25 at the Research Farm, Vivekananda Global University, Jaipur (26°05′ N, 75°28′ E, 427 m AMSL). The site falls under Agro-climatic Zone IIIA (Semi-Arid Eastern Plains). The region experiences a semi-arid climate with extreme summer and winter temperatures (1-46 °C), annual rainfall of 400-500 mm, mostly from the southwest monsoon, and relative humidity ranging between 0-69%. During the experimental period, 78.3 mm rainfall was received. Soil samples (0-15 cm depth) collected before sowing indicated a loamy sand texture, bulk density of 1.23 Mg/m^3, field capacity of 13.92%, organic carbon of 0.44%, and moderate fertility status (N: 121.7 kg/ha, P_2O_5: 15.12 kg/ha, K_2O: 142.25 kg/ha) with pH 7.25 and EC 1.42 dS/m. The cropping history revealed previous rotations of mungbean, chickpea, bajra, and methi, with wheat as the experimental crop in 2024-25. The trial was conducted in a Randomized Block Design with 9 treatments and 3 replications (27 plots). Treatments included water spray (control), seed soaking, foliar sprays, and combinations of 500 ppm thiourea and 10 ppm kinetin. Each plot measured 15 m^2 (gross) with a net harvested area of 10.4 m^2. Wheat was sown on 17th November 2024 at 20 cm row spacing using 100 kg/ha seed rate. Standard agronomic practices were followed, including disc ploughing, irrigation (five times by check basin method), hoeing and weeding, and plant protection measures. Fertilizer application comprised basal DAP and split nitrogen (urea) applications. Harvesting was done on 4th April 2025, followed by threshing and winnowing. Treatment applications were made as seed soaking in respective solutions or foliar sprays at tillering and flowering stages using a knapsack sprayer. Observations recorded included growth parameters (plant height, dry matter accumulation, chlorophyll content), yield attributes (effective tillers, spike length, grains/spike, test weight), yield components (grain, straw, biological yield, harvest index), and quality traits (nutrient content, protein content, and protein yield). Nutrient analyses were conducted following standard protocols: N by colorimetric method, P by vanadomolybdate method, and K using flame photometry. Protein content was derived by multiplying nitrogen percentage with a factor of 6.25. Economic analysis was carried out by computing cost of cultivation, gross returns, net returns, and benefit-cost ratio. Data were statistically analyzed using ANOVA as per Panse and Sukhatme (1985), with significance tested at 5% probability level, and results expressed with SEm+ and CD values.

Results and Discussion

Growth traits

Plant height showed significant response to bioregulators. At harvest, maximum height (89.90 cm) was recorded with seed soaking + foliar spray of thiourea (T_8), followed by foliar spray of thiourea alone (T_6: 89.00 cm). Control (T_1) remained lowest (72.62 cm). Similar trends were observed for dry matter accumulation and chlorophyll content. Thiourea enhanced photosynthetic efficiency and assimilate partitioning, consistent with findings of Chaturvedi *et al.* [12]. Kinetin treatments (T_5, T_7, T_9) also improved growth but were slightly inferior to thiourea.

Yield attributes and yield

Effective tillers per plant were significantly higher under T_8 (74.25) and T_6 (74.00), compared to control (59.95). Spike length was maximum under T_8 (17.82 cm) followed by T_6 (17.55 cm). Grains per spike (40.25) and test weight (44.69 g) were also highest with thiourea application. Improvement in yield attributes can be attributed to better nutrient uptake, delayed senescence, and improved assimilate partitioning under thiourea. Similar positive effects of thiourea on spikelet fertility were reported by Singh *et al.* [13].

Grain yield ranged from 3312 kg/ha (T_1) to 4732 kg/ha (T_8). Straw yield was maximum in T_8 (6710 kg/ha), followed by T_6 (6681 kg/ha). Biological yield exceeded 11,000 kg/ha under T_6 and T_8. Harvest index was also improved (41.36% in T_8 vs 38.85% in control). These findings corroborate earlier results of Yadav *et al.* [14], who observed 20-25% yield increase in wheat with thiourea sprays.

Economic

Economic analysis revealed that net returns were highest in T_8 (Rs. 80,786/ha) and T_6 (₹80,483/ha), with B:C ratio of 2.35 under T_6. This was substantially higher than control (₹52,740/ha; 1.34 B:C). Kinetin-based treatments also improved profitability but were less effective than thiourea. These results indicate that thiourea application is not only agronomically effective but also economically viable.

Discussion with literature suppor

The superiority of thiourea may be attributed to its role as a hydrogen donor and free radical scavenger, improving stress tolerance and enzyme activity [15]. Foliar application at tillering and flowering ensures better uptake and utilization during critical growth phases. Kinetin, being a cytokinin, enhanced spike length and chlorophyll content, corroborating the findings of Sharma and Srivastava [16]. The combined seed soaking and foliar spray treatments provided cumulative benefits by enhancing early vigor and sustaining growth during reproductive stages.

