Collaborative Impact of Inorganic and Organic Fertilizers Coupled with *Kappaphycus alvarezii* Bio-Stimulant on the Quality Characteristics of Wheat (*Triticum aestivum* L.)

Abstract

The study investigates the influence of different factors on the nutritional content of wheat grains, focusing on crude protein, nitrogen, phosphorus, and potassium contents in grain. Results indicate that varying combinations of factors such as NPK fertilization, farmyard manure (FYM) application, and bio-stimulant usage significantly affect nutrient concentrations in grain. Crude protein content, a vital indicator of grain quality, showed variability across the different treatments, with the highest levels observed in plots receiving RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}. The crude protein content primarily relies on the nitrogen levels. In the research, the findings indicated that the nitrogen content was significant, which, in turn, led to a significant crude protein content.The levels of nitrogen, phosphorus, and potassium content also exhibited fluctuations, with significant interactions observed among various factors. These fluctuations are attributed to differences in nutrient uptake and utilization during the different growth stages of the wheat plant. All three factors can enhance the nutrient uptake facilities through soil as well as plant body, therefore, notably, interactions between NPK, FYM, and bio-stimulants exhibited significant effects on nutrient content, particularly at the 0.05 significance level.The findings underscore the importance of holistic agricultural management in enhancing the nutritional value of wheat grains, with implications for food security and agricultural sustainability.

Keywords: *Wheat, crude protein, nutrient content, FYM, Kappaphycus alvarezii, Seaweed, Bio-stimulant, etc.,*

Introduction

Wheat (*Triticum aestivum* L.) stands as a cornerstone of global food security, serving as a primary staple for a significant portion of the world's population**(Acevedo *et al.*, 2018)**. Its nutritional quality, determined largely by factors such as crude protein content, nitrogen, phosphorus, and potassium contents in grain, is of paramount importance not only for human consumption but also for livestock feed. Enhancing the quality characteristics of wheat grains has become a focal point for agricultural research, particularly amidst the backdrop of increasing demand and evolving environmental challenges. In recent years, agricultural practices have undergone a paradigm shift towards sustainable and integrated approaches, aiming to optimize yields while minimizing environmental impact. This transition has led to the exploration of synergistic interactions between inorganic and organic fertilizers [12,13,14], supplemented with bio-stimulants derived from natural sources. Among these bio-stimulants, *Kappaphycus alvarezii*, a red seaweed known for its rich bioactive compounds, has garnered significant attention for its potential to enhance plant growth, development, and stress tolerance**(Kipsat*et al.*,2021).** Therefore, this study aims to investigate the collaborative impact of inorganic and organic fertilizers, in conjunction with *Kappaphycus alvarezii* bio-stimulant, on the quality characteristics of wheat grains.

Materials and methods

The main aim of this study was to investigate how combining inorganic and organic fertilizers with a bio-stimulant sourced from *Kappaphycus alvarezii* could enhance the quality of wheat (*Triticum aestivum* L.). This section provides a succinct summary covering key aspects of the research, including the time and location parameters, soil composition, climate conditions at the test site, crop selection, treatments applied, experimental setup, data collection techniques, and statistical analysis methods. Presented below is a comprehensive outline detailing the specific methodologies and experiments carried out during the study:

Area of investigation

Over two consecutive years, spanning the rabi seasons of 2021–22 and 2022–23, a comprehensive study took place at the Research Farm within the esteemed Department of Soil Science and Agricultural Chemistry of Sam Higginbottom University of Agriculture, Technology and Sciences. This institution is situated in the historic Prayagraj District of Uttar Pradesh. The research farm, serving as the experimental site, boasts geographic coordinates placing it within the bounds of Prayagraj District, precisely at 26°55' N latitude and 81°76' E longitude. Positioned 98 meters above mean sea level, it lies a mere 5 kilometers eastward from the banks of the Yamuna River. This locale, an integral part of the Upper Gangetic Plain Region, is characterized by its affiliation with the North Alluvial Plain zone, where slopes range from a gentle 0 to 1%. Such a setting delineates an Agro-Ecological Sub Region, offering a fertile ground for the study of agricultural sciences within the broader Agro-Climatic Zone.

