J. Indian Soc. Coastal Agric. Res. 44(1):88-98(2026) https://doi.org/10.54894/JISCAR.44.1.2026.177007

Impact of Seaweed Biostimulant on Growth and Productivity of Indigenous Rice Grown in Indian Sundarbans

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Received: 12.03.2026 Accepted: 01.07.2026

Soil salinity is a major constraint limiting rice productivity in the coastal agroecosystems of the Indian Sundarbans. The use of natural biostimulants such as seaweed extracts has emerged as a sustainable approach to enhance crop growth as well as stress tolerance under such adverse conditions. A field experiment was conducted during the *Kharif* 2022 and 2023 at Rangabelia, West Bengal to assess the effects of seaweed saps on the growth, yield, quality, nutrient uptake and economics of the rice variety, 'Dudheshwar'. Seven treatments, comprising RDF-alone and RDF with foliar application of Sagarika and *Sargassum* extracts (2.5, 5 and 10%), were evaluated in a randomized block design. Foliar application of seaweed extracts significantly ($p<0.05$) improved plant height, tiller density, leaf area index and dry matter accumulation when compared with RDF alone. Among the treatments, application of 10% *Sargassum* extract recorded the highest growth attributes and yield components, resulting in the maximum grain yield (4.51 t ha^{-1}). Seaweed treatments also enhanced grain quality parameters, particularly hulling and milling percentages, while kernel dimensions remained largely unaffected. Nutrient uptake of nitrogen, phosphorus and potassium increased progressively (increased by up to 41.69, 51.76 and 31.18%, respectively over control) with increasing concentrations of seaweed extracts. Economic analysis revealed higher gross and net returns with such sap application, while the highest benefit - cost ratio was obtained under the application of 5% *Sargassum* sap. The findings indicate that integration of seaweed-based biostimulants with recommended fertilizer management can enhance productivity and profitability of indigenous rice cultivated under coastal saline soils of the Indian Sundarbans.

(***Key words:*** *Biostimulants, Coastal saline soil, Indian Sundarbans, Indigenous rice, Seaweed extracts)*

Rice (*Oryza sativa* L.) is the principal food crop of the Indian Sundarbans and forms the backbone of livelihood security for millions of small and marginal farmers inhabiting this climatically fragile coastal region (Mainuddin *et al.,* 2024). Agriculture in the Sundarbans is largely rainfed and constrained by a combination of edaphic and climatic stresses, among which soil salinity is the most persistent and yield-limiting factor (Dey *et al.,* 2025). Seawater intrusion through tidal channels, poor natural drainage, scarcity of fresh irrigation water during the dry season and the increasing frequency of cyclonic events have collectively intensified soil salinization, resulting in declining crop productivity and restricted cropping intensity (Ghosh *et al.,* 2018).

Indigenous rice varieties traditionally cultivated in the Sundarbans possess valuable adaptive traits such as tolerance to salinity, submergence and low - input conditions (Sarkar *et al.,* 2022). These landraces have evolved under prolonged exposure to coastal stresses and are often preferred by farmers for their resilience and grain quality (Kumar *et al.,* 2025). However, despite their adaptive potential, the productivity of indigenous rice remains low due to physiological constraints imposed by salinity stress, nutrient imbalance and reduced soil biological activity (Banerjee *et al.,* 2018). Salinity - induced osmotic stress, ion toxicity and oxidative damage impair photosynthesis, nutrient uptake, and biomass accumulation, ultimately limiting yield formation in rice grown under coastal saline soils (Mishra *et al.,* 2023).

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Conventional strategies to enhance rice productivity in saline soils rely mainly on chemical fertilizers and soil amendments. In the Sundarbans context, such practices are often constrained by high input costs, limited resource availability and low efficiency under saline and waterlogged conditions (Mandal *et al.,* 2020). Moreover, long-term dependence on inorganic inputs may further degrade soil health and increase environmental risks in this ecologically sensitive region (Tilman *et al.,* 2002). This has necessitated the exploration of alternative, environmentally benign inputs that can improve crop performance by enhancing plant physiological efficiency rather than merely supplying nutrients.