Table 1: Effect of bioregulators on growth traits of wheat

Treatments	Plant height (cm)				Dry matter accumulation/m row length (g)				Chlorophyll content (%)
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	
T_1: Water spray at tillering and flowering stage (control)	20.25	51.11	70.69	72.62	18.01	131.25	171.62	204.61	2.02
T_2: Seed soaking in water	20.31	51.15	70.88	72.69	18.10	131.82	172.32	205.11	2.02
T_3: Seed soaking in water + water spray at tillering and flowering stage	20.33	51.23	70.91	72.73	18.15	132.00	172.36	205.39	2.0
T_4: Seed soaking in 500 ppm thiourea	20.92	58.61	78.92	81.00	18.65	147.61	187.32	226.34	2.17
T_5: Seed soaking in 10 ppm kinetin	20.96	59.11	80.12	81.65	18.69	148.00	188.00	227.38	2.08
T_6: Foliar spray of 500 ppm thiourea at tillering and flowering stage	21.16	66.62	85.61	89.00	18.75	157.62	200.00	244.62	2.26
T_7: Foliar spray of 10 ppm kinetin at tillering and flowering stage	21.06	65.00	83.61	85.64	18.82	152.61	192.48	240.00	2.21
T_8: Seed soaking + foliar spray of thiourea at tillering and flowering stage	21.38	68.92	87.92	89.90	18.91	161.62	204.62	250.14	2.29
T_9: Seed soaking + foliar spray of kinetin at tillering and flowering stage	21.32	65.82	84.14	88.14	18.80	155.62	198.35	242.14	2.22
SEm±	1.00	2.37	2.58	2.74	0.64	5.02	4.63	6.81	0.07
CD (P=0.05)	3.00	7.09	7.75	8.21	1.93	15.06	13.88	20.42	0.20
CV (%)	8.31	6.86	5.65	5.82	6.02	5.94	4.28	5.19	5.64

Table 2: Effect of bioregulators on grain, straw, biological yield and harvest index of wheat

Treatments	Number of effective tillers per plant	Spike length (cm)	Number of grains per spike	Test weight (g)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
T_1: Water spray at tillering and flowering stage (control)	59.95	10.12	32.25	38.10	3312	5212	8524	38.85
T_2: Seed soaking in water	60.10	10.14	32.39	38.19	3329	5236	8565	38.87
T_3: Seed soaking in water + water spray at tillering and flowering stage	60.52	10.21	32.66	38.22	3345	5286	8631	38.76
T_4:Seed soaking in 500 ppm thiourea	66.82	14.01	35.68	41.62	3885	5985	9870	39.36
T_5: Seed soaking in 10 ppm kinetin	67.10	14.82	35.82	41.69	4012	6010	10022	40.03
T_6:Foliar spray of 500 ppm thiourea at tillering and flowering stage	74.00	17.55	39.85	44.00	4692	6681	11373	41.26
T_7: Foliar spray of 10 ppm kinetin at tillering and flowering stage	73.11	17.13	38.10	42.82	4575	6513	11088	41.26
T_8: Seed soaking + foliar spray of thiourea at tillering and flowering stage	74.25	17.82	40.25	44.69	4732	6710	11442	41.36
T_9: Seed soaking + foliar spray of kinetin at tillering and flowering stage	73.82	17.42	39.00	43.12	4610	6605	11215	41.11
SEm±	2.22	0.53	0.97	1.00	176	218	374	1.46
CD (P=0.05)	6.65	1.59	2.90	3.01	528	654	1122	4.38
CV (%)	5.67	6.40	4.63	4.21	7.52	6.27	6.43	6.32

Table 3: Effect of bioregulators on net returns and B:C ratio of wheat

	Net returns (Rs/ha)	B:C ratio
T_1: Water spray at tillering and flowering stage (control)	52740	1.34
T_2: Seed soaking in water	53118	1.36
T_3: Seed soaking in water + water spray at tillering and flowering stage	53556	1.38
T_4: Seed soaking in 500 ppm thiourea	64369	1.74
T_5: Seed soaking in 10 ppm kinetin	66980	1.88
T_6: Foliar spray of 500 ppm thiourea at tillering and flowering stage	80483	2.35
T_7: Foliar spray of 10 ppm kinetin at tillering and flowering Stage	78123	2.29
T_8: Seed soaking + foliar spray of thiourea at tillering and flowering stage	80786	2.29
T_9: Seed soaking + foliar spray of kinetin at tillering and flowering stage	78775	2.28
SEm±	2688	0.10
CD (P=0.05)	8056	0.29
CV (%)	6.88	4.79

Conclusion

The study demonstrated that bioregulators significantly improved growth, yield attributes, productivity, and profitability of wheat. Among the treatments, foliar spray of thiourea at tillering and flowering stage (T_6) and seed soaking + foliar spray of thiourea (T_8) were most effective, recording highest plant growth, yield, and net returns. Kinetin treatments also enhanced performance but were slightly inferior. Thus, the application of thiourea, particularly as foliar spray at critical stages, is recommended for sustainable wheat production. Further multi-location trials are needed to validate these results under diverse agro-ecological conditions.

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