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Research Article

Aquatic Plant-Based Biostimulants: Comparative Evaluation of Sargassum sp. and Eichhornia crassipes Extracts for Rice Growth Promotion

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Abstract
Aquatic weeds are abundant biomass resources, yet their conversion into compost extracts for rice establishment remains insufficiently evaluated across the transition from seed germination to nursery growth. This study examined compost extracts from Sargassum sp. and water hyacinth (Eichhornia crassipes) as stage-specific nutrient-biostimulant inputs for Oryza sativa L. A randomized block design was used for germination, combining four extract types (biohumic, Sargassum sp., water hyacinth, and their mixture) with four concentrations (25, 50, 75, and 100 mL L-1). Extract chemistry and treatment means were interpreted conservatively because ANOVA did not detect significant treatment effects. The results showed Sargassum sp. extract had higher organic C, C/N ratio, K-equivalent concentration, and pH, whereas water hyacinth had higher N. Biohumic at 25 mL L-1 showed the highest germination means for plumule length, radicle length, leaf number, and fresh mass. The results support a cautious, hypothesis-generating model in which extract performance depends on rice developmental stage. Low-dose humic input appears more suitable for germination, whereas higher-dose aquatic weed extracts may be more useful during nursery growth.

Keywords: Oryza sativa; Sargassum sp.; water hyacinth; compost extract; liquid organic biostimulant

INTRODUCTION

Rice (Oryza sativa L.) establishment is a critical phase in crop production because seed germination, root initiation, early leaf expansion and nursery-stage seedling vigor determine stand uniformity and the capacity of plants to respond to later fertilization. Nitrogen is central to these processes because it contributes to chlorophyll formation, protein synthesis, photosynthetic activity and plant architecture, including root development, leaf expansion, tillering and biomass accumulation (Luo et al., 2020; Qi et al., 2025; Wang et al., 2024). However, fertilizer strategies for rice increasingly need to combine productivity with reduced dependence on mineral fertilizer and improved recycling of organic resources (Barus et al., 2024; Haque et al., 2021; Kaur et al., 2023; Marti-Jerez et al., 2023).

Organic and bio-organic inputs can improve rice growth, nutrient uptake and soil biological activity, but their effects are not universal. Recent studies on liquid organic fertilizers, humic inputs, microbial biostimulants and organic amendments indicate that crop response depends on feedstock chemistry, dose, plant developmental stage and environmental context (Cabrera et al., 2025; Chen et al., 2025; Dwi Nurcahyanti et al., 2024; Iriany et al., 2023; Riddech et al., 2025). For early rice establishment, this conditionality is especially important because germinating seeds are more sensitive than established seedlings to pH, soluble salts, oxygen limitation and potentially phytotoxic dissolved organic compounds.

Aquatic weeds provide a biologically and environmentally relevant feedstock for circular agricultural input development. Sargassum sp. is a brown marine macroalga that contains mineral and carbon-rich biochemical fractions, while water hyacinth (Eichhornia crassipes) is a rapidly proliferating freshwater macrophyte that can accumulate nutrients and generate large unmanaged biomass (Asmara et al., 2020; Begum et al., 2022; Choi et al., 2025; Liu et al., 2025; Zega et al., 2025). Converting these biomass streams into compost extracts may reduce disposal pressure and provide locally available inputs for rice nurseries. Yet the value of such extracts cannot be inferred from nutrient content alone, because seaweed-derived and aquatic-plant-derived products may also contain bioactive or inhibitory organic fractions (Banakar et al., 2022; Banakar et al., 2023; Fitriyah et al., 2022; Senthilkumar et al., 2024; Utomo & Guntoro, 2023; Xie et al., 2021).

Humic inputs provide a useful benchmark for this question. Humic acid and humic-like substances have been associated with improved rice germination, metabolic adjustment, rhizosphere nutrient distribution and field performance, although their effects also depend on stress context and formulation (Adhikari et al., 2023; Canellas et al., 2022; Ibraheem et al., 2023; Indriani et al., 2022; Izquierdo et al., 2025; Ji et al., 2024; Minhas et al., 2024). Comparing aquatic weed extracts with a humic benchmark therefore makes it possible to ask whether these local biomass-derived extracts act similarly across establishment stages or whether their usefulness is stage-dependent.