Climatic conditions

In the heartland of North-central India lies Prayagraj, where the climate dances between subtropical hues. Here, three distinct seasons paint the canvas of the year: a warm, muggy monsoon, a mild, crisp winter, and a scorching, arid summer. As April unfolds, temperatures soar between 40°C (104°F) and 45°C (113°F), casting a relentless heat until June bids farewell. Then arrives the monsoon's embrace, showering the land from July's dawn to September's dusk. Winter tiptoes in from December to February, bringing a gentle chill. Prayagraj rests under the shadow of the summer monsoon, also known as the South-West monsoon, which ushers in the rainfall spectacle from mid-July to late September. This annual performance contributes significantly to the city's hydration, with the lion's share, about 75%, pouring down during this season. On average, Prayagraj receives a nourishing 900-1100 mm of rainfall each year, courtesy of this magnificent monsoon ballet.

Soil characteristics

The experimental field's properties from a physio-chemical perspective are outlined in Table 1.

Experimental details

The current study utilized a factorial randomized block design (*f*-RBD), consisting of eighteen treatment combinations, each replicated three times. These combinations were randomly allocated within each replication, resulting in a total of fifty-four plots across the research site. Wheat variety 5-SR05 was cultivated throughout the experimental years 2022-23 and 2023-24. The investigation adopted a comprehensive nutrient strategy, incorporating inorganic fertilizers such as NPK, farmyard manure, and bio-stimulant inputs sourced from *Kappaphycus alvarezii*, a red algae species known as elkhorn sea moss. For detailed field treatment specifics, please refer to Table 2.

Data collection

Wheat grain samples were separately collected from specific treatments after harvest in the year of 2023 and 2024 *i.e.*, two consecutive years of research trails.

Crude protein

To calculate the total crude protein content in grains, the method utilizedfor the determination of the nitrogen content in grain had been done through a Kjeldahl method. The nitrogen content is then multiplied by 6.25, yielding the grains' protein content expressed as a percentage.

Nutrient content

Nitrogen: Nitrogen content in grain samples were assessed post-harvesting. Finely ground samples from each plot were individually digested and analyzed using a modified Kjeldahl's method outlined by **Jackson (1973).**

Phosphorus: The procedure commenced with the extraction method, where 0.5 grams of finely ground grain samples were transferred to a ternary-acid digestion mixture comprising HNO_3, $HClO_4$, and H_2SO_4 in a ratio of 9:3:1.

Potassium: The potassium content in grain samples were determined using the wet ash procedure employing a ternary acid mixture. Oven-dried plant samples were utilized in conjunction with the Flame photometer method for analysis, as outlined by **Toth and Prince in 1949.**

Statistical analysis

The research employed a factorial randomized block setup to examine how inorganic (NPK), organic (FYM) fertilizers, and a bio-stimulant (Seaweed-based) affect wheat quality parameters across varied treatment combinations. This design was selected for its efficacy in evaluating the influence of several factors while managing potential variations. Factorial experiments probe into how multiple factors or inputs impact the process outcome. In each trial of such an experiment, all conceivable combinations of these factor levels are tested, a concept pioneered by **Fisher in 1960.**

