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Elham A. Badr

National Research Centre

Saied ElSayed

elsayed.saied1993@yahoo.com

National Research Centre

Gehan A. Amin

National Research Centre

Doaa M. AbouBasha

National Research Centre

D. M. Sabra

National Research Centre

Ragheb M. Eladly

Alexandria University

Article

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Enhancing Growth Performance, Nutritional status of Oat as Affected by foliar application of Biostimulants under Sandy Soil Conditions

Elham A. Badr¹, Saied ElSayed^{2*}, Gehan A. Amin¹, Doaa M. AbouBasha², D. M. Sabra¹ and Ragheb M. Eladly³

¹Field Crops Department, National Research Centre, 33 El Behouth St. 12622, Dokki, Cairo, Egypt.

² Plant Nutrition Department National Research Centre, 33 El Behouth St. 12622, Dokki, Cairo, Egypt.

³Soil and Agricultural Chemistry Department, Faculty of Agriculture, Saba Basha, Alexandria University, Egypt

***Corresponding author: elsayed.saied1993@yahoo.com**

ABSTRACT

Biostimulants are essential for sustaining high forage yields and promoting environmental health, especially in semi-arid regions with sandy soil. Oat cultivation has expanded into newly reclaimed sandy soils as part of sustainable agricultural development strategies. A two-year field experiment (2022 and 2023) was conducted at the Research and Production Station of the National Research Centre in the Nubaria region, Behira Governorate, Egypt, to study the effects of biostimulant application on growth parameters and nutrient content of oat varieties grown in newly reclaimed sandy soil. Four treatment types were utilized: control, 50 ml/L of Tryptophan, 50 ml/L of Ascorbic Acid, and 5 ml/L of Blue Green Algae (BGA) foliar spray applied in two equal doses. Oat varieties (White Oat, Rad Oat, and Joinette) were randomly allocated in sub-plots. The results showed that biostimulant treatments significantly increased all photosynthetic pigments compared to the control. The lowest values for chlorophyll a, b, (a+b) and carotenoids were recorded under control conditions. The highest germination rate was observed under the BGA treatment, followed by ascorbic acid and tryptophan. The highest forage yield was recorded under the BGA treatment, showing an increase of 150-180% compared to the control. Crude protein content increased compared to the control, while total soluble solids (TSS) and total carbohydrates reached 44.238% and 11.157%, respectively. This study clearly demonstrates that the foliar application of biostimulants significantly enhances growth performance, physiological traits, and chemical composition of oats (*Avena sativa* L.) under newly reclaimed sandy soil conditions.

Keywords: Oat; Biostimulants; Nutrient assimilation; Carbohydrates; Sustainable intensification; Yield improvement.

1. Introduction

Oat (*Avena sativa* L.) is an important cereal crop widely recognized for its high nutritional value and multifunctional uses in both human consumption and animal feeding systems. It is particularly valued for its high content of dietary fiber, proteins, and essential micronutrients, which contributed to its increasing global demand. In arid and semi-arid regions, including Egypt, oat cultivation has expanded into newly reclaimed sandy soils as part of sustainable agricultural development strategies¹. Despite this expansion, sandy soils present significant agronomic challenges due to their low organic matter content, poor water-holding capacity, and limited nutrient retention. These constraints often result in reduced plant growth, low nutrient use efficiency, and ultimately decreased crop productivity². Therefore, improving crop performance under such marginal conditions requires the adoption of innovative and environmentally sustainable approaches.

In this context, plant biostimulants have emerged as a promising strategy to enhance plant growth and productivity under stress conditions. Biostimulants are defined as natural substances or microorganisms that stimulate plant physiological processes,

improve nutrient uptake, and increase tolerance to abiotic stresses^{3, 4}. Their application has gained increasing attention due to their eco-friendly nature and their ability to enhance crop performance without causing environmental harm⁵. Among the most effective biostimulants, amino acids such as tryptophan, antioxidants like ascorbic acid, and biofertilizers including blue-green algae (BGA) play crucial roles in plant metabolism. Tryptophan acts as a precursor of indole-3-acetic acid (IAA), thereby promoting cell division and elongation, which enhances plant growth and development. Ascorbic acid functions as key antioxidant that protects plant cells against oxidative stress and regulates various physiological processes, including photosynthesis and enzyme activity^{6,7}. In addition, cyanobacteria (BGA) contribute to biological nitrogen fixation, improve soil fertility, and enhance nutrient availability to plants^{8,9}. Previous studies have demonstrated the beneficial effects of biostimulants on different crops under stress conditions; however, there is still limited information regarding their comparative efficiency on oat cultivars grown under newly reclaimed sandy soils. Furthermore, the interaction between foliar-applied biostimulants and genetic variability among oat cultivars remains insufficiently investigated, particularly under Egyptian environmental conditions.

Differences among oat cultivars play a crucial role in determining plant performance under varying environmental and management conditions. Genetic variability among cultivars significantly influences growth characteristics, nutrient uptake efficiency, and tolerance to abiotic stresses such as drought and poor soil fertility. Several studies have reported that oat cultivars exhibit differential responses in terms of biomass production, photosynthetic efficiency, and nutrient accumulation depending on their genetic makeup^{10,11}. Moreover, cultivar selection is considered a key factor for optimizing productivity in newly reclaimed sandy soils, where environmental stresses are more pronounced. In addition, the interaction between cultivar genotype and external inputs, such as foliar-applied biostimulants, may enhance or limit the overall plant response. Some cultivars may show higher responsiveness to biostimulants due to their inherent physiological and biochemical traits, including hormonal balance and antioxidant capacity¹². Therefore, evaluating different oat cultivars under biostimulant treatments is essential to identify the most adaptable and efficient combinations for improving growth performance and nutrient status under sandy soil conditions. Therefore, the present study aimed to evaluate the effects of foliar application of selected biostimulants (tryptophan, ascorbic acid, and BGA) on growth performance, physiological traits, and nutrient composition of different oat cultivars grown in sandy soils. Additionally, the study sought to identify the most effective biostimulant–cultivar combination to enhance oat productivity and nutritional quality under newly reclaimed soil conditions.

