3. Bibi S., Qayyum A., Bibi A., Begum K. Multivariate analysis of selected agro-morphological traits of common wheat genotypes for estimation of genetic diversity // Emirates Journal of Food and Agriculture. 2022. Vol. 34, no. 12. P. 1020–1027.

4. Pradhan S., Babar M. A., Robbins K., Bai G., Mason R. E., Khan J., Shahi D., Avci M., Guo J., Maksud Hossain M., Bhatta M., Mergoum M., Asseng S., Amand P. S., Gezan S., Baik B. K., Blount A., Bernardo A. Understanding the genetic basis of spike fertility to improve grain number, harvest index, and grain yield in wheat under high temperature stress environments // Frontiers in Plant Science. 2019. Vol. 10. DOI: 10.3389/fpls.2019.01481.

5. Zewdu D., Mekonnen F., Geleta N. Cluster and principal component analysis for yield and yield related traits of bread wheat (Triticum aestivum L.) genotypes // AGBIR. 2024. Vol. 40, no. 2. P. 962–967.

NANO-FERTILIZER AND GROWTH REGULATORS TECHNOLOGY ON: IMPROVING CROP PRODUCTIVITY, AND NUTRITIONAL CONTENT OF SPRING WHEAT (*TRITICUM AESTIVUM L*)

Shimendi G Okbagabir*, Department of Agrobiotechnology*, *Agrarian Institute Technological, People's Friendship University (RUDN), Moscow, Russia, named after Patrice Lumumba, shimendigde20@gmail.com, (Tel. No +79777450344)*
Elena N. Pakina, *Department of Agrobiotechnology*, *Agrarian Institute Technological, People's Friendship University (RUDN), Moscow, Russia, named after Patrice Lumumba, pakina-en@rudn.ru, +79853472754*

Abstract A 2023–2024 field study at Agropoligon Research Institute assessed foliar/nano-fertilizers (Terrasay) and growth regulators (Centrino) on wheat using a randomized complete block design. Treatments (F0–F3 at 0–2 l/ha; GR1–GR3 at 0–1.5 l/ha) significantly affected tiller count, flowering, grain yield (peaking at 4142.9 kg/ha with GR2), and nutrient content (e.g., 28.25% wet gluten with F3 × GR2). Notable interactions ($p \leq 0.048$) included F2 × GR2 and F3 × GR3, enhancing fertile tillers, spike elongation, and grain weight. Tailored nano-fertilizer and growth regulator combinations show promise for sustainable wheat production.

Key Words: Foliar Nutrients; Growth Regulators; Spring Wheat; Productivity; and Qualitative traits**.**

INTRODUCTION

Chemical fertilizers particularly micronutrients like manganese, copper, boron, iron, molybdenum, zinc etc. are important for the growth and development. A substantial increase of crop yields with the green revolution and new farming practices has progressively decreased the micronutrients of soil like zinc, iron, and molybdenum [1]. Foliar application of iron compounds with the technology of nanoparticles may be a solution to the problem. The concentrations of iron nano-oxide solution has been used in five levels (0, 0.01%, 0.02%, 0.03% and 0.04%) to check

the effect on spike weight, 1000 grain weight, biologic yield, grain yield and grain protein content. Increase in these traits was found as compared to control. Nano-fertilizer application has emerged as a transformative agricultural practice, enhancing crop growth, yield, and quality while optimizing nutrient use efficiency, minimizing fertilizer wastage, and reducing cultivation costs [5].

Plant growth regulators (PGRs) can regulate plant growth and development in numerous ways. It has potential to modify cereal yield and plant stand structure additional to stem elongation. PGRs are the organic compounds, other than nutrients that stimulate the plant physiological process, they are the bio stimulants that stimulate or inhibit the specific enzymes which help to regulate or enhance the plant metabolism process [3]. The current study of PGRs revealed the effects on yield; also play a vital to role as preventing the lodging of crop, hastening maturity to decrease the turnover time. It also noticed that different PGR, are especially useful as preservative in drinking and beverages [3]. The grain yield and grain protein content of PGR-chemical-fertilizer-treated plants were more than those of non-inoculated controls. Grain yield was increased by 28%, 28%, 37%, and 33% with the integrated application of F, B, N1, and N2 PGPR and 50% of need-based N, P, and Zn chemical fertilizers, respectively [4]. The objective of this finding was to investigate the impact of nano-fertilizers on nutrient uptake efficiency, soil nutrient retention, and crop productivity compared to conventional fertilizers, while assessing their environmental sustainability through reduced nutrient runoff and leaching in selected crop systems and to examine the combined application of nano-fertilizers and plant growth stimulants in improving crop development parameters, and stress tolerance, to enhance overall productivity and nutritional quality.