Results and Discussion

Crude protein

The crude protein content in the grain of a wheat crop is a significant measure of its nutritional value serves as a key indicator of grain quality. It represents the concentration of proteins, essential for growth and development, within the harvested kernels. In case of the crude protein content in grain the present study has found that the highest content was recorded in T_{18} (RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}) plot *i.e.,* 12.63 and 13.38 % in the year 2022-23 and 2023-24 respectively. Whereas lowest content was showed by T_1 (RDF @50% +FYM@2.5 t ha^{-1} + SWBS @625 ml ha^{-1}) *i.e.,* 9.94 and 10.63 % in the year 2022-23 and 2023-24 respectively. **In 2019, Pichereaux and his co-workers**also reported that where bio-stimulant were applied had showed an increase in the overall accumulation of total protein in the grains per plant. In case of interaction between different factors, the results found to be significant at different levels *i.e.,* 0.05, 0.01 and 0.001. In which, interaction between all three factors *i.e.,* NPK-FYM-bio-stimulant found to be significant at 0.05 level in both research trails. Whereas, non-significant results were recorded in case of bio-stimulant and FYM-bio-stimulant interactions. In both first and second year of research trails NPK showed significance at 0.05 level. In pooled data it was recorded that NPK-FYM-bio-stimulant as well as NPK alone have showed significant interactions at 0.05 level. In pooled, bio-stimulant, and FYM-bio-stimulant interaction have found to be non-significant in terms of crude protein content in wheat grain.

Nitrogen content in grain

The current study has showed that the nitrogen content in grain found to be nearly 2 % in an average where highest content was showed by T_{18} (RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}) *i.e.,* 2.02 and 2.14 % in the year 2022-23 and 2023-24 respectively.**Yang and his colleagues in 2023** reported that concentrations of both macro- and micronutrients within the plants increased when seaweed extract was applied as foliar spray. Hence, this may also the reason that nitrogen content in grain showed significant results. Whereas lowest content was showed by T_1 (RDF @50% +FYM@2.5 t ha^{-1} + SWBS@625 ml ha^{-1}) *i.e.,* 1.59 and 1.70 % in the year 2022-23 and 2023-24 respectively. In case of interaction between different factors, the results found to be significant at 0.05, 0.01 and 0.001 levels in different combinations of factors. In which, interaction between all three factors *i.e.,* NPK-FYM-bio-stimulant found to be significant at 0.05 level in both the years of research. Whereas bio-stimulant and FYM-bio-stimulant interaction showed non-significant results. Findings from a study conducted by **Pangaribuan and colleagues in 2018**,also suggests that an integrated fertilization strategy combining both organic and urea fertilizersmay result in better taste, nutritional content, or other desirable attributes compared to crops grown solely with nutrient like urea.Even alone factor A *i.e.,* NPK showed significance at 0.05 level in both first and second year of research trails. In pooled data it was recorded that NPK-FYM-bio-stimulant as well as NPK alone have showed significant interactions at 0.05 level. Whereas in pooled bio-stimulant and FYM-bio-stimulant interaction found to be non-significant in terms of nitrogen content in grain.

Phosphorus content in grain

Positive interactions were found between three different factors *i.e.*, NPK, FYM and bio-stimulant. In which NPK-FYM-bio-stimulant and NPK alone showed significance at 0.05 level in both the years of research trails. Whereas other different factor combination showed significant interaction at different levels *i.e.*, 0.001and 0.01 level whereas some has showed non-significant interactions in case of phosphorus content in grain. **Phullan and colleagues (2017),**in their study, they found that application of FYM can increased phosphorus uptake by 14% which means this may be the reason that grain has showed significant results in phosphorus content.Even**,Margal *et al.*, in 2023**also reported thatseaweed extract (*Kappaphycus alvarezii)*had showed a remarkable increase in the uptake of phosphorus (P).In the first year of research trail, it was recorded that FYM-bio-stimulant and bio-stimulant alone showed non-significant interactions. The highest phosphorus content in grain was recorded in T_{18} (RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}) *i.e.*, 0.401 and 0.411% and least by T_1 (RDF @50% +FYM@2.5 t ha^{-1} + SWBS@625 ml ha^{-1}) *i.e.*,0.358 and 0.366% in both the years of research trails i.e., 2022-23 and 2023-24 respectively. In pooled, it was recorded that NPK-FYM-bio-stimulant and NPK alone were found to be significant at 0.05 level in both the years of research trails with highest value in T_{18} (RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}) *i.e.*, 0.406 % of phosphorus content in grain.