The research gap addressed here is not simply whether aquatic weed biomass contains nutrients, but whether compost extracts from contrasting aquatic weeds show different response profiles during seed germination and seedling growth. The study was designed to evaluate nutrient composition, germination response and nursery-stage growth response of rice exposed to biohumic, Sargassum sp., water hyacinth and combined extracts. In response to reviewer concerns, the present revised manuscript frames the results as a preliminary stage-specific response model rather than as definitive evidence of treatment superiority, because the available ANOVA results did not indicate statistically significant treatment effects.

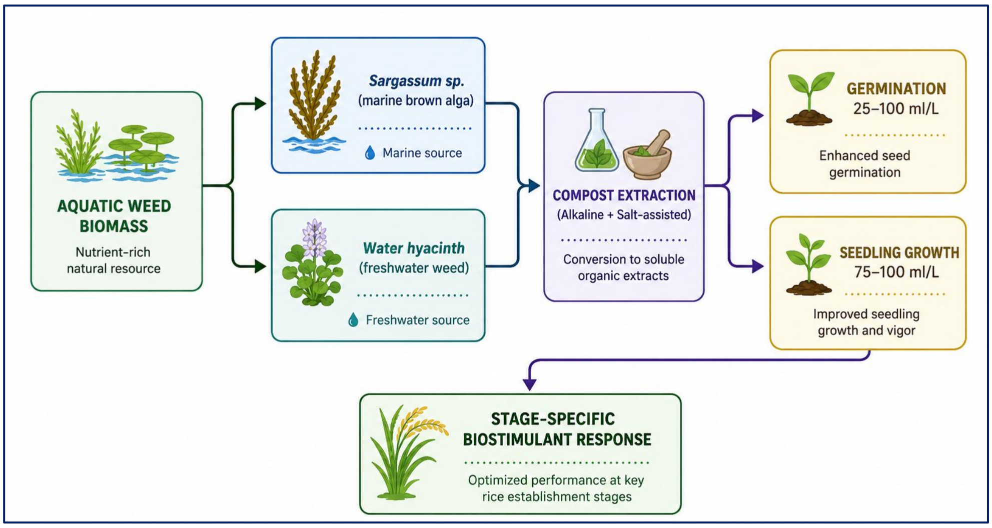

Figure 1. Experimental logic linking aquatic weed biomass, compost extraction, concentration gradient and stage-specific rice establishment responses

RESEARCH METHOD

Study site and biological material

The experiment was conducted at the Integrated Laboratory of the Faculty of Agriculture, Animal Husbandry and Fisheries, Universitas Muhammadiyah Parepare, Indonesia, from July 2025 to April 2026. The test crop was rice (Oryza sativa L.) cultivar Inpari. The aquatic materials were composted Sargassum sp. and composted water hyacinth (Eichhornia crassipes), representing contrasting marine and freshwater weed biomass sources. Biohumic was included as a reference organic biostimulant to compare aquatic weed extracts with a humic-type benchmark.

Compost extract preparation

Composted aquatic weed material was sun-dried, ground and sieved to obtain a fine powder. For each extract, 100 g of powdered compost was mixed with 1000 mL distilled water. NaOH was dissolved into the aqueous phase before the compost powder was added, and the suspension was homogenized using a magnetic stirrer for 2 h. The suspension was allowed to stand for 24 h, NaCl solution was added, and the mixture was left overnight to improve separation. The liquid fraction was separated from sediment, centrifuged at 4000 rpm for 15 min, and filtered through Whatman 42 paper to obtain a clarified extract. The procedure was intended to recover soluble nutrient and humic-like fractions while removing coarse particles that could interfere with seed contact and oxygen diffusion (Du et al., 2023; Kurniawan et al., 2024; Ros et al., 2020).

Experimental design

The germination experiment used a factorial randomized block design with two factors. The first factor was extract type: biohumic (N1), Sargassum sp. extract (N2), water hyacinth extract (N3), and combined Sargassum sp. + water hyacinth extract (N4). The second factor was extract concentration: 25, 50, 75 and 100 mL L-1 (K1-K4). The 4 x 4 factorial structure produced 16 treatment combinations arranged in three blocks, giving 48 experimental units.