MATERIALS AND METHODS

Location of experimental site

A 2023–2025 study at the Research Institute of Agrochemistry in Barybino, Moscow Region (55°15'52.6248"N, 37°53'13.1712"E, 137 m altitude) on sod-podzolic heavy loamy soil investigated nano-fertilizers and growth stimulants for sustainable wheat productivity and nutrition. The climate featured warm summers (13–35.5°C) and 500–600 mm annual precipitation. Wheat was planted at 250 kg/ha, with seed emergence at 5–7 days. The experiment tested eight treatments: plant growth regulators (Centrino: GR0–GR3 at 0, 1, 1.25, 1.5 l/ha) containing chlormequat chloride (750 g/l), applied once during tillering, and Terrasay nano-fertilizers (F0–F3 at 0, 0.5, 1, 2 l/ha) with Fe (0.15%), Mn (0.08%), B (0.02%), Cu (0.01%), and Zn (0.02%), applied twice during tillering and earing. Data were analyzed using GenStat ANOVA (LSD 5%). The study highlights the potential of nano-fertilizers and growth regulators to enhance wheat yield and nutritional quality sustainably.

RESULT AND DISCUSSION

The study investigated the interplay of foliar fertilizers (F0–F3) and growth regulators (GR0–GR3) on yield and yield metrics like Grain yield, biological yield and harvest index, spike length (SL) cm, spikelet number per spike (SN), and 1000-grain weight (TGW) (g) and nutritional quality (protein, gluten and carbohydrate), over 2023–2024. The analysis leverages ANOVA and $LSD_5\%$ to evaluate treatment effects, ensuring statistical precision in interpreting parameter interactions.

Effects of Foliar Fertilizer and Growth Regulator Interactions on Wheat Yield Attributes:

In 2023 and 2024, F3 × GR3 significantly increased wheat spike elongation by 3.48 cm (59.3%) over the control (F0 × GR0), with ANOVA results (2023: $p < 0.001$; 2024: $p = 0.018$) and $LSD_5\%$ values (0.52–0.9 cm). F2 × GR2 showed the largest difference (2.14 cm, 2023). F2 × GR2 maximized spike proliferation (2.16 spikelets, 17.0%) via cytokinin-driven tillering, while F3 × GR1 suppressed spikelets (12.69) due to regulator overdose, aligning with Gupta et al. (2023). Significant differences (2.05–2.45 spikelets) were observed, with 2024 showing reduced effects due to environmental factors. Synergistic fertilizer-growth regulator applications enhanced spike development [1].

Table 1.

Effects of Foliar Fertilizer and Growth Regulator Interactions on Wheat Yield Attributes

Treatment Interactions (F x GR)	2023			2024		
	SL (cm)	SN (No.)	TGW (g)	SL (cm)	SN (No.)	TGW (g)
F0 x GR0	5.87	12.27	30.89	7.62	13.12	28.20
F0 x GR1	7.25	14.47	30.05	9.02	14.07	29.08
F0 x GR2	7.57	14.08	30.63	8.82	13.88	29.62
F0 x GR3	7.09	13.85	30.02	8.27	14.48	29.18
F1 x GR0	7.20	14.33	30.38	7.73	14.30	27.52
F1 x GR1	7.37	14.32	32.26	7.89	14.25	32.20
F1 x GR2	6.95	13.47	32.83	7.63	13.20	29.60
F1 x GR3	7.63	14.15	30.88	8.96	14.70	28.47
F2 x GR0	7.62	14.02	32.12	8.31	14.90	29.37
F2 x GR1	7.20	13.73	30.53	8.54	14.25	30.10
F2 x GR2	8.01	14.33	35.43	8.24	14.30	31.97
F2 x GR3	7.75	14.24	34.73	9.00	14.55	30.82
F3 x GR0	7.73	14.72	29.20	9.18	14.93	28.08
F3 x GR1	7.92	14.65	32.68	9.17	15.05	31.77
F3 x GR2	7.62	13.47	34.80	9.22	14.75	32.07
F3 x GR3	7.59	13.85	33.77	9.35	15.25	32.89
Mean	7.4	14	31.95	8.56	14.37	30.06
F-value	15.2	18.6	3.12	7.8	2.98	7.63*