2. Materials and Methods

Experimental Procedures:

Two field experiments were carried out at the Research and Production Station of the National Research Centre, Nubaria region (30° 30.054' N - 30° 19.421' E), Behira Governorate, Egypt during 2022 and 2023 to study the effect of foliar application of stimulants on growth parameters and nutrient content of oat varieties grown in newly reclaimed sandy soil. Seeds of Oat (*Avena sativa* L.) were sown on 20th November in both seasons. Occupied the main plots the stimulants treatments (Control, 50 ml L⁻¹

Tryptophan, 50 ml L⁻¹ Ascorbic Acid and 5 ml L⁻¹ BGA foliar spray at two equal doses).and Oat varieties (White Oat, Rad Oat and Joinette) were allocated at random in sub-plots, the experimental design was a split plot with four replications. The plot area was 10.5 m² (3.5 m × 3.0 m). Some physical and chemical properties of a representative soil sample used in the experimental soil were determined before cultivation according to ¹³ and presented in (Table 1).

Table (1): Some physical and chemical properties of soil.

pH (1:2.5)	EC dSm ⁻¹	OM %	CaCO ₃ %	Particle size distribution			Texture Class
				pH (1:2.5)	EC dSm ⁻¹	OM %	
7.85	1.31	0.77	2.98	74.8	4.85	16.22	Sandy loam
Cation (mg / 100 g soil)				Anion (mg / 100 g soil)			
Na ⁺	K ⁺	Ca ⁺⁺	Mg ⁺⁺	CO ₃ ⁻	HCO ₃ ⁻	CL ⁻	SO ₄ ⁻
3.55	1.16	3.33	1.47	0.32	3.41	1.72	3.44
Available macronutrients (mg/100 g soil)				Available micronutrients (mg /kg)			
N	P	K	Fe	Zn	Mn	Cu	
14.31	3.45	13.52	13.11	0.13	4.16	0.009	

Calcium super-phosphate (15.50% P₂O₅) was added pre-sowing at 358 kgha⁻¹ to the soil; similarly, nitrogen in the form of ammonium nitrate (33.0%N) at the rate of 42 kg Nha⁻¹ as starter dose was added before first irrigation, Potassium sulphate (48% K₂O) was added at the rate of 119 kgha⁻¹ to the soil in two equal doses at 20 and 40 days after sowing.

Chemical composition and mineral concentration of Algae extracts were determined according to the standard methods of ¹⁴ and presented in (Table 2).

Table (2): Chemical composition and mineral concentration of algae (spirulina) before foliar applying.

Chemical composition (%)		Mineral concentration					
Moisture	6.12	Nitrogen	(%)	8.00	Iron	(ppm)	12.4
crude protein	50.67	Phosphorus	(ppm)	123.1	Zinc	(ppm)	0.72
Ash	10.55	Potassium	(ppm)	170	Manganese	(ppm)	2.6 0
Total lipids	7.13	Calcium	(ppm)	63.7	Copper	(ppm)	5.1 0
crude fiber	4.11	Sodium	(ppm)	216.7	Lycine	(ppm)	19.1
carbohydrates	20.4	Magnesium	(ppm)	6.2	Methionine	(mg/g)	5.31

Measurement of vegetative growth and yield: At maturity stage, the following data were taken: Plant height, fresh and dry matter of leaves and bulb g /plant, Plant height (cm), leaves number /plant, bulb diameter (cm) and total leave area (cm²).

Fiber percentage was calculated by = $\frac{\text{Weight of total fiber (g)}}{\text{Weight of straw after retting (g)}} \times 100$

Recorded data Chemical constituents:

- Chlorophyll a, b and total carotenoids in leaves were determined using the method described by ¹⁵.

- Total soluble sugars (TSS) extracted according to ¹⁶ and assayed according to ¹⁷.

- Total carbohydrates content in bulb (percentage) in powdered dry matter of bulb determined calorimetrically according to ¹⁸.
- Total N, P K, Na and Ca in fresh and dry matter of leaves and bulb were determined according to the methods of the ¹⁹. Iron, zinc and copper contents were determined using atomic absorption spectrophotometer ¹⁹.

Statistical analysis

The means of data recorded were subjected to the analysis of variance according to ²⁰. The least significant differences (LSD) at $P=0.05$ level was used to verify the differences among means of the treatments.

3. Results and Discussion

3.1. Photosynthetic Pigments:

Data in Table (3) indicate that the foliar application of biostimulants significantly enhanced photosynthetic pigments, including chlorophyll a, chlorophyll b, total chlorophyll (a+b), and carotenoids in all oat varieties. Biostimulant treatments significantly increased all photosynthetic pigments compared to the control. The lowest values of chlorophyll a ($0.736 \text{ mg g}^{-1} \text{ FW}$), chlorophyll b ($0.538 \text{ mg g}^{-1} \text{ FW}$), total chlorophyll ($1.274 \text{ mg g}^{-1} \text{ FW}$), and carotenoids ($0.242 \text{ mg g}^{-1} \text{ FW}$) were recorded under control conditions. In contrast, BGA treatment resulted in the highest pigment concentrations, reaching $0.959 \text{ mg g}^{-1} \text{ FW}$ (Chl a), $0.607 \text{ mg g}^{-1} \text{ FW}$ (Chl b), and $1.566 \text{ mg g}^{-1} \text{ FW}$ (Chl a+b), along with carotenoids ($0.284 \text{ mg g}^{-1} \text{ FW}$). This corresponds to an increase of approximately 30% in chlorophyll a, 13% in chlorophyll b, and 23% in total chlorophyll compared to the control. These differences exceeded the LSD values (0.0412, 0.0146, and 0.0066, respectively), confirming statistical significance. Ascorbic acid ranked second, with total chlorophyll reaching $1.492 \text{ mg g}^{-1} \text{ FW}$, followed by tryptophan ($1.395 \text{ mg g}^{-1} \text{ FW}$). The increase in pigment content under these treatments may be attributed to enhanced chloroplast development and protection of photosynthetic machinery against oxidative damage. These results are consistent with previous findings that biostimulants enhance chlorophyll biosynthesis and delay pigment degradation by improving antioxidant activity and nutrient assimilation ^{21,22}. Significant differences were observed among oat varieties. Joinette recorded the highest chlorophyll a ($0.867 \text{ mg g}^{-1} \text{ FW}$) and total chlorophyll ($1.442 \text{ mg g}^{-1} \text{ FW}$), while Rad oat showed slightly higher chlorophyll b ($0.579 \text{ mg g}^{-1} \text{ FW}$) and carotenoids ($0.269 \text{ mg g}^{-1} \text{ FW}$). White oat recorded comparatively lower pigment values. The superiority of Joinette in chlorophyll accumulation reflects its higher photosynthetic capacity and genetic efficiency in pigment synthesis. Such varietal differences are commonly attributed to genetic variability in chloroplast structure and metabolic activity ²³. The interaction between stimulants and varieties was statistically significant for all pigments, as indicated by LSD values. The highest pigment content was recorded under **Joinette × BGA**, Chlorophyll a reached $0.972 \text{ mg g}^{-1} \text{ FW}$, Chlorophyll b reached $0.607 \text{ mg g}^{-1} \text{ FW}$, Total chlorophyll reached $1.578 \text{ mg g}^{-1} \text{ FW}$ and Carotenoids reached $0.278 \text{ mg g}^{-1} \text{ FW}$. Similarly, **Rad oat × BGA** recorded the highest carotenoid content ($0.293 \text{ mg g}^{-1} \text{ FW}$), indicating enhanced photo protection capacity. These results suggest a strong synergistic interaction between genotype and biostimulant application, where the stimulants enhance the expression of genetic potential, leading to improved pigment accumulation. This enhancement is likely associated with increased enzymatic activity