Measurements

During germination, treated seeds were placed on merang paper and evaluated at week 5. Plumule length was measured from the shoot base to the highest leaf tip, radicle length from the root base to the longest root tip, and root and leaf numbers were counted directly. Fresh mass was recorded immediately after harvest, and dry mass was recorded after oven drying. During seedling growth, plant height, leaf number, tiller number, root length, root number, fresh mass and dry mass were evaluated at week 8. These traits describe shoot emergence, root initiation, vegetative vigor, water accumulation and dry matter formation.

Chemical analysis and terminology

Extract chemistry was assessed for organic C, N, C/N ratio, P, K and pH. The source dataset reported phosphate and potassium oxide equivalent values; these were converted to elemental P and K equivalents for journal terminology using standard conversion factors (P = P2O5 x 0.4364; K = K2O x 0.8301). This terminology follows the Plant and Soil preference for elemental nutrient reporting. Because additional indicators such as electrical conductivity, nitrate, ammonium, dissolved organic C, total dissolved solids and phenolics were not measured, mechanistic interpretation is explicitly treated as provisional.

Statistical interpretation

The source analysis used ANOVA followed by a post hoc test when appropriate, and reported that treatment effects were not statistically significant for the measured variables. Complete raw replicate-level data, F-values, degrees of freedom, p-values and standard errors were not available in the manuscript file used for revision. Therefore, the revised Results section avoids claims of statistical superiority and presents treatment means as descriptive patterns only. Figures based on normalized values are intended to support visual synthesis and do not imply significant differences. This cautious reporting directly addresses the reviewer concern that mean-based contrasts could otherwise overstate the strength of the evidence.

RESULTS AND DISCUSSION

Extract chemistry

The two aquatic weed extracts differed in chemical profile (Table 1). Sargassum sp. extract had higher organic C, C/N ratio, K-equivalent concentration and pH. Water hyacinth extract had higher N, whereas the converted P-equivalent concentration was similar for both extracts. These differences indicate that Sargassum sp. contributed a more carbon-rich and K-associated extract, while water hyacinth provided a relatively N-richer and lower-C/N extract. Both extracts were alkaline, which may have influenced seed-solution interactions and nutrient availability.

Table 1. Chemical composition of Sargassum sp. and water hyacinth compost extracts used in the rice establishment experiment.

Extract	Organic C (%)	N (%)	C/N ratio	P equivalent (%)	K equivalent (%)	pH
Sargassum sp.	0.58	0.07	8.15	0.0105	0.0232	8.5
Water hyacinth	0.27	0.09	3.07	0.0105	0.0158	8.4

Note: P and K are reported as elemental equivalents converted from the source oxide-equivalent values to align with Plant and Soil terminology.

