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ORIGINAL ARTICLE

Relationship between Yield and Yield Attributing Parameters of Rice (*Oryza sativa* L.) Crop as Affected by the Bay Leaf (*Laurus nobilis* L.), Potato (*Solanum tuberosum* L.) Peel and Banana (*Musa species*) Peel Extracts under Higher Iron and Manganese in Acid Soil Conditions

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ABSTRACT

Introduction: Soil acidity is one of the environment driven factors impacting growth and productivity of rice crop. Because, leaching of base cations that causes soil acidic (lower pH), and enrichments of mineralized ions like iron and manganese in calcifuges (acid loving), mesophytic plants. Higher rainfall in summer especially in tropic and subtropics is influenced by elevated temperature due to anthropogenic activities causing climate change.

Mathodology: Two laboratory experiments were carried out to investigate the effects of locally available bio-inputs viz., bay leaf, potato peel, and banana peel extracts on the physiological performance of some upland (Ahu) rice crop (varieties: Inglongkiri, Dehangi (tolerant), Lachit (susceptible), and Luit) under higher iron and manganese in acid soil conditions during the Autumn season (March-September, 2024). In the experiments, the treatments were viz.,100 ppm FeSO4 or 200 ppm Mn as $MnSO_4.3H_2O$ as basal at vegetative stage (control), was kept constant. Along with this, treatments comprised of root dip before transplanting and foliar spray with bay leaf, banana peel and potato peel extracts (10% (w/v) separately at 20 days after transplanting. Natural soil without any treatment served as an absolute control. ***The Pearson correlation coefficient (r)*** was used to measure the strengh and direction of the linear relationship between two parametrs ranging from -1 to 1.

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Results: The studies revealed that seed yield was positively correlated with, panicle weight, panicle number per plant, seeds per panicle, test weight, HD grains, Economic yield, Biological yield, Grain Harvest Index under higher iron condition. In the other study, the application of 200 ppm of $MnSO_4$ supplemented with aqueous bay leaf extract (10 g/100 mL) was found to be the most effective under higher manganese condition. Correlation analysis further revealed that economic yield had positive associations with panicle weight, number of panicles per plant, seeds per panicle, test weight, percentage of high-density grains, economic yield, biological yield, and grain harvest index but negatively correlated with sterility percentage.

Conclusion: Among the treatments, bay leaf extract was the best and among the varieties, Dehangi consistently outperformed the other rice varieties under study ahhering the better physiological, biochemical, and yield traits.

KEYWORDS

• Bay Leaf • Banana Peel • Iron • Manganese • Potato Peel • Rice

INTRODUCTION

Rice is one of the staple food crops in Assam grown as kharif (70%), Rabi (upland) 23% and Boro (7%) covering 2.54 million hectares. The higher iron content in the acid soil (80% of geographical area i.e. 25 mha) of the region is one of the factors for lower productivity (<3tha^{-1}) of the traditional rice genotypes. Moreover, The Northeast India has been experiencing an increase in temperature and rainy days over the years **(Deka *et al.*, 2009)**. Climate variability is one of the major sources of risk for farmers who depend on crop production (De and Bodosa. 2015; Nath and Deka 2010). The high rainfall (>2000 mm) makes the soil acidic in nature (pH<5.0) due to leaching of basic cations (Mandal, 1995; **Asfika** *et al.,* **2017;** Mandal *et al.*, 2019). So, the ground water contains higher iron (0.25 - 67.0 ppm), where it's adsorption by the plant roots, enriches the concentration of iron in plants. The toxicity of iron is diagnoised as potassium deficiency (at 150-450 ppm), yellowing of green leaves (at 350-450 ppm), dark brown or bronze spots (at 450-780 ppm) and plant lethality at >800 ppm iron in soil (Baruah *et al.,* 1983; Bora and Borkakati, 1997). Although iron toxicity could be lessened by broadcasting potassium fertilizer (Singh and Singh, 1987), managing water (Borah and Nath, 1979), appliying growth hormones, organic acids, coconut milk, and varietal sorting (Bey *et al.,* 2022), applying rice husk and bamboo biochar to soil for adosrption of iron (Laxmanarayanan *et al.,* 2026), little is known about its amelioration by the extracts of bio-inputs viz., bay leaf, banana peel and potato peel... Manganese (Mn) is a vital micronutrient that supports numerous metabolic functions within plant cell organelles. However, when present beyond its threshold level, Mn disrupts normal biochemical activities and becomes toxic, particularly in plants grown on acidic soils (Alejandro *et al*., 2020). Excess Mn accumulation can lead to visual symptoms such as inter veinal or marginal chlorosis and necrotic spotting on leaves (Mora *et al*., 2009). Elevated Mn concentrations also impair photosynthetic efficiency by destabilizing pigments and reducing carbon assimilation (Hauck *et al*., 2003). In the acidic soils of Assam, Mn levels typically range between 3 and 52 ppm, exceeding the critical soil limit of 2-3 ppm. In plants, the corresponding toxicity threshold is around 15-20 ppm on a dry weight basis (Basumatary *et al*., 2014).