involved in chlorophyll biosynthesis and improved stress tolerance mechanisms ^{24,25}. The increase in chlorophyll and carotenoid contents under biostimulant treatments directly reflects improved photosynthetic efficiency. Chlorophyll plays a central role in light absorption; while carotenoids protect the photosynthetic apparatus from oxidative damage. The observed increases in pigment concentration indicate enhanced light harvesting capacity, improved energy conversion efficiency, and greater biomass production potential. These improvements are strongly linked to the yield increases observed in the previous results, confirming that enhanced photosynthetic performance is a key driver of productivity. Similar conclusions were reported by ²⁶, who highlighted that biostimulants significantly enhance photosynthetic performance and plant growth through improved metabolic regulation and stress tolerance. The results clearly demonstrate that foliar application of biostimulants, particularly BGA, significantly enhances photosynthetic pigment content in oat plants. The combination of BGA with high-performing varieties such as Joinette resulted in the highest pigment accumulation, indicating improved photosynthetic efficiency and growth potential. These findings highlight the critical role of biostimulants in improving plant physiological performance and supporting sustainable crop production systems ²⁷.

Table (3): Effect of foliar biostimulants on Photosynthetic Pigments in oat varieties

Treatments		Chlo a	Chlo b	Chlo a+b	Carotenoids
Stimulants	Varieties	mg/g F.w			
Control	White Oat	0.713	0.531	1.244	0.235
	Rad Oat	0.712	0.537	1.250	0.244
	Joinette	0.781	0.546	1.328	0.247
Tryptophan (50 ml L)	White Oat	0.812	0.547	1.359	0.242
	Rad Oat	0.872	0.579	1.450	0.262
	Joinette	0.809	0.567	1.376	0.281
Ascorbic Acid (50 ml L)	White Oat	0.893	0.597	1.490	0.265
	Rad Oat	0.906	0.591	1.497	0.278
	Joinette	0.905	0.583	1.488	0.261
BGA (5 cm L)	White Oat	0.945	0.604	1.549	0.281
	Rad Oat	0.961	0.609	1.570	0.293
	Joinette	0.972	0.607	1.578	0.278
Mean of Stimulants	Control	0.736	0.538	1.274	0.242
	Tryptophan	0.831	0.564	1.395	0.261
	Ascorbic Acid	0.902	0.590	1.492	0.268
	BGA	0.959	0.607	1.566	0.284
Mean of Varieties	White Oat	0.841	0.570	1.411	0.256
	Rad Oat	0.863	0.579	1.442	0.269
	Joinette	0.867	0.576	1.442	0.267
LSD 0.05	Stimulants	0.0412	0.0146	0.0066	0.0123
	Varieties	0.0398	0.0105	0.0125	0.0289
	Interaction	0.1240	0.0441	0.0135	0.0372

3.2. Vegetative Growth Parameters:

Data in Table (4) demonstrate that significant effects of stimulants, varieties, and their interaction on all studied growth parameters, including germination count, plant height, number of tillers, and number of leaves per tiller, leaf area, and leaf-to-stem ratio. The application of stimulants significantly enhanced all growth traits compared to the control treatment. The highest germination count was recorded under BGA treatment (206.6 plants m⁻²), followed by ascorbic acid (190.5 plants m⁻²) and tryptophan (179.1 plants m⁻²), compared to the lowest value in the control (159.3 plants m⁻²). This represents an increase of approximately 30% over the control. The differences exceeded the LSD value (1.987), indicating statistical significance.

Similarly, plant height increased significantly with stimulant application, reaching 144.0 cm under BGA compared to 125.5 cm in the control. This improvement may be attributed to enhanced cell division and elongation processes stimulated by bioactive compounds ²¹. The number of tillers per m² also showed a marked increase, with BGA recording the highest value (777.7 tillers m⁻²) compared to 686.9 tillers m⁻² in the control. This reflects an increase of approximately 13%, indicating improved vegetative propagation and canopy development. Leaf traits were also significantly affected. The highest number of leaves per tiller (6.08) and leaf area (200.7 cm²) were recorded under BGA treatment, compared to 5.51 leaves and 141.4 cm² in the control. This substantial increase in leaf area (approximately 42%) suggests enhanced photosynthetic capacity and assimilate production. The leaf-to-stem ratio followed a similar trend, with the highest value (0.406) under BGA compared to 0.362 in the control, indicating improved forage quality. These results are consistent with findings that biostimulants enhance biomass allocation toward leaves and improve plant physiological performance ^{26,22}. Significant differences were observed among the tested varieties. Joinette recorded the highest values for most parameters, including germination count (190.0 plants m⁻²), plant height (139.6 cm), number of tillers (745.8 m⁻²), and number of leaves per tiller (6.16), followed by White oat and Rad oat. The superiority of Joinette may be attributed to its genetic potential for higher growth vigor and better adaptation to environmental conditions. Similar varietal differences in growth and productivity have been reported in cereal crops due to genetic variability and differential nutrient utilization efficiency ²³. The interaction between stimulants and varieties was significant for all studied traits, as indicated by the LSD values. The highest overall performance was recorded with Joinette under BGA treatment, which achieved germination count (215.5 plants m⁻²), plant height 150.1 cm, number of tillers 802.9 m⁻², number of leaves 6.64, leaf area 223.7 cm² and leaf-stem ratio 0.420. These values represent the maximum recorded across all treatments and clearly exceed the LSD for interaction, confirming a strong synergistic effect. This enhancement may be explained by the combined effect of genetic potential and stimulant-induced physiological improvements, including enhanced nutrient uptake, hormonal balance, and metabolic activity. Such synergistic interactions have been widely reported, where biostimulants amplify the expression of genetic traits, leading to improved growth and productivity ^{24,25}. Overall, the results indicate that the application of biostimulants, particularly BGA, significantly improved all vegetative growth parameters. The improvements in leaf area and leaf-to-stem ratio suggest enhanced photosynthetic efficiency and forage quality, which are critical for biomass production. These findings highlight the importance of integrating suitable stimulants with high-performing varieties such as Joinette to maximize growth performance under field conditions. The observed improvements are in line with recent studies emphasizing the role of biostimulants in sustainable crop production and resource use efficiency ²⁷.