The application of biostimulants like seaweed extracts is among the sustainable strategies for improving the overall performance of the crops. Seaweed-based biostimulants have recently emerged as promising natural inputs capable of improving crop growth and stress tolerance. Some commonly reared species of seaweeds are *Kappaphycus alvarezii*, *Sargassum fusiforme*, *Saccharina japonica*, *Glacilaria* spp. etc. (Trivedi *et al.,* 2023). Seaweed saps contain bioactive compounds such as phytohormones, amino acids, polysaccharides, betaines and micronutrients that enhance plant growth, nutrient uptake, and tolerance to abiotic stresses (Elumalai *et al.,* 2025; Chanthini *et al.,* 2024). In rice, seaweed-based biostimulants have been reported to improve photosynthetic efficiency, root development, nutrient use efficiency, and antioxidant activity, resulting in higher biomass and yield under both normal and stress conditions (Pramanick *et al.,* 2016; Pramanick *et al.,* 2017; Mondal *et al.,* 2025). Foliar application of seaweed extracts has also been shown to alleviate salinity stress through improved antioxidant defence and osmotic regulation, making them a promising sustainable input for rice production in stress-prone environments (Latique *et al.,* 2021; Thaimei *et al.,* 2024; Ibrahim *et al.,* 2025; Surma *et al.,* 2025)

However, existing studies on seaweed-based biostimulants in rice have largely focused on high-yielding or improved varieties grown under non-saline or moderately stressed environments. The response of indigenous rice varieties cultivated under naturally saline field conditions, particularly in the Indian Sundarbans, remains unclear. There is a lack of evidence on their effectiveness in indigenous rice landraces cultivated under naturally saline coastal ecosystems. Because indigenous rice landraces differ fundamentally from modern cultivars in their growth behaviour, stress adaptation strategies and nutrient acquisition patterns. Therefore, their interaction with biostimulants derived from marine resources represents a distinct and under explored research domain. Considering the above background, the present study provides novel insights into the potentiality of seaweed-based biostimulants as a climate-resilient and sustainable management strategy for indigenous rice cultivation in coastal saline environments.