Bay leaf contains important nutrients (Batool *et al.,* 2020; Cakmak *et al*., 2013) viz., Ca (377mg/100g), P (112mg/100g), K (550mg/100g), Fe (45mg/100g), Cu (0.63mg/100g), Mg (112mg/100g), Mn (7.313mg/100g), and Zn (2.90mg/100g). A medium-sized banana has 450- 467mg of potassium. Banana peel contains dietary fiber, proteins, essential amino acids, polyunsaturated fatty acids, and potassium (Emaga, *et al*., 2007), macro and micronutrients, phenolic compounds, fat, and fiber (Nguyen, *et al*.,2003; Sidhu and Zafar, 2018). The minerals with the highest concentrations in raw potato (Burton, 1989; Buckenhüskes, 2005, Karan, 2023) are potassium (564mg/g f.w.), phosphorus (30-60mg/g f.w.), and calcium (6-18mg/g f.w.). Potatoes also contain antioxidants (FAO, 2008, Bharali *et al.,* 2016). No noteworthy information on how to reduce iron and manganese toxicity using locally available bay leaf, banana and potato peels are available yet.

MATERIALS AND METHOD

The laboratory experiments were carried out in the department of Plant Physiology of Assam Agricultural University (topography: 26° 45′ N Latitude, 94° 12′ E Longitude, 87 meters above mean sea level), during March-September of 2024. Four upland (Ahu) cultivars (Inglongkiri, Dehangi (tolerant), Lachit (susceptible), and Luit) were collected from the Assam Rice Research Institute, Titabor and KVK, Diphu. The cultivars were planted in pots using a mixture of sand and loam soil. Before sowing the seeds in the pots, the soil was well soaked and combined with farm yard manure in a 50:50 ratio. 25 to 30 days old seedlings were transplanted into the pots again. NPK Fertilizers were applied @ 60:40:40 kg/ha (10.7 g of muriate of potash (MOP) as a basal application, 80.3 g of single super phosphate (SSP), and 20.9 g of urea (the first dosage of nitrogen). The calculations for the amount of fertilizers required were based on the volume of soil per hectare. Water level (2–3 cm) had been maintained throughout the period from transplanting to a week before harvest. Intercultural operations including weeding and prophylactic measures against insect pests were taken up when necessary.

In case of the *first experiment*, Iron solution of 100ppm strength was prepared using $FeSO_4$ (MW: 151.908 g). As 36.2 g of Fe is present in 100 g of $FeSO_4$, 276 mg of $FeSO_4$ was dissolved in 1000 ml of distilled water to create a 100 ppm solution. Each pot received a basal application of the solutions throughout the rice crop's vegetative state (10 days prior to transplanting). In the *second experiment*, Mn was applied in the form of $MnSO_4.3H_2O$ (MW:159.08g). In 100g $MnSO_4.3H_2O$, 32.503 g of Mn is present. Therefore, in preparation of 200 ppm Manganese solution, 615.3 mg of $MnSO_4.3H_2O$ was dissolved in 1000 ml distilled water. The solutions were applied to each pot (1000 ml) in the form of basal application 10 days before transplanting of the rice crop. So, the total amount of solution received by each variety under each treatment was 1000 ml.