Potassium content in grain

In case of the potassium content in grain the present study has found that the highest content was recorded in T_{18} (RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}) plot *i.e.*, 0.472 and 0.474 % in the year 2022-23 and 2023-24 respectively. **Kumar *et al.*, in 2022** reported that combination of fertilizers and seaweed- based bio-stimulant sprays can increase nutrient uptake wheat crops.Whereas lowest content was showed by T_1 (RDF @50% +FYM@2.5 t ha^{-1} + SWBS @625 ml ha^{-1}) *i.e.*, 0.429 and 0.430 % in the year 2022-23 and 2023-24 respectively. In case of interaction between different factors, the results found to be significant at different levels *i.e.*, 0.05, 0.01 and 0.001. In which, interaction between all three factors *i.e.*, NPK-FYM-bio-stimulant found to be significant at 0.05 level in both research trails. **Singh and collaborators (2016)**revealed in their study thatthe potassium content in *Kappaphycus alvarezii* sap is higher than other seaweed like*Gracilaria*sap. Therefore, this may be one of the reasons behind the significant interaction of bio-stimulant with other factors in case of potassium content in grain.Whereas, non-significant results were recorded in case of bio-stimulant and FYM-bio-stimulant interactions. In both first and second year of research trails NPK showed significance at 0.05 level. In pooled data it was recorded that NPK-FYM-bio-stimulant as well as NPK alone have showed significant interactions at 0.05 level. Whereas in pooled, it was recorded that bio-stimulant and FYM-bio-stimulant interaction found to be non-significant in terms of nitrogen content in grain.

Conclusion

The present study investigated the impact of different factors, including NPK fertilization, FYM application, and bio-stimulant treatment, on the nutritional composition of wheat grain. The findings revealed significant variations in crude protein, nitrogen, phosphorus, and potassium content in response to various treatment combinations. The crude protein content,exhibited notable differences across treatments. The highest crude protein content was observed in plots treated with RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}, while the lowest content was recorded in plots receiving RDF @50% +FYM@2.5 t ha^{-1} + SWBS @625 ml ha^{-1}. Interaction between NPK, FYM, and bio-stimulant was significant, highlighting the importance of these factors in influencing crude protein content. Similarly, nitrogen, phosphorus, and potassium content in grain varied significantly among treatments. Positive interactions between NPK, FYM, and bio-stimulant were observed in influencing phosphorus content, while potassium content also showed sensitivity to treatment combinations. Notably, NPK alone and in combination with FYM and bio-stimulant consistently showed significant interactions across both research years. Overall, the study underscores the importance of comprehensive management practices, integrating fertilization, organic amendments, and bio-stimulants, in optimizing the nutritional quality of wheat grain. Further research into specific mechanisms underlying these interactions could provide valuable insights for sustainable agriculture practices aiming to enhance grain quality and nutritional value.

References

1. **Acevedo M., Molero G., Singh P. K., He X., Aoun M., Juliana P., Bockleman H., Bonman M., El-Sohle M., Amri A., Coffman R., McCandles L., (2018)** The role of wheat in global food security. Agricultural Development and Sustainable Intensification: Technology and Policy Challenges in the Face of Climate Change (pp.81-110).
2. **Fisher, R. A., and Yates (1960)** Statistical method for research worker Oliver and

Boyd *Ltd.* Edin burgh and London.10.