p-value	<0.001	<0.001	<0.001	0.018	0.015	0.001
LSD_5%	0.52	0.63	1.91	0.9	0.95	2.35

Influence of Foliar Fertilizer and Growth Regulator main treatments on Wheat Yields:

This study examines the agronomic impacts of foliar fertilizers (F), and growth regulators (GR) on Grain Yield (GY), Biological Yield (BY), and Harvest Index (HI) across 2023–2024. The analysis targets these yield-related traits, interpreting the effects of the independent variables (F, GR) through comprehensive data evaluation presented (Table 2). Foliar fertilizers significantly increased GY and BY ($p < 0.001$), with F2 peaking at 4143.83 kg/ha in 2024, enhancing photosynthesis and grain filling, but HI was non-significant ($p = 0.059$ in 2023, $p = 0.103$ in 2024). GY rose from 3593.21 kg/ha (F0) to 4143.83 kg/ha (F2) in 2024 ($LSD_5\% = 152.07$). Growth regulators increased GY and BY ($p < 0.001$), with GR2 at 4142.9 kg/ha in 2024, improving tillering and hormonal balance, though HI remained stable ($p = 0.576$ in 2023, $p = 0.103$ in 2024). Results align with studies on cytokinin analogs enhancing sink strength, with biomass increases dominating over partitioning efficiency.

Growth regulators (GR1–GR3) significantly enhanced GY and BY ($p < 0.001$), with GR2 showing the highest GY (4142.9 kg/ha in 2024). This could be due to improved hormonal balance, leading to enhanced tillering and grain development. The non-significant HI differences ($p = 0.576$ in 2023, $p = 0.103$ in 2024) indicate that GRs primarily increased biomass rather than altering assimilate partitioning. R2 consistently maximized yields (2024 GY=4142.9 kg/ha; $LSD_5\%$=152.07). GR2's efficacy aligns with studies emphasizing cytokinin analogs in enhancing sink strength [2].

Table 2

Influence of Foliar Fertilizer, Growth Regulator Interactions on Wheat Yields (2023–2025):

Main Traits	2023			2024		
	GY (kg/ha)	BY (kg/ha)	HI %	GY (kg/ha)	BY (kg/ha)	HI %
Foliar Fertilizer (F)						
F0	3373.30	3593.21	9820.50	10490.50	34.67	34.58
F1	3673.40	3890.64	10484.01	11261.10	35.17	34.92
F2	3811.58	4143.83	10820.13	11808.24	35.37	35.33
F3	3894.00	3949.60	10829.99	12069.75	36.17	32.83
Means	3688.07	3894.32	10488.66	11407.40	35.35	34.42
p-value	<0.001	<0.001	<0.001	<0.001	0.06	0.103
LSD_5%	145.72	152.07	320.91	575.55	1	1.553
Growth Regulators (GR)						
GR0	3339.46	3451.92	9355.54	10588.08	35.54	33.37
GR1	3760.98	4092.19	10614.58	11771.50	35.71	34.92
GR2	3857.98	4142.90	11047.28	11815.64	35.17	35.37

GR3	3793.87	3890.28	10937.23	11454.38	34.96	34.00
Means	3688.07	3894.32	10488.66	11407.4	35.34	34.42
p-value	<0.001	<0.001	<0.001	<0.001	0.576	0.103
$LSD_5\%$	138.45	152.07	305.62	575.55	1	1.553

Effects of the Foliar fertilizer, and growth regulators main traits on quality of Spring Wheat:

A 2023–2024 study demonstrated that foliar fertilizer F3 significantly increased wheat protein content (15.17% in 2024, $p < 0.001$) and carbohydrate content (85.47% in 2024, $p < 0.001$), driven by enhanced nitrogen and micronutrient availability promoting amino acid synthesis and assimilate partitioning.