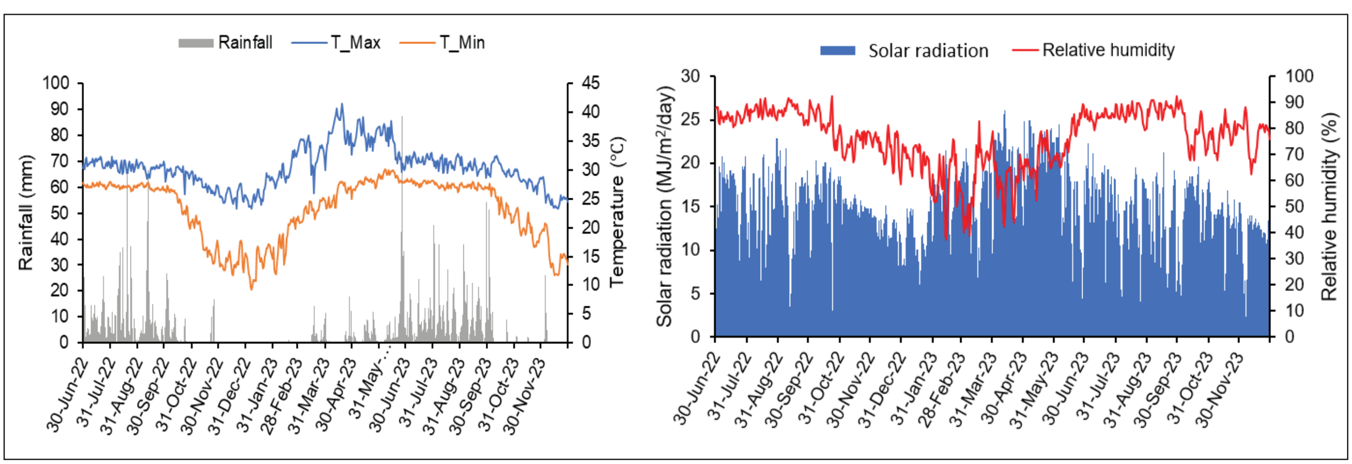

Fig. 1. *Meteorological parameters during the crop growing period*

MATERIALS AND METHODS

A field experiment was carried out during *Kharif* seasons of 2022 and 2023 at Rangabelia (21.92° N, 88.80° E; 4 m AMSL) in Gosaba Block of South 24 Parganas district, West Bengal, India. Meteorological observations during the crop growth period are presented in Fig. 1. The experimental site, under lower deltaic tract of the Gangetic basin, is characterized by clayey soil comprising of 56.2% sand, 20.3% silt and 23.5% clay formed from recent alluvial deposits and influenced by shallow groundwater (Bandyopadhyay *et al.,* 2003). The surface layer (0-30 cm) exhibited slightly an acidic reaction with a pH of 6.74, electrical conductivity ($EC_{1:5}$) of 0.28 dS m^{-1} (measured using a 1:5 soil-to-water suspension) and organic carbon content of 0.56%. Initial available nutrient status of the soil prior to the experiment depicts 203.3 kg N ha^{-1}, 18.50 kg P ha^{-1} and 176.33 kg K ha^{-1}. The trial was laid out in Randomized Block Design (RBD) comprising of seven treatments replicated thrice. The plot size of each treatment was 30 m^2. During the experimental period, two types of seaweed saps were applied at different concentrations over control. Treatment details were T_1:100% RDF, T_2: 100% RDF + 2.5% Sagarika, T_3: 100% RDF + 5% Sagarika, T_4: 100% RDF + 10% Sagarika, T_5: 100% RDF + 2.5% *Sargassum*, T_6: 100% RDF + 5% *Sargassum*, T_7: 100% RDF + 10% *Sargassum*. The *Sargassum wightii* extract (unit cost Rs. 25 L^{-1}) was obtained from the Central Salt and Marine Chemicals Research Institute (CSMCRI), Bhavnagar, Gujarat, India. Likewise, Sagarika, a commercial seaweed-based formulation derived from *Kappaphycus alvarezii* (marketed by IFFCO), was purchased from the market (unit price Rs. 500 L^{-1}). The chemical composition and nutrient profile of these two seaweed extracts, applied during a couple of years of experimentation, has been expanded in Table 1. Foliar sprays of Sagarika and *Sargassum* extracts at 2.5, 5 and 10% concentrations were applied

Table 1. *Proximate bio-chemical composition of the experimental seaweed extracts*

Composition	Concentration	
	Sagarika (*Kappaphycus alvarezii*)	*Sargassum wightii*
Carotenoids (mg g^{-1})	4.26 ± 0.05[a]	4.11 ± 0.14[a]
Ascorbate (µg g^{-1})	334.67 ± 52.15[b]	902.64 ± 71.20[a]
GA_3 (ppm)	14.31 ± 0.0	ND
IAA (ppb)	117.00 ± 0.0[b]	381.07 ± 0.0[a]
Zeatin (ppb)	5680.0 ± 0.0[b]	3868.40 ± 0.0[a]
N (%)	0.33 ± 0.09[a]	0.09 ± 0.01[b]
P (%)	0.08 ± 0.007[b]	0.95 ± 0.08[a]
Na (%)	8.81 ± 0.322[a]	1.85 ± 0.04[b]
K (%)	30.24 ± 0.735[a]	9.72 ± 0.14[b]
Ca (mg kg^{-1})	12,637 ± 2519[a]	10,557 ± 192[b]
S (%)	3.29 ± 0.49[a]	3.22 ± 0.13[a]
Mg (mg kg^{-1})	9707 ± 300[a]	7629 ± 555[b]
B (mg kg^{-1})	21.74 ± 2.65[b]	56.89 ± 3.34a
Al	754.28 ± 35.65[a]	405.25 ± 28.83[b]
Mn	100.22 ± 0.65[b]	127.67 ± 8.84[a]
Fe	202.53 ± 91.65[a]	83.01 ± 23.84[b]
Co	1.16 ± 0.002[b]	2.80 ± 0.16[a]
Cu	1.0 ± 0.002[b]	3.19 ± 0.25[a]
Zn	1.99 ± 0.29[b]	4.39 ± 1.07[a]
Mo	7.13 ± 0.02[b]	200.49 ± 11.17[a]

**(Data originated from CSMCRI, Bhavnagar, Gujarat, India and determined in accordance with the standard protocols of AOAC; Anonymous (n.d.);* Vaghela *et al., 2023)*