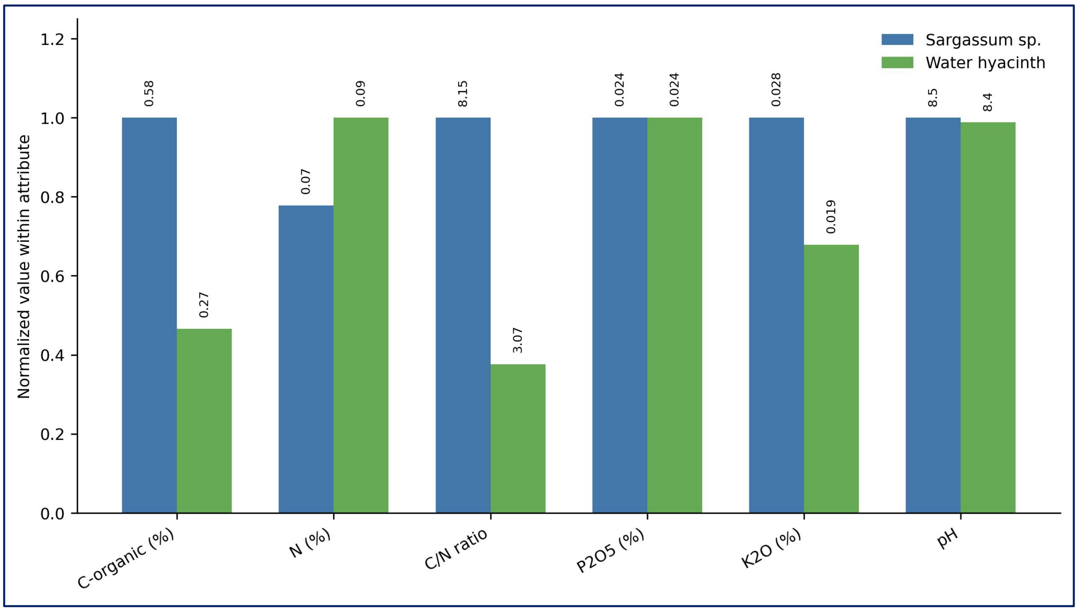

Figure 2. Relative nutrient profile of *Sargassum sp.* and water hyacinth extracts. Values are normalized within each attribute; raw values in the figure correspond to the source extract-chemistry dataset

Germination response

ANOVA did not detect significant treatment effects for germination traits. Nevertheless, the treatment means showed a consistent descriptive pattern. Biohumic at 25 mL L-1 (N1K1) had the highest mean plumule length, radicle length, leaf number and fresh mass, while biohumic at 25 and 50 mL L-1 showed the highest mean root number. Dry mass reached the same maximum mean value in several treatments, including low-dose biohumic, low-dose Sargassum sp. and combined extract treatments at 75 and 100 mL L-1. Water hyacinth at 75 mL L-1 (N3K3) had zero mean values for all germination traits. This pattern is reported descriptively and should not be interpreted as statistically proven toxicity.

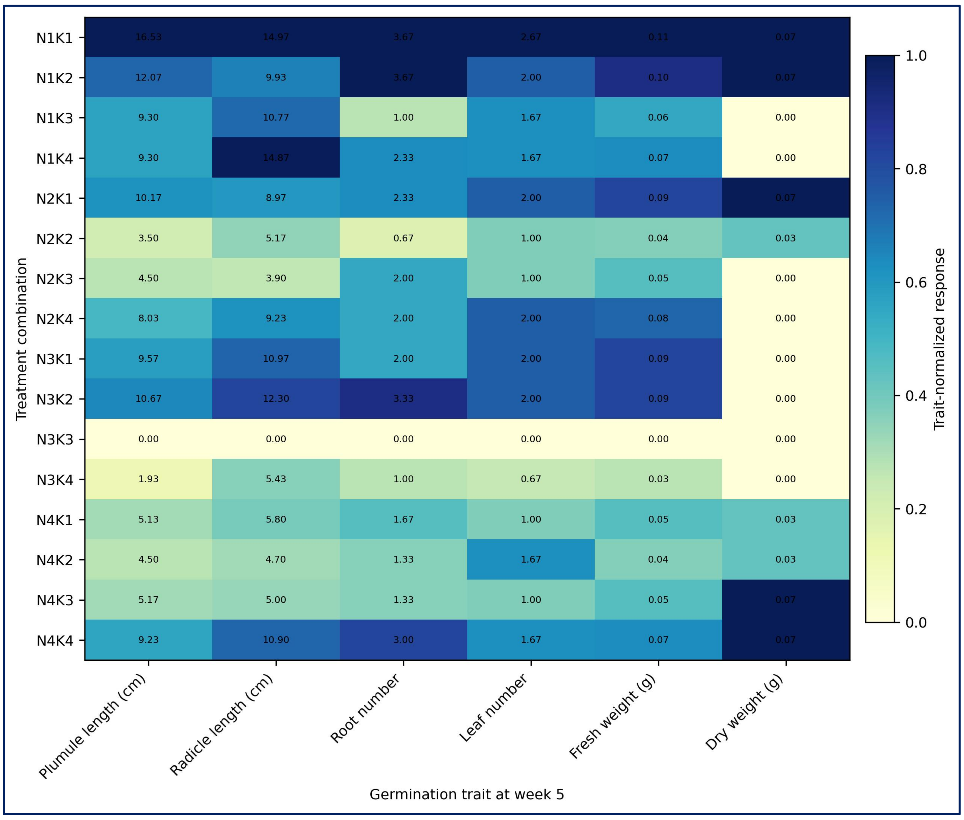

Figure 3. Mean germination responses of rice at week 5 under four extract types and four concentrations. Cell values are treatment means; color intensity indicates trait-normalized descriptive response and does not imply statistical significance.