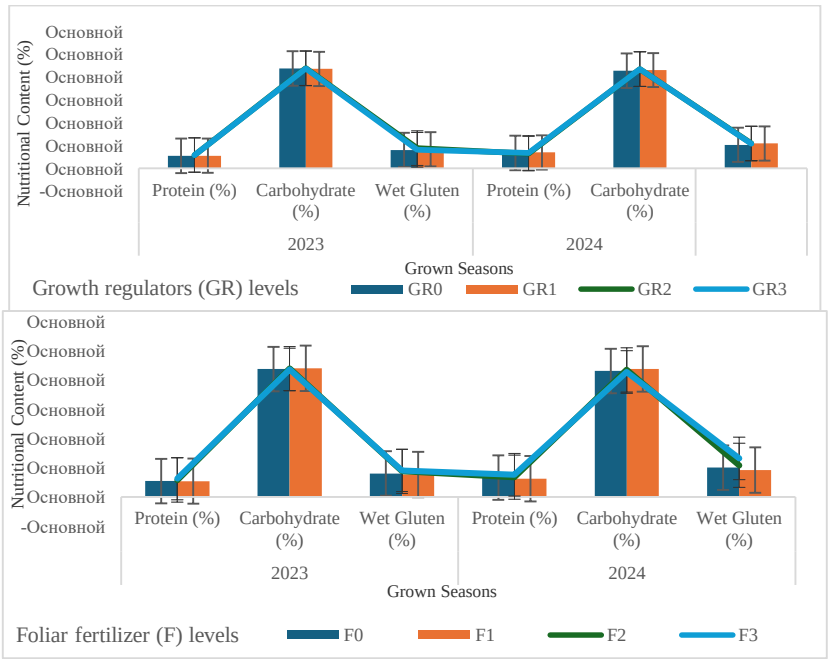

Fig 1. Effects of the Foliar fertilizer, and growth regulators main traits on quality of Spring Wheat

Growth regulators, particularly GR2, boosted carbohydrate content (87.55% in 2023, $p < 0.001$) via cytokinin-mediated effects. Wet gluten content peaked at 26.29% with F3 in 2024 and 18.55% with GR3 in 2023 ($p < 0.001$), reflecting stronger gluten networks due to nutrient and hormonal synergies. Significant differences in protein (4.05% in 2023, 2.77% in 2024) and wet gluten (9.5% in 2023, 8.01% in 2024) highlight treatment efficacy, though 2024's inconsistent results suggest environmental influences like temperature or precipitation, aligning with Zhang et al. (2023).

Influence of Foliar Fertilizer and Growth Regulator Synergy on Wheat Quality Attributes:

The dataset from the combined influence of foliar fertilizer levels (F0, F1, F2, F3) and growth regulator doses (GR0, GR1, GR2, GR3) on vital wheat quality attributes

Protein (%), Carbohydrate (%), and Wet Gluten (%). A 2023–2024 study showed significant foliar fertilizer (F0–F3) and growth regulator (GR0–GR3) interactions ($p \leq 0.001$) on wheat protein, carbohydrate, and wet gluten content, in 2024). F3 × GR2 maximized protein (13.37% in 2023) and wet gluten (28.25% in 2024), while F3 × GR1 peaked protein (16.61% in 2024), outperforming F0 × GR0 (9.64% protein, 12.96% wet gluten in 2023). F1 × GR2 led carbohydrate content (88.53% in 2024), surpassing F3 × GR0 (84.91%). F3's lower carbohydrates suggest a protein synthesis shift.

Table 3.