** The values are means ± S.D. (n=3) followed by different letters are significantly different by Duncan's Multiple Range Test (DMRT) at p≤0.05* at 30 DAT as per the treatment protocol. 'Dudheshwar', a traditional short-grain, non-aromatic rice variety predominantly cultivated in the districts of South and North 24 Paraganas of West Bengal (Banerjee *et al.,* 2018), was chosen for this study. The cultivar is locally preferred for its distinctive milky-white caryopsis, reduced cooking duration and desirable post-cooking physicochemical properties characterized by a soft consistency and slight adhesiveness. Twenty-five days old rice seedlings having 3-4 leaves were transplanted in the main puddled field at a spacing of 20 cm × 20 cm during the second fortnight of July in two consecutive experimental years. All the agronomic management practices, except the nutrient management component, were carried out in accordance with the recommended package of practices. Recommended doses of nitrogen (60 kg ha^{-1}), phosphorus (30 kg ha^{-1}) and potassium (30 kg ha^{-1}) were applied across all the treatments through urea, single super phosphate and muriate of potash, respectively. One-fourth (25%) of the recommended dose of nitrogen along with full amount of phosphorus and potassium was applied as basal at transplanting. The remaining nitrogen was top-dressed in two splits half of its required amount (50%) was applied at 30 DAT and the rest one-fourth (25%) at 60 DAT. Sampling of plants for recording growth parameters *viz.* plant height, total tillers $hill^{-1}$, leaf area index (LAI) and dry matter accumulation (g m^{-2}) was carried out at 30, 60 and 90 days after transplanting (DAT). Yield attributes along with grain and straw yields were recorded at harvest. Harvest index was calculated as the ratio of grain weight to the total above-ground biomass, including both grain and straw (Donald, 1962). Physical quality attributes, *viz.* hulling (%), milling (%), kernel length, breadth and L/B ratio were determined after harvest using standard formulas (Razavi and Farahmandfar, 2008). LAI (Eq 1) was calculated following the specified formulae proposed by Watson (1952).

$$\text{LAI} = \frac{\text{Total leaf area (m}^2\text{)}}{\text{Ground area (m}^2\text{)}} \quad .... (1)$$

Economic analysis was carried out based on prevailing market prices of produce and agro-inputs. Net return was computed by subtracting the total cost of cultivation from gross return, while the benefit-cost ratio was determined as the ratio of gross return to cost of cultivation. The data were analyzed statistically following the procedure outlined by Gomez and Gomez (1984), and treatment effects were tested for significance. Duncan's Multiple Range Test (DMRT) was performed using OPSTAT software (Sheoran and Pannu, 1999).

RESULTS AND DISCUSSION

Growth attributes

Growth attributes of rice *viz.* plant height, tillers $hill^{-1}$, leaf area index (LAI) and dry matter accumulation (DMA) were recorded at different days after transplanting (DAT) during both the years of experimentation. Foliar application of seaweed extracts significantly ($p<0.05$) improved these vegetative parameters over control (RDF). The magnitude of enhancement increased progressively and attained statistical significance with higher concentrations of seaweed extract (Fig. 2). Most of the growth parameters of rice did not differ significantly ($p<0.05$) among the treatments at 30 DAT during both the experimental years indicating no noticeable impact of seaweed extract regardless of its source and concentration on early vegetative growth of the crop. Whereas, comparable differences were observed at later growth stages (60 and 90 DAT). The treatment receiving 10% seaweed extract of *Sargassum* (T_7) recorded the tallest plants being statistically at par with those receiving upper doses (5 and 10%) of both the seaweed saps. These results are consistent with those reported by Layek *et al.* (2018). Number of tillers $hill^{-1}$ exhibited the same trend as that the plant height showed. Being a key yield determining trait, it differed significantly ($p<0.05$) at 60 and 90 DAT with the application of seaweed sap. The highest number of tillers $hill^{-1}$ was recorded in the plot treated with *Sargassum* at 10% rate (T_7) and it was closely followed by the treatment receiving 10% Sagarika (T_4) at 60 DAT. At 90 DAT, statistically comparable tiller counts $hill^{-1}$ was observed among the higher concentrations (5 and 10%) of both the seaweed saps. The enhanced tillering under seaweed sap application along with RDF over control (RDF) may be attributed to better nutrient uptake as well as stimulation of physiological processes in the plants (Pramanick *et al.,* 2020). LAI was also enhanced with the higher rates of seaweed sap application and it was found to be the maximum under the treatment getting foliar spray of 10% *Sargassum* sap (T_7) in both the succeeding years, exhibiting the increase in LAI by 25.77 and 31.50% at 60 DAT, and 15.31 and 13.24% at 90 DAT, during Year I and Year II, respectively. Likewise, DMA increased progressively with the escalating rates of seaweed extract application at 60 and 90 DAT. The rise in dry matter accumulation may be linked to the use of seaweed sap, which in turn positively impairs plant physicochemical properties, involving hormonal balance, enzymatic regulation and photosynthetic efficiency (Singh *et al.,* 2016). In contrast, the control treatment (RDF) consistently recorded the lowest growth attributes across all the phenological stages of rice crop during both the years.