Ripe bananas, matured bay leaves, and harvested potatoes were collected from the neighborhood market, cleaned, peeled off, and dried at 55°C in a hot air oven. In order to create aqueous potato peel extracts, 10 g of dried and ground potato peel were combined with 100 ml of distilled water, and then the mixture was heated to 50°C for 60 minutes in a thermostatic bath. The extracts were cooled, filtered (with a pore size of 0.45 mm), and kept in dark flasks at 4°C (Gebre Christos, *et al*., 2020). Before being transplanted, root dip treatments (RDT) including extracts of banana, potato, and bay leaf were applied to the 30-day-old seedlings (100 seedlings per liter solution).

Morpho-physiological parameters viz., specific leaf weight (SLW)**:** mg cm-2 **(**Amanullah, 2015), plant height, shoot biomass (g plant-1)**,** number of tillers per plant, number of effective tillers per plant, number of leaves per plant, toot biomass at harvest, yield and yield attributing parameters viz., panicle length, panicle weight, panicle number per plant, number of seeds per panicle, 'Test' weight, HD grains and sterility per cent (Provinch, 1967), economic yield, biological yield and HI at harvest were recorded following standard protocol (Bey *et al.,* 2026a). The biochemical indices used for measuring the response score of the varieties were estimated as per the standard procedures as mentioned by Bey *et al.,* (2026) and Das, S (2025).

Pearson's equation was used to assess the magnitude and direction of relationships through simple correlation. The p-value was used to determine statistical significance.*&** at 5% & 1% respectively (Panse and Sukhatme, 1967).

RESULTS AND DISCUSSION

Correlation studies between economic yield and yield-attributing parameters under different stress conditions are frequently used to link physiological parameters obtained at different stages for crop genotype identification (Fageria *et al*., 2008). Grain yield and 1000 grain weight were found to be positively related in wheat (Virk and Anand 1970). Sandhu and Mangat (1985), Eunus *et al*. (1986), Chowdhary *et al*. (1991), Belay *et al*. (1993), and Aycecik and Yildirim (2006) all discovered positive connections between grain yield and the number of grains per spike, plant height, and 1000 grain weight. Wheat grain yield is primarily determined by yield parameters such as tillers per plant, grains per spike, and grain weight per thousand (Gupta *et al*. 1999; Chowdhury *et al*. 2000).

In the first experiment, results on correlation coefficient **(Table 1)** revealed that panicle length is positively correlated with panicle weight (.726**), panicle number per plant (.756**), no. of seeds per panicle (.834**), test weight (.901**), HD grains (.866**), economic yield (.979**), biological yield (.935**), grain harvest index (.837**) but it's negatively correlated with sterility percent (-.780**). Panicle weight is positively correlated with panicle number per plant (.916**), number of seeds per panicle (.820**), test weight (.892**), HD grains (.695**), economic yield (.719**), biological yield (.805**), grain harvest index (.865**) but it is negatively correlated sterility percent (-.746**). Panicle number per plant is positively correlated with number of seeds per panicle (.847**), test weight (.921**), HD grains (.736**), economic yield (.782**), biological yield (.820**), Grain harvest index (.915**) but is negatively correlated with sterility percent (-.819**). Number of seeds per panicle is positively correlated with test weight (.867**), HD grains (.848**), economic yield (.841**), biological yield (.822**), Grain Harvest index (.883**) but negatively correlated with grain sterility percent (-.851**). Test weight is positively correlated with HD grains (.807**), economic yield (.896**), biological yield (.925**), Grain harvest index (.912**), but it is negatively correlated with sterility percent (-.824**). HD grains is negatively correlated with sterility percent (-.758**) but positively correlated with economic yield (.846**), biological yield (.888**) and grain harvest index (.840**). Sterility percent is negatively correlated with economic yield (-.805**), biological yield (-.754**) and grain harvest index (-.819**). Economic yield is positively correlated with biological yield (.893**) and grain harvest index (.834**). Biological yield is positively correlated with grain harvest index (.889**). Among the varieties, the highest response score was observed in the variety Dehangi (23), followed by Lachit (04). Varieties Inglongkiri and Luit scored 0. Among the treatments, treatment with 100 ppm FeSO4 plus aqueous bay leaf (10 g in 10ml) recorded the highest response card (22), followed by the treatment with 100 ppm $FeSO_4$ **(Table 2a)**.