Descriptive synthesis

The descriptive synthesis suggests a stage-dependent response pattern. During germination, low-dose biohumic showed the most favorable mean profile. During nursery growth, higher-dose aquatic weed extracts showed the most favorable mean profile, with Sargassum sp. associated mainly with height and root number and water hyacinth associated mainly with leaf production, tillering and biomass. Because statistical significance was not detected, this pattern is best interpreted as a preliminary response model that should guide future dose-response and mechanistic experiments rather than as an agronomic recommendation.

Table 2. Highest and lowest treatment means for rice germination responses

Stage	Variable	Highest mean treatment	Highest value	Lowest mean treatment	Lowest value	Inference
Germination	Plumule length (cm)	N1K1	16.53	N3K3	0.00	ANOVA not significant
Germination	Radicle length (cm)	N1K1	14.97	N3K3	0.00	ANOVA not significant
Germination	Root number	N1K1/N1K2	3.67	N3K3	0.00	ANOVA not significant
Germination	Leaf number	N1K1	2.67	N3K3	0.00	ANOVA not significant
Germination	Fresh mass (g)	N1K1	0.11	N3K3	0.00	ANOVA not significant
Germination	Dry mass (g)	Multiple treatments	0.07	Multiple treatments	0.00	ANOVA not significant

Note: N1 = biohumic; N2 = Sargassum sp.; N3 = water hyacinth; N4 = Sargassum sp. + water hyacinth. K1-K4 = 25, 50, 75 and 100 mL L-1. Values are descriptive treatment means.

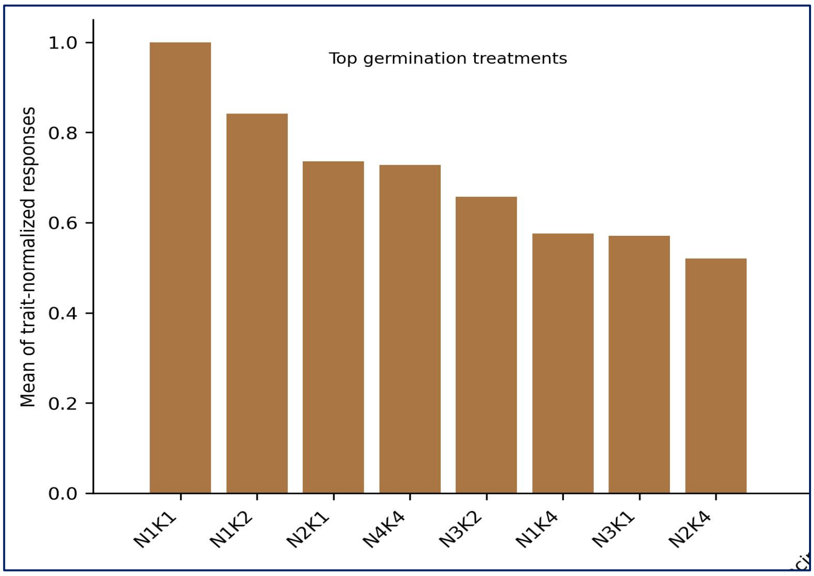

Figure 5. Descriptive integrated vigor indices for germination and seedling growth. The indices are unweighted means of trait-normalized responses and are provided only as exploratory synthesis.

Discussion

Stage-specificity rather than treatment superiority

The strongest contribution of this study is the separation of germination from seedling growth. Rice seeds and established seedlings differ in physiology: germination depends on water imbibition, reserve mobilization, oxygen availability and early hormonal regulation, whereas seedling growth increasingly depends on photosynthesis, nutrient uptake, root branching and tiller initiation (Dai et al., 2025; Ishaq et al., 2025; Linda et al., 2024; Monajjem et al., 2023; Vaishnavi et al., 2024). The observed mean reversal between low-dose biohumic at germination and higher-dose aquatic weed extracts at seedling stage is therefore biologically plausible, but it remains descriptive because the treatment effects were not statistically significant.