Yield attributes and yield

Yield attributes and yield were significantly enhanced by the foliar application of seaweed extracts (Table 2). In comparison with the control, treatments receiving 10% *Sargassum* sap recorded significantly higher number of productive tiller hill^{-1} being statistically at par with T_4 (Sagarika @10%). Effective grains panicle^{-1} also attained the maximum value under the application of 10% *Sargassum*. At a fixed chemical fertilizer rate, grain yield improved progressively with increasing sea weed sap levels. The highest grain yield (4.51 t ha^{-1}) was recorded with the application of 10% *Sargassum* and this treatment represented no statistical discrepancy with other three treatments, *viz.* T_4 (10% Sagarika), T_3 (5% Sagarika) and T_6 (5% *Sargassum*). A comparatively higher grain yield (4.61 t ha^{-1}) was obtained in the second year than the yield harvested in the first year. The harvest index of rice remained higher under 5-10% application of either sap, possibly due to enhanced dry matter production, improved translocation of photosynthates from source to sink and better yield attributes (Partani, 2013; Kurakula and Rai, 2021). In the present study, the lowest grain yield

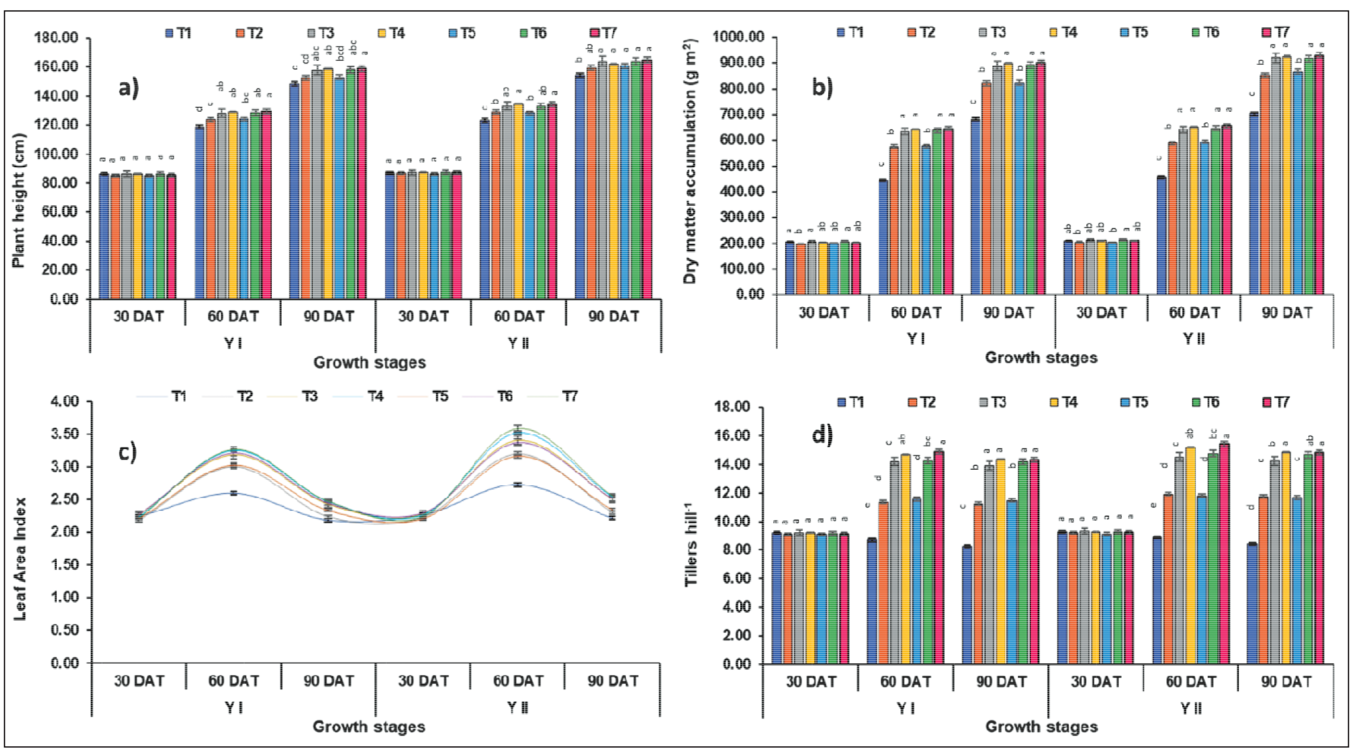

Fig. 2. *Growth parameters viz (A) Plant height, (B) Tillers hill^{-1}, (C) Leaf area index (LAI) and (D) Dry matter accumulation (DMA) at 30, 60 and 90 days after transplanting (DAT) during Year I and Year II (T_1: 100% RDF; T_2: 100% RDF + 2.5% Sagarika; T_3: 100% RDF + 5% Sagarika; T_4: 100% RDF + 10% Sagarika; T_5: 100% RDF + 2.5% Sargassum; T_6: 100% RDF + 5% Sargassum; T_7: 100% RDF + 10% Sargassum)*