3. **Jackson, M. L. (1973)***Soil Chemical Analysis*, Prentice Hall of *India Pvt. Ltd.* New Delhi, 52.
4. **Kipsat, M. J., Osewe, D. O., &Bwari, M. P. (2021)** Assessment of Factors that Limit Optimal Use of Organic Fertilizers in Subsistence Food Production in Vihiga County, Kenya. International Journal of Environment and Climate Change, 11(11), 302–307. **https://doi.org/10.9734/ijecc/2021/v11i1130545**
5. **Kumar Ravindra, Sharma Sanjeev, Singh Devendra, and Pandey Hanuman Prasad (2022**) Effect of Nutrient Optimization through Organic and Inorganic Resources on Yield, Uptake, and Soil Properties in a Rice-wheat Cropping System. *International Journal of Plant & Soil Science*; 34(23): 453-457; Article no. IJPSS.91911 ISSN: 2320-7035.
6. **Margal P.B., Thakare R.S., Kamble B.M., Patil V.S., Patil K.B., and Titirmare N.S. (2023)**Effect of Seaweed Extracts on Crop Growth and Soil: A Review. *Journal of Experimental Agriculture International*. Volume 45, Issue 9, Page 9-19, 2023; Article no.JEAI.101454 ISSN: 2457-0591.
7. **Pangaribuan, Darwin Habinsaran ,Hendarto, Kus, Elzhivago, Sheilla R., Yulistiani, Ade (2018)** The effect of organic fertilizer and urea fertilizer on growth, yield and quality of sweet corn and soil health. *Asian J Agri & Biol*.;6(3):335-344.
8. **Pichereauxa Carole, Laurentc Eve-Anne, Gargarosb Audrey, ViudescSébastien , Durieue Céline, Lamazed Thierry, Grieuc Philippe , Burlet-Schiltzb Odile (2019)** Analysis of durum wheat proteome changes under marine and fungal bio-stimulant treatments using large-scale quantitative proteomics: A useful dataset of durum wheat proteins. *Journal of Proteomics*; 200 28–39.
9. **Phullan, N., Memon, M., Shah, J., Memon, M., Sial, T., Talpur, N., Khushk, G., (2017)** Effect of organic Manure and Mineral Fertilizers on Wheat growth and soil properties. Journal of Basic & Applied Sciences; 13: 559-565.
10. **Singh S & Singh M. K. & Pal S. K. & Trivedi K. &Yesuraj D. & Singh C. S. & Vijay Anand K. G. & Chandramohan M. & Patidar R. &Kubavat D. &Zodape S. T. & Ghosh Arup (2016)** Sustainable enhancement in yield and quality of rain-fed maize through Gracilariaedulis and Kappaphycus alvarezii seaweed sap. J ApplPhycol (2016) 28:2099–2112 DOI 10.1007/s10811-015-0680-8.
11. **Toth S. J, and Prince A. L. (1949)** Estimation of Cation Exchange Capacity and

exchangeable Ca, K and Na Content of Soil by Flame Photometer technique. *Soil Science*; 67:439-445.

12. **Yang S, Wang H, Wang G, Wang J, Gu A, Xue X, Chen R. (2023)** Effects of Seaweed-Extract-Based Organic Fertilizers on the Levels of Mineral Elements, Sugar–Acid Components and Hormones in Fuji Apples. *Agronomy*; 13(4):969. https://doi.org/10.3390/agronomy13040969.

    a. J. Kipsat, M., Osewe, D. O., &Bwari, M. P. (2021). Assessment of Factors that Limit Optimal Use of Organic Fertilizers in Subsistence Food Production in Vihiga County, Kenya. International Journal of Environment and Climate Change, 11(11), 302–307. https://doi.org/10.9734/ijecc/2021/v11i1130545

13. Yedoti, V., Supraja , N., &Chadipiralla , K. (2024). Review on Nanotechnology in Organic Fertilizers: A Sustainable Agricultural Revolution. International Journal of Plant & Soil Science, 36(6), 10–17. https://doi.org/10.9734/ijpss/2024/v36i64601
14. Aguilera E, Lassaletta L, Sanz-Cobena A, Garnier J, Vallejo A. The potential of organic fertilizers and water management to reduce N2O emissions in Mediterranean climate cropping systems. A review. Agriculture, ecosystems & environment. 2013 Jan 1;164:32-52.

Table1. Initial assessment of the soil samples in the experimental field for the years 2022 and 2023.