Table (4): Effect of foliar biostimulants on Growth parameters in oat varieties

Treatments		Germination count (m ²)	Plant height (cm)	Number of tiller (m ²)	No. of leaves (tiller)	Leave area per tiller (cm ²)	Leave-stem ratio
Stimulants	Varieties						
Control	White Oat	155.7	125.8	684.5	5.34	140.4	0.360
	Rad Oat	160.2	125.4	688.1	5.49	141.7	0.363
	Joinette	161.9	125.4	688.1	5.70	142.0	0.363
Tryptophan (50 ml L)	White Oat	171.8	133.4	765.2	6.08	193.5	0.400
	Rad Oat	177.3	137.4	705.3	5.52	161.2	0.370
	Joinette	188.2	138.6	741.0	6.30	185.4	0.367
	White Oat	191.2	138.5	723.8	5.50	176.1	0.380

Ascorbic Acid (50 ml L)	Rad Oat	185.9	135.2	733.5	5.51	179.6	0.383
	Joinette	194.4	144.3	751.1	6.00	186.9	0.380
BGA (5 cm L)	White Oat	210.7	143.5	787.3	6.05	195.4	0.413
	Rad Oat	193.5	138.3	743.0	5.54	183.1	0.383
	Joinette	215.5	150.1	802.9	6.64	223.7	0.420
Mean of Stimulants	Control	159.3	125.5	686.9	5.51	141.4	0.362
	Tryptophan	179.1	136.5	737.2	5.97	180.0	0.379
	Ascorbic Acid	190.5	139.3	736.1	5.67	180.9	0.381
	BGA	206.6	144.0	777.7	6.08	200.7	0.406
Mean of Varieties	White Oat	182.3	135.3	740.2	5.74	176.4	0.388
	Rad Oat	179.2	134.1	717.5	5.51	166.4	0.375
	Joinette	190.0	139.6	745.8	6.16	184.5	0.383
LSD 0.05	Stimulants	1.987	1.405	2.463	0.289	2.081	0.009
	Varieties	2.256	1.582	2.401	0.448	1.420	0.015
	Interaction	5.960	4.210	7.930	0.896	6.240	0.028

3.3. Grain forage and Dry matter yield (ton ha⁻¹)

The results illustrated in Fig 1 reveal a clear and progressive enhancement in both grain forage yield and dry matter yield (ton ha⁻¹) across the studied treatments. Grain forage yield exhibited relatively low values under the initial treatments, ranging from approximately 1.8 to 2.2 ton ha⁻¹, followed by a substantial increase in the intermediate treatments (3.5 to 4.8 ton ha⁻¹). The highest grain forage yield was recorded under the final treatment, reaching approximately 5.5–5.8 ton ha⁻¹, representing an increase of nearly 150–180% compared to the lowest treatment. This marked improvement indicates a strong positive response of crop productivity to the applied treatments, which may be attributed to enhanced nutrient uptake efficiency and improved physiological performance ^{24,21}. A similar increasing trend was observed for dry matter yield, which rose from approximately 2.0–2.5 ton ha⁻¹ in the initial treatments to 4.0–5.0 ton ha⁻¹ in the intermediate stages, and peaked at around 6.0–6.5 ton ha⁻¹ in the final treatment. This corresponds to an overall increase of about 140–170%, confirming the consistency of treatment effects on total biomass production. These findings are in agreement with previous reports indicating that biostimulants enhance photosynthetic efficiency and biomass accumulation ^{23,26}. The parallel increases in both grain forage and dry matter yields suggest that the applied treatments enhanced overall plant growth rather than selectively affecting yield components. This improvement can be attributed to enhanced photosynthetic activity, better assimilate partitioning, and improved nutrient use efficiency. Similar observations were reported by ²⁵, who demonstrated that biostimulant application significantly improves plant growth and productivity. Moreover, the relatively small error bars across treatments indicate low experimental variability. In contrast, the observed differences between treatments appear to be statistically significant ($P \leq 0.05$), highlighting the reliability of the obtained results. The superior performance observed in the advanced treatments may also be linked to improved plant tolerance to abiotic stresses and enhanced metabolic activity. Biostimulants are known to regulate physiological processes, stimulate enzymatic activity, and improve water use efficiency, which ultimately contributes to higher yield stability under field conditions ^{22,27}.

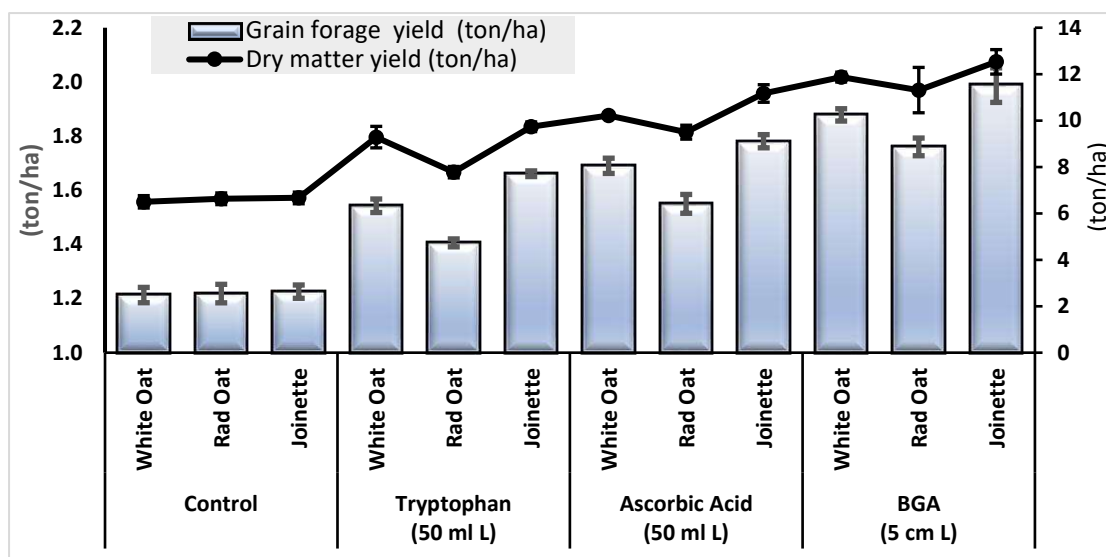


Fig (1): Effect of Foliar Stimulants on Grain forage and Dry matter yield (ton/ha)