Influence of Foliar Fertilizer and Growth Regulator Synergy on Wheat Quality Attributes

Treatment Interactions	2023			2024		
	Protein (%)	Carbo hydrate (%)	Wet Gluten (%)	Protein (%)	Carbo hydrate (%)	Wet Gluten (%)
F0 x GR0	9.64	86.82	12.96	11.38	85.08	16.95
F0 x GR1	11.19	87.10	17.05	13.87	85.67	20.58
F0 x GR2	11.19	87.47	16.78	13.58	86.46	21.37
F0 x GR3	11.38	88.47	17.18	13.78	87.50	21.30
F1 x GR0	10.52	87.95	15.05	12.74	87.04	17.82
F1 x GR1	9.88	88.27	13.67	12.12	87.50	18.13
F1 x GR2	10.93	88.32	16.35	11.32	88.53	18.17
F1 x GR3	11.89	87.21	16.22	13.42	87.00	19.00
F2 x GR0	11.73	88.21	17.98	15.88	85.58	22.33
F2 x GR1	11.10	87.43	16.90	13.70	86.20	22.43
F2 x GR2	11.50	88.46	17.63	11.55	87.58	19.80
F2 x GR3	11.96	87.32	17.77	12.95	88.25	21.97
F3 x GR0	12.14	87.31	18.75	14.39	84.91	25.57
F3 x GR1	12.59	86.54	19.20	16.61	85.57	26.78
F3 x GR2	13.37	87.40	20.32	15.89	86.16	28.25
F3 x GR3	11.76	87.39	14.22	13.79	85.25	24.57
Mean	11.42	87.6	16.75	13.56	86.51	21.56
p-value	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
$LSD_5\%$	1.05	1.25	1.85	1.1	1.22	2.46

CONCLUSION

This 2023–2024 study in Russian agroecosystems underscores the synergistic potency of foliar fertilizers (F0–F3) and growth regulators (GR0–GR3) in enhancing spring wheat (Triticum aestivum L.) productivity and quality. F2 enhanced grain yield (GY) and biological yield (BY) ($p < 0.001$), with F2 × GR2 increasing spike development (2.16 spikes, 17.0%) and 1000-grain weight (7.91 g, 28.8%). GR2 boosted GY (4142.9 kg/ha) and tillering ($p \leq 0.016$), with stable harvest index (p =

0.576). F3 × GR2 maximized protein (16.61%) and wet gluten (28.25%) ($p < 0.001$), while F1 × GR2 optimized carbohydrates (88.53%). Environmental variability in 2024 ($p = 0.307$ for GR in wet gluten) highlighted the need for precision agriculture to optimize F × GR applications and explore genotype-environment interactions for sustainable wheat production.

REFERENCE

1. Ali, N., Alam, P., Sah, A., Izhar, T., & Kumar, S. (2021). Influence of Fertility Levels and Plant Growth Retardants on Growth and Productivity of Wheat (Triticum aestivum L.) in Jharkhand // International Journal of Current Microbiology and Applied Sciences. 2021. № 01 (10). С. 2779–2786.
2. Chen, P., Yang, R., Bartels, D., Dong, T., & Duan, H. Roles of Abscisic Acid and Gibberellins in Stem/Root Tuber Development // International Journal of Molecular Sciences. 2022. Т. 23. № 9.
3. Mukhtar, F. B. (2008). Effect of Some Plant Growth Regulators on the Growth and Nutritional Value of Hibiscus sabdariffa L . (Red sorrel). International Journal of Pure and Applied Sciences, 2(3).
4. Pleskachiov, Y., Voronov, S., Kurbanov, S., Saquee, F. S., & Zargar, M. (2022). Application of New-Generation Growth Regulators and Topdressing Nitrogen Fertilizers Increases Improver Winter Wheat Yield and Grain Quality in South Russia. Agriculture (Switzerland), 12(9). https://doi.org/10.3390/agriculture12091310.
5. Tang, Y., Zhao, W., Zhu, G., Tan, Z., Huang, L., Zhang, P., Gao, L., & Rui, Y. (2024). Nano-Pesticides and Fertilizers: Solutions for Global Food Security. In Nanomaterials (Vol. 14, Issue 1). https://doi.org/10.3390/nano14010090.