Table 2. *Yield parameters, yield and harvest index (HI) of rice (var. Dudheshwar) as influenced by the application of seaweed saps*

Tr.	Effective tillers/hill		filled grains/panicle		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		HI (%)	
	Yr I	Yr II	Yr I	Yr II	Yr I	Yr II	Yr I	Yr II	Yr I	Yr II
T_1	7.77^d	8.01^e	110.9^c	112.68^c	3.21^c	3.31^c	6.02^c	6.11^c	34.78^c	35.13^c
T_2	8.49^c	8.80^d	115.94^b	117.38^b	3.81^b	3.92^b	6.57^b	6.65^b	36.71^b	37.08^b
T_3	9.79^{ab}	10.01^b	120.22^a	121.44^{ab}	4.46^a	4.56^a	7.07^a	7.13^a	38.68^a	39.02^a
T_4	9.96^{ab}	10.22^a	120.31^a	122.39^a	4.47^a	4.58^a	7.11^a	7.19^a	38.60^a	38.91^a
T_5	8.77^c	9.18^c	115.39^b	120.23^{ab}	3.78^b	3.91^b	6.66^b	6.78^b	36.21^b	36.58^{bc}
T_6	9.7^b	10.11^{ab}	118.48^{ab}	121.05^{ab}	4.40^a	4.54^a	7.13^a	7.26^a	38.16^a	38.48^a
T_7	10.09^a	10.28^a	121.58^a	123.41^a	4.51^a	4.61^a	7.15^a	7.23^a	38.68^a	38.93^a

Tr.: Treatments; T_1:100% RDF; T_2: 100% RDF + 2.5% Sagarika; T_3: 100% RDF + 5% Sagarika; T_4: 100% RDF + 10% Sagarika; T_5: 100% RDF + 2.5% Sargassum; T_6: 100% RDF + 5% Sargassum; T_7: 100% RDF + 10% Sargassum;

Means followed by different letters are significantly different by Duncan's Multiple Range Test (DMRT) at P≤0.05

was recorded under the control (RDF) representing the importance of seaweed extract application for achieving optimum yield. The enhancement in yield of rice under seaweed treated plots may be due to presence of hormonal constituents in the extract.