3.4. Macronutrient contents (N, P, K and Mg)

Data in Table (5) Clearly demonstrated that the biostimulant application significantly enhanced nutrient accumulation and biochemical quality traits of oat, with a consistent superiority of cyanobacteria-based biostimulant (BGA) across all studied parameters. These responses reflect integrated physiological and metabolic reprogramming of nutrient uptake, assimilation, and carbon–nitrogen balance. The significant increase in nitrogen content from 1.393% in the control to 1.945% under BGA treatment indicates a strong stimulation of nitrogen uptake and assimilation pathways. This improvement is physiologically associated with enhanced nitrate reductase activity and activation of nitrogen transporters in roots, which increase nitrogen flux into shoots. Recent studies confirmed that biostimulants, particularly microbial and amino-acid-based formulations, upregulate nitrogen acquisition systems and improve nitrogen use efficiency through modulation of root membrane H^+ -ATPase activity and gene expression related to nitrate transport and assimilation ^{4,28}. The observed increase in phosphorus and potassium contents under BGA treatment (0.453% and 0.679%, respectively) suggests improved rhizosphere mobilization mechanisms. Cyanobacteria release organic acids and extracellular polysaccharides that enhance mineral solubilization and chelation, thereby increasing P availability and K diffusion in the soil matrix. This mechanism aligns with recent findings showing that microbial biostimulants enhance nutrient solubility and root absorption capacity by modifying soil enzymatic activity and microbial structure ²⁹. Magnesium accumulation followed a similar trend, which may be linked to improved chlorophyll biosynthesis, since Mg is a central atom in chlorophyll molecules. Increased Mg uptake under biostimulant application is therefore physiologically associated with enhanced photosynthetic capacity and energy metabolism. Among oat varieties, Joinette exhibited the highest macronutrient accumulation, particularly for nitrogen (1.737%) and phosphorus (0.370%), indicating a genetically superior capacity for nutrient uptake and translocation. However, magnesium showed no significant varietal differences, suggesting a more conservative genetic control for Mg accumulation compared to N and P. This suggests genotype-dependent regulation of transporter activity and root architecture, which has been widely reported as a key determinant of nutrient use

efficiency in cereals ³⁰. The significant interaction between biostimulants and oat varieties suggests a strong genotype $\times$ environment $\times$ management interaction. BGA combined with Joinette consistently produced the highest values across most traits, indicating synergistic enhancement of metabolic efficiency. At the physiological level, this synergy reflects improved root–shoot communication, higher nutrient uptake capacity and enhanced hormonal signaling pathways (auxins, cytokinins, and amino-acid-derived signaling molecules such as tryptophan derivatives). Recent studies have confirmed that cyanobacterial biostimulants enhance plant growth by modulating hormonal balance, improving antioxidant defense systems, and stimulating carbon–nitrogen integration pathways under field conditions ³¹.

Table (5): Effect of Foliar Stimulants on Macronutrient accumulation in oat varieties

Treatments		Macronutrient Contents			
Stimulants	Varieties	N %	P %	K %	Mg %
Control	White Oat	1.317	0.236	0.545	0.118
	Rad Oat	1.447	0.269	0.565	0.125
	Joinette	1.416	0.261	0.556	0.122
Tryptophan (50 ml L)	White Oat	1.577	0.297	0.602	0.129
	Rad Oat	1.535	0.277	0.593	0.127
	Joinette	1.651	0.328	0.612	0.131
Ascorbic Acid (50 ml L)	White Oat	1.723	0.408	0.635	0.139
	Rad Oat	1.701	0.362	0.629	0.134
	Joinette	1.785	0.421	0.645	0.143
BGA (5 cm L)	White Oat	1.897	0.453	0.672	0.148
	Rad Oat	1.839	0.436	0.659	0.146
	Joinette	2.098	0.469	0.706	0.152
Mean of Stimulants	Control	1.393	0.255	0.556	0.122
	Tryptophan	1.587	0.301	0.602	0.129
	Ascorbic Acid	1.736	0.397	0.636	0.139
	BGA	1.945	0.453	0.679	0.149
Mean of Varieties	White Oat	1.628	0.349	0.614	0.134
	Rad Oat	1.631	0.336	0.612	0.133
	Joinette	1.737	0.370	0.630	0.137
LSD 0.05	Stimulants	0.045	0.015	0.023	0.0112
	Varieties	0.039	0.013	0.020	ns
	Interaction	0.078	0.025	0.039	ns

3.5. Micronutrient accumulation (Fe, Zn, Mn and Cu)

Data in Table (6) showed that a significant enhancement in Fe, Zn, Mn, and Cu under BGA application reflects improved micronutrient mobilization and uptake efficiency. The highest values recorded for Fe (194.9 ppm) and Zn (40.68 ppm) suggest that cyanobacteria-based treatments enhance siderophore-like activity and organic acid secretion, which increase micronutrient solubility in the rhizosphere. Recent studies have demonstrated that microalgae and cyanobacteria act as natural chelating agents and stimulate root surface activity, thereby enhancing micronutrient uptake and transport through improved membrane permeability and transporter activation ³². Additionally, biostimulants have been shown to regulate antioxidant metabolism, which indirectly stabilizes micronutrient homeostasis under active growth conditions. Varietal differences again indicated that Joinette possessed higher micronutrient uptake efficiency, likely due to enhanced expression of metal transport proteins and stronger root metabolic activity. The increase in micronutrients could be due to the chelating properties of organic compounds present in Algae extracts, which enhance nutrient availability and uptake efficiency ³³.