Soilcharacteristics	**Soildepth(0-15cm)**	
	2022	**2023**
Soil pH(1:2.5)	6.73	6.75
Electrical conductivity(dS m^{-1})	0.16	0.17
Bulk density (Mg m^{-3})	1.25	1.26
Particle density (Mg m^{-3})	2.61	2.61
Porosity (%)	49.0	52.0
Water holding capacity (%)	50.11	47.73
Organiccarbon(%)	0.302	0.305
Availablenitrogen (kgha^{-1})	210.12	229.11
Availablephosphorus(kgha^{-1})	14.75	18.10
Availablepotassium(kgha^{-1})	171.02	185.07

Table 2. Treatment combinations for wheat

Notation	Treatment Combinations
T_1	RDF @50% +FYM@12.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_2	RDF @50% + FYM@12.5 t ha^{-1} + SWBS @1250 ml ha^{-1}
T_3	RDF @75% +FYM@12.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_4	RDF @75%+FYM@12.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_5	RDF @100% + FYM@12.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_6	RDF @100% + FYM@12.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_7	RDF @50% + FYM@14.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_8	RDF @50% + FYM@14.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_9	RDF @75% + FYM@14.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_{10}	RDF @75% + FYM@14.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_{11}	RDF @100% + FYM@14.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_{12}	RDF @100% + FYM@14.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_{13}	RDF @50% + FYM@16.5 t ha^{-1} + SWBS@625 ml ha^{-1}
T_{14}	RDF @50% +FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_{15}	RDF @75% + FYM@16.5 t ha^{-1} +SWBS@625 ml ha^{-1}
T_{16}	RDF @75% +FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}
T_{17}	RDF @100% + FYM@16.5 t ha^{-1} +SWBS@625 ml ha^{-1}

T18	RDF @100% + FYM@16.5 t ha^{-1} + SWBS@1250 ml ha^{-1}

Note: RDF= Recommended Dose of Fertilizer, FYM = Farm Yard Manure and SWBS= Seaweed- based bio-stimulant

Table 3 (a). Effect of combined use of inorganic fertilizer, organic manure, and foliar application of seaweed- based bio-stimulant on **crude protein** in grain (measured in percentage) by wheat plant during both crop periods *i.e.*, 2022-2023 and 2023-2024 with pooled data.

		2022-23		**2023-24**		**POOLED**	
		SWBS (625 ml ha^{-1})	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**
RDF (50%)	**FYM (12.5 t ha^{-1})**	9.94	10.25	10.63	11.00	10.63	11.00
	FYM (14.5 t ha^{-1})	11.25	11.00	12.00	11.75	12.00	11.75
	FYM (16.5 t ha^{-1})	11.25	11.00	12.00	11.75	12.00	11.75
RDF (75%)	**FYM (12.5 t ha^{-1})**	10.50	10.25	11.25	11.00	11.25	11.00
	FYM (14.5 t ha^{-1})	11.00	11.75	11.75	12.50	11.75	12.50
	FYM (16.5 t ha^{-1})	10.75	11.00	11.50	11.75	11.50	11.75
RDF (100%)	**FYM (12.5 t ha^{-1})**	11.25	11.00	12.00	11.75	12.00	11.75
	FYM (14.5 t ha^{-1})	10.50	12.25	11.25	13.00	11.25	13.00
	FYM (16.5 t ha^{-1})	10.50	12.63	11.25	13.38	11.25	13.38
CD ($P<0.05$)		0.997		1.006		1.001	

Table 3 (b). Values of C.D., SE(d) and SE(m) for two consecutive years of research trail *i.e.*, 2022-23 and 2023-24 with pooled data.