Quality parameters of rice

The results from pooled analysis revealed that (Table 3) foliar application of 10% *Sargassum* sap along with 100% RDF enhanced the grain quality of rice. Hulling and milling percentages were increased by 4.06 and 4.66%, respectively, as compared with the control treatment. The improvement in these quality attributes may be associated with enhanced availability and uptake of essential nutrients such as P, K, Mg, N, Cu and Zn; as seaweed extracts are known to be the rich sources of plant nutrients as well as growth-promoting substances. Similar results on superior grain quality through the application of seaweed extract along with chemical fertilizers were witnessed by Pramanick *et al.* (2020), Erulan *et al.* (2009) and Sivasankari *et al.* (2006). The kernel length, kernel breadth and L/B ratio of Dudheshwar rice did not show any significant ($p<0.05$) variation among the treatment combinations. However, the values of these parameters ranged from 5.36 to 5.55 mm, 2.00 to 2.05 mm and 2.65 to 2.71, respectively. This may be attributed to the fact that grain shape is a highly stable varietal characteristics predominantly governed by genetic factors and is less responsive to external agronomic interventions (Chen *et al.,* 2025). The physical dimensions of the milled rice clearly indicated that Dudheshwar belongs to medium slender kernel type.

Nutrient uptake and post–harvest soil EC and pH

The uptake of nitrogen (N), phosphorus (P) and potassium (K) by rice was significantly influenced by the application of seaweed sap along with the recommended dose of fertilizers (RDF) (Table 4). Among the treatments, 100% RDF + 10% *Sargassum* sap (T_7) recorded the highest nutrient uptake (48.23 kg ha^{-1} N, 48.23 kg ha^{-1} P and 196.05 kg ha^{-1} K) and it was statistically at par with T_4 (10% Sagarika) for N and P uptake but slightly superior in terms of potassium uptake. In contrast, the control treatment (T_1: 100% RDF) showed the lowest uptake of nutrients (31.78 kg ha^{-1} N, 31.78 kg ha^{-1} P and 149.45 kg ha^{-1} K). A progressive increase in nutrient uptake was observed with the increasing concentration of seaweed saps, both Sagarika and *Sargassum*. This improvement may be attributed to enhanced root development and improved physiological efficiency, which facilitated greater absorption of soil nutrients, leading to higher accumulation of N, P and K in plants. Similar results

Table 3. *Quality parameters of rice (var. Dudheshwar) as influenced by the application of seaweed saps (Pooled data of two years)*

Treatments	Hulling (%)	Milling (%)	Kernel length (mm)	Kernel breadth (mm)	L : B ratio
T_1: 100% RDF	79.42^{b}	67.21^{b}	5.36^{a}	2.00^{a}	2.67^{a}
T_2: 100% RDF + 2.5% Sagarika	81.01^{ab}	68.62^{ab}	5.37^{a}	2.02^{a}	2.65^{a}
T_3: 100% RDF + 5% Sagarika	82.13^{ab}	70.08^{a}	5.43^{a}	2.02^{a}	2.68^{a}
T_4: 100% RDF + 10% Sagarika	82.62^{a}	70.16^{a}	5.52^{a}	2.04^{a}	2.71^{a}
T_5: 100% RDF + 2.5% Sargassum	81.19^{ab}	68.95^{ab}	5.39^{a}	2.00^{a}	2.68^{a}
T_6: 100% RDF + 5% Sargassum	82.25^{ab}	70.06^{a}	5.47^{a}	2.03^{a}	2.69^{a}
T_7: 100% RDF + 10% Sargassum	82.65^{a}	70.34^{a}	5.55^{a}	2.05^{a}	2.71^{a}

were reported from several studies where the application of seaweed extracts significantly enhanced nutrient uptake and their use efficiency in rice and other crops also (Layek *et al.,* 2018; Singh *et al.,* 2025). Post harvest soil pH and electrical conductivity ($EC_{1:5}$) did not differ significantly ($p<0.05$) among the treatments (Table 4). The rice crop was harvested following the cessation of monsoon rainfall as the soil progressively dried. This post-monsoon soil desiccation resulted in a bit increase in EC values. However, variation in post-harvest EC and pH were reported by Adak *et al.* (2026) and Dhar *et al.* (2025).