Table (6): Effect of Foliar Stimulants on Micronutrient accumulation in oat varieties

Treatments		Micronutrient Contents			
Stimulants	Varieties	Fe ppm	Zn ppm	Mn ppm	Cu ppm
Control	White Oat	170.0	31.24	46.43	9.76
	Rad Oat	178.1	33.39	51.42	10.46
	Joinette	173.7	32.73	49.14	10.16
Tryptophan (50 ml L)	White Oat	181.5	34.70	52.79	10.92
	Rad Oat	179.5	34.33	52.19	10.74
	Joinette	183.5	35.46	53.90	11.28
Ascorbic Acid (50 ml L)	White Oat	187.1	36.76	55.41	12.05
	Rad Oat	185.7	35.81	54.91	11.51
	Joinette	190.5	37.25	56.54	12.18
BGA (5 cm L)	White Oat	193.3	40.62	58.48	12.82
	Rad Oat	192.2	38.92	57.53	12.59
	Joinette	199.2	42.51	59.76	13.24
Mean of Stimulants	Control	173.9	32.45	49.00	10.13
	Tryptophan	181.5	34.83	52.96	10.98
	Ascorbic Acid	187.8	36.60	55.62	11.92
	BGA	194.9	40.68	58.59	12.88
Mean of Varieties	White Oat	183.0	35.83	53.28	11.39
	Rad Oat	183.9	35.61	54.01	11.33
	Joinette	186.7	36.99	54.83	11.71
LSD 0.05	Stimulants	2.195	0.642	0.877	0.167
	Varieties	1.901	0.556	0.760	0.144
	Interaction	3.809	1.115	1.522	0.289

3.6. Biochemical quality traits (Protein, fiber, carbohydrates, TSS):

The results in Table (7) indicate that biostimulant treatments significantly improved crude protein, crude fiber, TSS, and total carbohydrates compared with the control ($P \leq 0.05$). The highest overall values were recorded under BGA treatment, where crude protein increased to 10.262% compared to 7.493% in the control, while TSS and total carbohydrates reached 44.238% and 11.157%, respectively. This enhancement reflects the strong role of cyanobacteria extracts in improving nutrient assimilation and metabolic activity. Such effects are attributed to their richness in amino acids, vitamins, and phytohormones, which stimulate nitrogen metabolism and photosynthesis ^{4, 34}. Ascorbic acid ranked second, particularly enhancing TSS (42.174%) and total carbohydrates (10.972%), likely due to its antioxidant role in protecting the photosynthetic apparatus and improving carbon fixation efficiency ³⁵. Tryptophan also improved all traits relative to the control, especially crude protein (8.919%), which can be linked to its function as a precursor of auxin (IAA), promoting growth and nutrient uptake ³. Significant differences were also observed among varieties. Joinette recorded the highest crude protein (9.502%) and total carbohydrates (10.938%), whereas Rad oat showed the highest TSS (41.005%). These variations reflect genotypic differences in photosynthetic efficiency and assimilate partitioning ³⁶. The interaction between treatments and varieties was significant, where the highest crude protein (11.367%) was obtained from BGA with Joinette, while maximum TSS (44.630%) and total carbohydrates (11.540%) were recorded with BGA applied to Rad oat. This confirms that plant response to biostimulants is genotype-dependent ³⁷. Overall, the improvement in crude protein is associated with enhanced nitrogen assimilation, while increases in TSS and total carbohydrates reflect improved photosynthetic activity and carbohydrate metabolism. These findings are consistent with reports that biostimulants enhance plant biochemical composition through stimulation of physiological and metabolic processes ⁹.

Table (7): Effect of Foliar Stimulants on Biochemical quality traits in oat varieties

Treatments		Crude Protein %	Crude Fiber %	TSS %	Total Carbohydrates
Stimulants	Varieties				
Control	White Oat	7.070	29.180	35.503	10.433
	Rad Oat	7.647	29.363	35.750	10.080
	Joinette	7.763	30.303	37.640	10.550
Tryptophan (50 ml L)	White Oat	9.123	32.470	38.397	10.030
	Rad Oat	8.433	33.283	41.100	10.787
	Joinette	9.200	34.167	39.527	10.870
Ascorbic Acid (50 ml L)	White Oat	8.333	33.283	42.027	10.780
	Rad Oat	8.990	31.533	42.540	10.977
	Joinette	9.677	35.600	41.957	11.160
BGA (5 cm L)	White Oat	9.837	35.053	43.680	10.760
	Rad Oat	9.583	34.313	44.630	11.540
	Joinette	11.367	33.370	44.403	11.170
Mean of Stimulants	Control	7.493	29.616	36.298	10.354
	Tryptophan	8.919	33.307	39.674	10.562
	Ascorbic Acid	9.000	33.472	42.174	10.972
	BGA	10.262	34.246	44.238	11.157
Mean of Varieties	White Oat	8.591	32.497	39.902	10.501
	Rad Oat	8.663	32.123	41.005	10.846
	Joinette	9.502	33.360	40.882	10.938
LSD 0.05	Stimulants	0.341	0.782	0.584	0.321
	Varieties	0.333	0.381	0.501	0.177
	Interaction	0.988	2.494	1.501	0.532

3.7. Correlation Matrix Interpretation

The correlation matrix revealed a highly integrated and coordinated relationship among growth, physiological, yield, and nutritional traits of oat plants under different treatments, indicating that plant performance is governed by a tightly interconnected physiological network rather than isolated traits in Table 8. A very strong positive correlation was observed between grain yield (G.F.Y) and dry matter yield (D.M.Y) ($r = 0.994$), indicating that total biomass accumulation is directly translated into grain production. This reflects a strong source–sink relationship, where enhanced photosynthetic assimilates are efficiently partitioned toward grain filling. Similar strong associations between biomass and yield in cereals have been reported under biostimulants and nutrient optimization strategies, where improved carbon assimilation enhances sink strength and grain productivity ^{4,9}. D.M.Y also showed strong correlations with chlorophyll a ($r = 0.893$) and chlorophyll b ($r = 0.868$), indicating that photosynthetic pigment concentration is a key determinant of biomass accumulation. This relationship reflects the physiological role of chlorophyll in light harvesting and energy conversion, where higher pigment content increases photosynthetic efficiency and carbon fixation capacity. Chlorophyll a and b were highly correlated ($r = 0.971$), confirming coordinated regulation of pigment biosynthesis. Both pigments also showed strong positive relationships with carotenoids ($r \approx 0.82$ – 0.88), indicating integrated regulation of the photosynthetic apparatus. Carotenoids play a dual physiological role: they act as accessory light-harvesting pigments and protect chloroplasts from oxidative damage. Their correlation with yield and biomass suggests that improved photoprotection enhances sustained photosynthetic activity under high metabolic demand. Recent studies have confirmed that biostimulants enhance chloroplast stability and pigment biosynthesis through modulation of antioxidant systems and chlorophyll biosynthetic genes ^{29,33}. A very strong correlation was found between number of tillers