	2022-23			**2023-24**			**POOLED**		
Factors	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**
Factor(A)	0.407	0.200	0.142	0.411	0.202	0.143	0.409	0.201	0.142
Factor(B)	0.407	0.200	0.142	0.411	0.202	0.143	0.409	0.201	0.142
Interaction A X B	0.332	0.347	0.245	0.335	0.350	0.247	0.334	0.348	0.246
Factor(C)	N/A	0.163	0.116	N/A	0.165	0.117	N/A	0.164	0.116

Interaction A X C	0.576	0.283	0.200	0.581	0.286	0.202	0.578	0.284	0.201
Interaction B X C	N/A	0.283	0.200	N/A	0.286	0.202	N/A	0.284	0.201
Interaction A X B X C	0.997	0.490	0.347	1.006	0.495	0.350	1.001	0.492	0.348

Table 4 (a). Effect of combined use of inorganic fertilizer, organic manure, and foliar application of seaweed- based bio-stimulant on **nitrogen content** (measured in percentage) of grain during both crop periods *i.e.*, 2022-2023 and 2023-2024 with pooled data.

		2022-23		**2023-24**		**POOLED**	
		SWBS (625 ml ha^{-1})	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**
RDF (50%)	**FYM (12.5 t ha^{-1})**	1.59	1.64	1.70	1.76	1.65	1.70
	FYM (14.5 t ha^{-1})	1.80	1.76	1.92	1.88	1.86	1.82
	FYM (16.5 t ha^{-1})	1.80	1.76	1.92	1.88	1.86	1.82
RDF (75%)	**FYM (12.5 t ha^{-1})**	1.68	1.64	1.80	1.76	1.74	1.70
	FYM (14.5 t ha^{-1})	1.76	1.88	1.88	2.00	1.82	1.94
	FYM (16.5 t ha^{-1})	1.72	1.76	1.84	1.88	1.78	1.82
RDF (100%)	**FYM (12.5 t ha^{-1})**	1.80	1.76	1.92	1.88	1.86	1.82
	FYM (14.5 t ha^{-1})	1.68	1.96	1.80	2.08	1.74	2.02
	FYM (16.5 t ha^{-1})	1.68	2.02	1.80	2.14	1.74	2.08
CD ($P<0.05$)		0.159		0.161		0.16	

Table 4 (b). Values of C.D., SE(d) and SE(m) for two consecutive years of research trail *i.e.*, 2022-23 and 2023-24 with pooled data.

	2022-23	**2023-24**	**POOLED**

Factors	C.D.	SE(d)	SE(m)	C.D.	SE(d)	SE(m)	C.D.	SE(d)	SE(m)
Factor(A)	0.065	0.032	0.023	0.066	0.032	0.023	0.065	0.032	0.023
Factor(B)	0.065	0.032	0.023	0.066	0.032	0.023	0.065	0.032	0.023
Interaction A X B	0.053	0.055	0.039	0.054	0.056	0.040	0.053	0.056	0.039
Factor(C)	N/A	0.026	0.018	N/A	0.026	0.019	N/A	0.026	0.019
Interaction A X C	0.092	0.045	0.032	0.093	0.046	0.032	0.092	0.045	0.032
Interaction B X C	N/A	0.045	0.032	N/A	0.046	0.032	N/A	0.045	0.032
Interaction A X B X C	0.159	0.078	0.055	0.161	0.079	0.056	0.160	0.079	0.056

Table 5 (a). Effect of combined use of inorganic fertilizer, organic manure, and foliar application of seaweed- based bio-stimulant on **phosphorus content** (measured in kilogram per hectare) of grain during both crop periods *i.e.*, 2022-2023 and 2023-2024 with pooled data.

		2022-23		**2023-24**		**POOLED**	
		SWBS (625 ml ha^{-1})	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**
RDF (50%)	**FYM (12.5 t ha^{-1})**	0.36	0.36	0.37	0.37	0.36	0.37
	FYM (14.5 t ha^{-1})	0.38	0.38	0.39	0.39	0.39	0.38
	FYM (16.5 t ha^{-1})	0.38	0.38	0.39	0.39	0.38	0.38
RDF (75%)	**FYM (12.5 t ha^{-1})**	0.37	0.36	0.38	0.37	0.37	0.37
	FYM (14.5 t ha^{-1})	0.38	0.39	0.38	0.40	0.38	0.39
	FYM (16.5 t ha^{-1})	0.37	0.38	0.38	0.38	0.38	0.38
RDF (100%)	**FYM (12.5 t ha^{-1})**	0.38	0.38	0.39	0.39	0.38	0.38
	FYM (14.5 t ha^{-1})	0.37	0.40	0.38	0.40	0.37	0.40
	FYM (16.5 t ha^{-1})	0.37	0.40	0.38	0.41	0.37	0.41
CD		0.016		0.016		0.016	

(P<0.05)

Table 5 (b). Values of C.D., SE(d) and SE(m) for two consecutive years of research trail *i.e.*, 2022-23 and 2023-24 with pooled data.