Economics

The economic analysis, including common cost, treatment cost, total cost, gross return, net return and benefit - cost ratio, have been presented in Table 5. Although the common cultivation cost remained the same (Rs. 41,258 ha^{-1}), treatment and total costs varied depending on the treatment combinations. The highest treatment cost (Rs. 33,482 ha^{-1}) and total cost (Rs. 74,740 ha^{-1}) were recorded under T_4 (10% Sagarika) due to the higher market price of the biostimulant. The maximum gross return (Rs. 1,10,075 ha^{-1}) and net return (Rs. 59,226 ha^{-1}) were obtained from treatment T_7 (10% *Sargassum*) and (5% *Sargassum*), respectively. However, the highest benefit - cost ratio (2.17) was observed under treatment T_6 (5% *Sargassum*) and it was closely followed by treatment T_7 (2.15). In contrast, the lowest gross return (Rs. 80,220 ha^{-1}) and net return (Rs. 31,180 ha^{-1}) were recorded under treatment T_1 (100% RDF alone), indicating the economic advantage of integrating seaweed extracts with RDF and this finding is corroborated the opinion of Pramanick *et al.* (2017).

Table 4. *Nutrient uptake by rice (var. Dudheshwar) and post - harvest soil EC and pH as influenced by the application of seaweed saps (Pooled data of two years)*

Treatments	Nutrient uptake			$EC_{1:5}$ ($dS\ m^{-1}$)	pH
	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)		
T_1: 100% RDF	73.19^{d}	31.78^{d}	149.45^{c}	0.78^{a}	6.85^{a}
T_2: 100% RDF + 2.5% Sagarika	86.55^{c}	37.60^{c}	171.78^{b}	0.76^{a}	6.86^{a}
T_3: 100% RDF + 5% Sagarika	99.57^{b}	46.21^{b}	191.61^{a}	0.76^{a}	6.81^{a}
T_4: 100% RDF + 10% Sagarika	102.84^{ab}	47.09^{ab}	194.13^{a}	0.75^{a}	6.77^{a}
T_5: 100% RDF + 2.5% Sargassum	87.02^{c}	38.23^{c}	176.87^{b}	0.77^{a}	6.8^{a}
T_6: 100% RDF + 5% Sargassum	100.33^{ab}	46.71^{ab}	195.58^{a}	0.75^{a}	6.82^{a}
T_7: 100% RDF + 10% Sargassum	103.70^{a}	48.23^{a}	196.05^{a}	0.75^{a}	6.78^{a}

Means followed by different letters are significantly different by Duncan's Multiple Range Test (DMRT) at $P\leq0.05$

CONCLUSION

Based on the experimental findings, it was observed that the application of the recommended dose of fertilizers (RDF) along with 5 or 10% of either Sagarika or *Sargassum* seaweed extract significantly improved the productivity of rice crop. However, greater economic benefits were observed from the treatment constituting of RDF and 5% *Sargassum* application, and it was closely followed by the treatment with RDF and 10% *Sargassum*. Hence, it can be concluded that the application of 5 or 10% *Sargassum* along with recommended dose of fertilizers significantly improves the productivity and economic returns of traditional rice (Dudheshwar) in the Indian Sundarbans during *kharif* season. The integration of seaweed saps with conventional chemical nutrient management not only enhances crop yield but also contributes to higher profitability for farmers. It is also a researchable issue to study similar experiment with reducing 10, 15 or 20% of chemical fertilizers of K and meet the K supplement *via.,* Sagarika and *Sargassum*. Ultimately, seaweed-based fertilizers may serve as a tool in sustainable nutrient management strategy, as they stimulate plant growth and biochemical activities while supporting the nutritional and economic well-being of the small and marginal farming community.

Table 5. *Production economics of rice (var. Dudheshwar) under different treatments (Pooled data of two years)*

Treatments	Common cost (Rs. ha^{-1})	Treatment cost (Rs. ha^{-1})	Total cost (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs ha^{-1})	BC ratio
T_1: 100% RDF	41258	7782	49040	80220^c	31180^d	1.64^d
T_2: 100% RDF+2.5% Sagarika	41258	14732	55990	94005^b	38015^c	1.68^d
T_3: 100% RDF+5% Sagarika	41258	20982	62240	109349^a	47109^b	1.75^c
T_4: 100% RDF+10% Sagarika	41258	33482	74740	109833^a	35093^c	1.46^e
T_5: 100% RDF+2.5% *Sargassum*	41258	8794.5	50052.5	94283^b	44230.5^b	1.89^b
T_6: 100% RDF+5% *Sargassum*	41258	9107	50365	109591^a	59226^a	2.17^a
T_7: 100% RDF+10% *Sargassum*	41258	9732	50990	110075^a	59085^a	2.15^a

CONFLICTS OF INTEREST

The authors of this article declare that there is no conflict of interest.

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