and leaf area per tiller ($r = 0.972$), indicating that tillering capacity is tightly linked with canopy expansion. Leaf area and leaf number are critical determinants of light interception efficiency, which directly affects photosynthetic productivity. Leaf area to shoot ratio (L/S) also showed strong correlations with tiller number ($r = 0.932$) and biomass traits, confirming that canopy architecture plays a major role in determining assimilate production and distribution. These relationships reflect hormonal regulation (auxins and cytokinins) controlling tiller formation and leaf expansion, which are known to be enhanced under biostimulants application through improved nutrient and signaling balance ^{3, 4}. A very strong and consistent positive correlation was observed between macronutrients (N, P, K, Mg) and growth traits. N% correlated strongly with grain yield ($r = 0.965$) and DMY ($r = 0.966$). K% showed an almost perfect correlation with DMY ($r = 0.977$). P% was highly associated with chlorophyll content and biomass ($r > 0.90$). These relationships indicate that nutrient availability is directly linked to photosynthetic efficiency and metabolic activity. Nitrogen is a central component of chlorophyll and enzymes such as Rubisco, while phosphorus is essential for ATP production and energy transfer. Potassium regulates stomatal function and enzyme activation, which explains its strong relationship with biomass production. Recent physiological studies confirm that improved nutrient use efficiency under biostimulants application is driven by enhanced root transporter activity and up regulation of nutrient assimilation pathways. Micronutrients (Fe, Zn, Mn, Cu) showed very strong positive correlations with both growth and macronutrient traits ($r > 0.95$ in most cases). Iron exhibited strong association with chlorophyll and biomass, reflecting its essential role in electron transport chains and chlorophyll biosynthesis. Zinc correlated strongly with tillering and leaf development, indicating its role in auxin metabolism and enzymatic activation. Manganese is directly involved in photosystem II function, which explains its correlation with chlorophyll and yield traits. These findings suggest that micronutrients act as catalytic cofactors that regulate both photosynthetic and metabolic efficiency. Recent research highlights that biostimulants enhance micronutrient bioavailability by stimulating siderophore production and improving rhizosphere microbial activity ^{32, 3}.

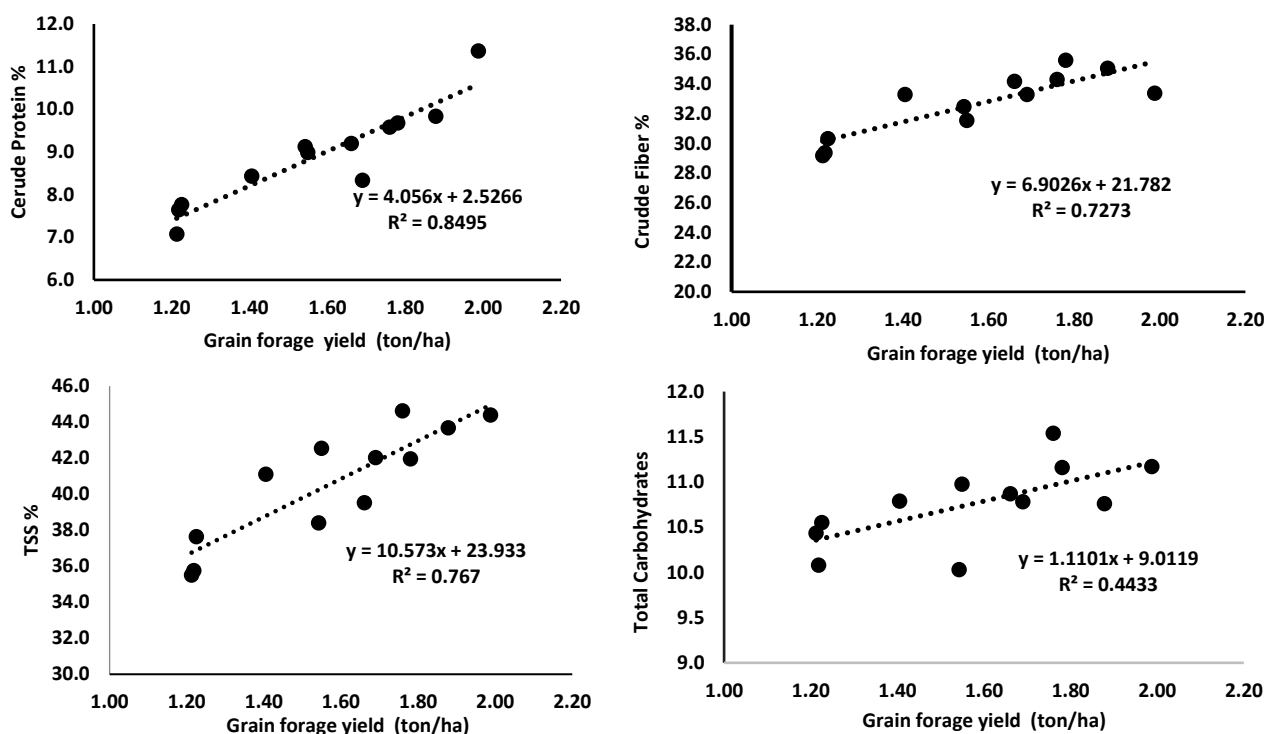
Table (8): Correlation matrix among growth, physiological traits, and nutrient content in oat varieties