Table 1: Relationship between yield and yield attributing parameters under higher iron conditions

	Panicle length	Panicle weight	Panicle no, per plant	No. of seeds per panicle	Test weight	HD Grains	Sterility percent	Economic yield	Biological yield	Grain harvest index
Panicle length	1									
Panicle weight	.726**	1								
Panicle no. per plant	.756**	.916**	1							
No. of seeds per panicle	.834**	.820**	.847**	1						
Test weight	.901**	.892**	.921**	.867**	1					
HD grains	.866**	.695**	.736**	.848**	.807**	1				
Sterility percent	-.780**	-.746**	-.819**	-.851**	-.824**	-.758**	1			
Economic yield	.979**	.719**	.782**	.841**	.896**	.846**	-.805**	1		
Biological yield	.935**	.805**	.820**	.822**	.925**	.888**	-.754**	.893**	1	
Grain Harvest index	.837**	.865**	.915**	.883**	.912**	.840**	-.819**	.834**	.889**	1

Table 2 (a): The highest response traits of the varieties at maximum tillering toheading (70DAS) and harvest stages of rice crop

Stages	**Maximum tillering to heading andharvest stages**			
Traits / **Varieties**	**Inglongkiri**	**Dehangi**	**Lachit**	**Luit**
SLW at MT		✓		
SLW at heading stage		✓		
Plant height		✓		
Shoot biomass		✓		
No. of tillers		✓		
No. of effective tillers		✓		
No. of Leaves		✓		
Root biomass		✓		
Chlorophyll Content at MT		✓		
Chlorophyll content at heading stage		✓		
NR activity at MT		✓		
NR activity at heading stage		✓		
Carbohydrate Content		✓		
Cation Leakage at MT		✓		
Cation Leakage at Heading stage		✓		
Lipid peroxidation at MT		✓		
Lipid peroxidation at heading stage		✓		
Panicle length		✓		
Panicle weight		✓		
Panicle number per plant		✓		
No. of seeds per panicle		✓		
Test weight		✓		
HD grains		✓		
Sterility Per cent		✓		
Economic Yield		✓		
Biological Yield		✓		
Grain Harvest Index		✓		
Total response score of the varieties at maximum tillering to Heading stages (70DAS) and harvest stage	00	23	04	00

Dehangi (Iron tolerant) showed the highest response score (23) irrespective of the treatments. On the other hand, 100 ppm FeSO4 plus aqueous bay leaf (10 g in 100 ml) was the treatment showing the highest response (22) irrespective of the varieties **(Table 2b).** Bay leaf by evidence in this study helped in proliferation of roots as root biomass was increased significantly for absorption of nutrients for producing more assimilates (viz., Carbohydrates) profoundly and increased all other physiological parameters.

Table 2 (b): Response scores of the treatment at maximum tillering (MT) to Heading (70DAS) and harvest stages of rice crop under higher iron condition

Traits \ Treatments	100 ppm $FeSO_4$	100 ppm $FeSO_4$ plus aqueous Bay leaf (10 g in 100 ml)	100 ppm $FeSO_4$ Plus aqueous Banana peel (10 g in 100 ml)	100 ppm $FeSO_4$ plus aqueous Potato peel (10 g in 100 ml)	Natural soil
SLW at MT		✓			
SLW at heading stage		✓			
Plant Height at harvest		✓			
Shoot Biomass at harvest		✓			
No. of tillers at MT		✓			
No. of effective tillers at MT		✓			
No. of leaves at MT		✓			
Root biomass at harvest		✓			
Total chlorophyll content at MT		✓			
Total chlorophyll content at headingstage		✓			
NR activity at MT		✓			
NR activity at heading stage		✓			
Carbohydrate content at harvest		✓			
Cation leakage at MT	✓				
Cation leakage at heading stage	✓				