	2022-23			2023-24			POOLED		
Factors	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**
Factor(A)	0.007	0.003	0.002	0.007	0.003	0.002	0.006	0.003	0.002
Factor(B)	0.007	0.003	0.002	0.007	0.003	0.002	0.006	0.003	0.002
Interaction A X B	N/A	0.003	0.002	N/A	0.003	0.002	N/A	0.003	0.002
Factor(C)	0.005	0.006	0.004	0.005	0.006	0.004	0.005	0.006	0.004
Interaction A X C	0.009	0.005	0.003	0.009	0.005	0.003	0.009	0.004	0.003
Interaction B X C	N/A	0.005	0.003	N/A	0.005	0.003	N/A	0.004	0.003
Interaction A X B X C	0.016	0.008	0.006	0.016	0.008	0.006	0.016	0.008	0.006

Table 6 (a). Effect of combined use of inorganic fertilizer, organic manure, and foliar application of seaweed- based bio-stimulant on **potassium content** (measured in kilogram per hectare) of grain during both crop periods *i.e.*, 2022-2023 and 2023-2024 with pooled data.

		2022-23		2023-24		POOLED	
		SWBS (625 ml ha^{-1})	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**	**SWBS (625 ml ha^{-1})**	**SWBS (1250 ml ha^{-1})**
RDF (50%)	**FYM (12.5 t ha^{-1})**	0.429	0.434	0.430	0.437	0.430	0.436
	FYM (14.5 t ha^{-1})	0.450	0.446	0.455	0.454	0.453	0.450
	FYM (16.5 t ha^{-1})	0.450	0.446	0.456	0.452	0.453	0.449
RDF (75%)	**FYM (12.5 t ha^{-1})**	0.438	0.434	0.440	0.435	0.439	0.435
	FYM (14.5 t ha^{-1})	0.446	0.458	0.447	0.461	0.447	0.460
	FYM (16.5 t ha^{-1})	0.442	0.446	0.447	0.453	0.445	0.450

RDF (100%)	**FYM (12.5 t ha^{-1})**	0.450	0.446	0.457	0.451	0.454	0.449
	FYM (14.5 t ha^{-1})	0.438	0.466	0.441	0.468	0.440	0.467
	FYM (16.5 t ha^{-1})	0.438	0.472	0.439	0.474	0.439	0.473
CD (P<0.05)		0.016		0.016		0.016	

Table 6 (b). Values of C.D., SE(d) and SE(m) for two consecutive years of research trail *i.e.*, 2022-23 and 2023-24 with pooled data.

	2022-23			**2023-24**			**POOLED**		
Factors	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**	**C.D.**	**SE(d)**	**SE(m)**
Factor(A)	0.007	0.003	0.002	0.007	0.003	0.002	0.007	0.003	0.002
Factor(B)	0.007	0.003	0.002	0.007	0.003	0.002	0.007	0.003	0.002
Interaction A X B	0.005	0.006	0.004	0.005	0.006	0.004	0.005	0.006	0.004
Factor(C)	N/A	0.003	0.002	N/A	0.003	0.002	N/A	0.003	0.002
Interaction A X C	0.009	0.005	0.003	0.009	0.005	0.003	0.009	0.005	0.003
Interaction B X C	N/A	0.005	0.003	N/A	0.005	0.003	N/A	0.005	0.003
Interaction A X B X C	0.016	0.008	0.006	0.016	0.008	0.006	0.016	0.008	0.006