	<i>G.F.Y</i>	<i>D.M.Y</i>	<i>Chlo a</i>	<i>Chlo b</i>	<i>Carot</i>	<i>No. of tiller</i>	<i>No. of leaves</i>	<i>L.A/ tiller</i>	<i>L/S ratio</i>	<i>N %</i>	<i>P %</i>	<i>K %</i>	<i>Mg %</i>	<i>Fe ppm</i>	<i>Zn ppm</i>	<i>Mn ppm</i>
D.M.Y	0.994															
Chlo a	0.879	0.893														
Chlo b	0.860	0.868	0.971													
Carot	0.763	0.769	0.820	0.885												
No. of tiller	0.915	0.912	0.752	0.673	0.585											
No. of leaves	0.667	0.625	0.382	0.297	0.327	0.800										
L.A/ tiller	0.934	0.925	0.788	0.720	0.637	0.972	0.788									
L/S ratio	0.798	0.805	0.720	0.632	0.447	0.932	0.659	0.873								
N %	0.965	0.966	0.908	0.892	0.784	0.890	0.638	0.909	0.828							
P %	0.948	0.963	0.905	0.912	0.777	0.807	0.479	0.813	0.744	0.960						
K %	0.973	0.977	0.926	0.911	0.791	0.893	0.598	0.912	0.832	0.996	0.967					
Mg %	0.956	0.967	0.910	0.905	0.775	0.844	0.532	0.843	0.787	0.979	0.990	0.982				
Fe ppm	0.960	0.967	0.902	0.891	0.782	0.873	0.594	0.890	0.802	0.991	0.968	0.990	0.988			
Zn ppm	0.945	0.946	0.889	0.877	0.765	0.885	0.624	0.875	0.852	0.987	0.951	0.982	0.978	0.978		
Mn ppm																

Mn ppm	0.947	0.954	0.904	0.902	0.809	0.856	0.563	0.871	0.781	0.975	0.956	0.976	0.977	0.992	0.962	
Cu ppm	0.965	0.973	0.915	0.916	0.796	0.851	0.542	0.860	0.789	0.985	0.989	0.988	0.997	0.991	0.980	0.981

3.8. Regression analyses

The regression analyses presented in Figure (2) reveal strong and biologically meaningful relationships between grain forage yield and key quality traits, namely crude protein content and total soluble solids (TSS%). A strong relationship was detected ($R^2 = 0.8495$), demonstrating that yield increases were accompanied by enhanced protein accumulation. This reflects improved nitrogen uptake and assimilation efficiency, alongside increased biosynthesis of amino acids supported by higher photosynthetic activity. The absence of a dilution effect suggests that productivity gains enhanced rather than compromised forage quality, consistent with findings reported by ^{4,38}. A significant positive relationship was also observed ($R^2 = 0.767$), indicating increased accumulation of soluble carbohydrates with higher yield. This is likely due to enhanced photosynthetic efficiency and improved source–sink balance, facilitating assimilate translocation and sugar storage. Elevated TSS values reflect improved forage energy quality, in agreement with ^{39,40}. Overall, the strong correlations confirm that yield improvement was closely linked to enhanced nitrogen metabolism and carbohydrate accumulation, indicating improved nutrient use efficiency and metabolic performance. These findings support the effectiveness of sustainable agronomic practices in achieving simultaneous gains in productivity and quality ⁴¹.



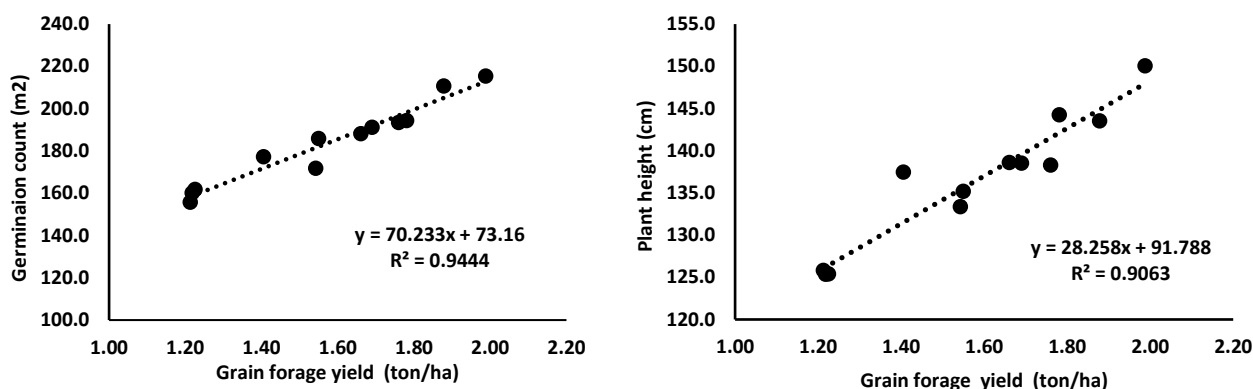


Fig (2): Effect of Foliar Stimulants on Regression analyses in oat varieties

4. Study Limitations

Despite the promising results obtained in this study, some limitations should be acknowledged. The experiments were conducted under specific environmental conditions of newly reclaimed sandy soils in the Nubaria region, which may limit the generalization of the findings to other soil types or climatic conditions. In addition, the study focused on a limited number of oat varieties and foliar stimulant treatments; therefore, further research including a wider range of genotypes and biostimulant concentrations is recommended. Moreover, the study primarily evaluated growth, physiological, and chemical parameters without investigating underlying molecular mechanisms or gene expression related to stress tolerance and nutrient uptake. Future studies should also consider long-term field trials and economic analysis to assess the cost-effectiveness and sustainability of foliar biostimulant applications in large-scale agricultural systems.

5. Conclusion

The present study clearly demonstrated that foliar application of different stimulants significantly improved growth performance, physiological traits, and chemical composition of oat (*Avena sativa* L.) grown under newly reclaimed sandy soil conditions. Among the tested treatments, blue-green algae (BGA) extract proved to be the most effective biostimulant, resulting in the highest enhancement in photosynthetic pigments, vegetative growth parameters, nutrient uptake, and quality attributes. Furthermore, varietal differences were evident, where the Joinette variety exhibited superior performance in most studied traits, particularly when combined with BGA treatment, indicating a strong interaction between genotype and foliar application. The observed improvements could be attributed to the synergistic effects of bioactive compounds present in the applied stimulants, including amino acids, vitamins, antioxidants, and plant growth regulators, which collectively enhanced physiological efficiency and nutrient assimilation. Therefore, the combined use of suitable oat varieties and foliar biostimulants, particularly algae extract, can be considered a promising strategy to improve oat productivity and quality under sandy soil conditions.

However, further investigations are required to evaluate long-term effects, optimize application rates, and explore the underlying physiological and molecular mechanisms.

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Dear Dr,

Please note the following:

This research was conducted on the farm where we work, and was entirely self-funded, without any external funding.