Low-dose humic input during germination

Biohumic at 25 mL L-1 showed the highest mean performance for several germination traits. This agrees with the broader literature indicating that humic substances can influence early root development, nutrient availability and rice metabolic adjustment (Canellas et al., 2022; Ibraheem et al., 2023; Indriani et al., 2022; Ji et al., 2024). The response was not linear with concentration, supporting the view that seed-stage biostimulant application requires careful dilution. Higher concentrations may alter water potential, increase dissolved solids or expose seeds to organic fractions that are not favorable during imbibition. Because electrical conductivity and osmotic potential were not measured, this explanation should be treated as a proposed mechanism rather than a demonstrated cause.

Water hyacinth caution at the seed stage

Water hyacinth at 75 mL L-1 had the weakest germination mean profile despite its higher N content. This contrast shows why nutrient content alone is insufficient to predict early seed response. Water hyacinth biomass can improve soil and plant properties after composting, but plant extracts may also contain bioactive fractions with inhibitory potential if decomposition or dilution is unsuitable (Begum et al., 2022; Guidoni et al., 2021; Rosawanti, 2019; Utomo & Guntoro, 2023; Zega et al., 2025). Future work should include a standard germination index, electrical conductivity, total dissolved solids, pH, total phenolics and phytotoxicity screening before recommending direct seed exposure.

Implications for circular rice nursery management

Aquatic weed biomass can be considered a candidate bioresource for circular rice nursery inputs, but formulation science is essential. The present results do not support a single universal concentration. Instead, they support a cautious two-step hypothesis: a low-dose humic or highly diluted extract treatment for germination, followed by stronger Sargassum sp. or water hyacinth extract during nursery growth. This approach aligns with integrated nutrient-management and waste-valorization studies showing that organic inputs can improve rice performance when feedstock, dose and crop demand are synchronized (Bagheri Novair et al., 2024; Barus et al., 2024; Cabrera et al., 2025; Consorti et al., 2025; Dwi Nurcahyanti et al., 2024; Haque et al., 2021; Kaur et al., 2023; Kanga et al., 2026; Kumar et al., 2024; Marti-Jerez et al., 2023; Prasedya et al., 2023; Riddech et al., 2025; Rozen et al., 2024; Selvam & Kumar, 2022; Thaimei et al., 2025; Umamaheswari & Shanthakumar, 2021; Zhang et al., 2025).

CONCLUSION

This study evaluated compost extracts from Sargassum sp. and water hyacinth as potential inputs for rice establishment. Sargassum sp. extract had higher organic C, C/N ratio, K-equivalent concentration and pH, while water hyacinth extract had higher N. ANOVA did not detect significant treatment effects; therefore, the findings should be interpreted as descriptive and hypothesis-generating. The highest germination means were associated mainly with biohumic at 25 mL L-1, whereas the highest seedling-growth means shifted toward 100 mL L-1 aquatic weed extracts. Sargassum sp. at 100 mL L-1 showed the highest mean plant height and root number, while water hyacinth at 100 mL L-1 showed the highest mean leaf number, tiller number, root length and biomass.

The revised interpretation is that aquatic weed compost extracts are better considered stage-sensitive nutrient-biostimulant candidates than direct fertilizer substitutes. Low-dose humic input may be more suitable for seed germination, whereas higher-dose aquatic weed extracts may be more useful for nursery-stage vegetative development. These tendencies require validation with complete replicate-level statistics, improved extract characterization and field-based seedling-to-yield assessment before agronomic recommendation.

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AUTHOR CONTRIBUTIONS

Conceptualization, I.R; Methodology, I.R.; Investigation, J.J.; Data Curation, I.R, H.A., and Y.R.; Writing-Original Draft Preparation, I.R; Writing Review & Editing, H.A. I.R, S.Z, and Y.R.; Supervision, I.R. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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