In the second experiment, the correlation analysis **(Table 3)** highlights significant interrelationships among key yield-related traits. Panicle length showed strong positive correlations with panicle weight (r = .715****), panicle number per plant (r = 0. .745**), number of seeds per panicle (r = 0. 823**), test weight (r = 0. 901**), HD grains (r = 0. 855**), economic yield (r = 0. 968**), biological yield (r = 0. 924**), and grain harvest index (r = 0. 826**), while displaying a significant negative correlation with sterility percentage (r = -0. 770**). Similarly, panicle weight was positively correlated with panicle number per plant (r = 0.906**), number of seeds per panicle (r = 0. 810**), test weight (r = 0. 881**), HD grains (r = 0.685**), economic yield (r = 0.708**), biological yield (r = 0.804**), and grain harvest index (r = 0. 854**), but negatively correlated with sterility percentage (r = -0.736**). Panicle number per plant exhibited strong positive correlations with number of seeds per panicle (r = 0. 836**), test weight (r = 0.910**), HD grains (r = 0.725**), economic yield (r = 0.771**), biological yield (r = 0.810**), and grain harvest index (r = 0.904**), while also negatively correlating with sterility percentage (r = -0.808**). The number of seeds per panicle showed significant positive correlations with test weight (r = 0.856**), HD grains (r = 0.847**), economic yield (r = 0.914**), biological yield (r = 0.811**), and grain harvest index (r = 0.872**), and a negative correlation with sterility percentage (r = -0. 841**). Test weight demonstrated strong positive associations with HD grains (r = 0.806**), economic yield (r = 0.885**), biological yield (r = 0.914**), and grain harvest index (r = 0.901**), and a significant negative relationship with sterility percentage (r = -0.813**). HD grains were positively correlated with economic yield (r = 0.835**), biological yield (r = 0.877**), and grain harvest index (r = 0.830**), while negatively correlated with sterility percentage (r = -0.747**).

Table 3: Relationship between yield and yield attributing parameters under higher Maganese in acid soil condition

	Panicle length	Panicle weight	Panicle no, per plant	No. of seeds per panicle	Test weight	HD grains	Sterility percent	Economic yield	Biological yield	Grain harvest index
Panicle length	1									
Panicle weight	.715**	1								
Panicle no, per plant	.745**	.906**	1							
No. of seeds per panicle	.823**	.810**	.836**	1						
Test weight	.901**	.881**	.910**	.856**	1					
HD grains	.855**	.685**	.725**	.847**	.806**	1				
Sterility percent	-.770**	-.736**	-.808**	-.841**	-.813**	-.747**	1			
Economic yield	.968**	.708**	.771**	.914**	.885**	.835**	-.805**	1		
Biological yield	.924**	.804**	.810**	.811**	.914**	.877**	-.743**	.883**	1	
Grain harvest index	.826**	.854**	.904**	.872**	.901**	.830**	-.809**	.823**	.878**	1

Moreover, sterility percentage showed a strong inverse correlation with economic yield (r = -0.805**), biological yield (r = -0.743**), and grain harvest index (r = -0.808**). Economic yield was positively associated with biological yield (r = 0.882**) and grain harvest index (r = 0.823**), and biological yield itself was positively correlated with grain harvest index (r = 0.878**). Sterility percent is negatively correlated with economic yield (-.804**), biological yield (0.713**) and grain harvest index (-.808**). Economic yield is positively correlated with biological yield (0.882**) and grain harvest index (0.823**). Biological yield is positively correlated with grain harvest index (0.878**). Among the varieties, the Highest response card was observed in the variety Dehangi (23), followed by Lachit (05). Varieties Inglongkiri and Luit scored 0. Among the treatments, treatment with 200 ppm MnSO4 Plus aqueous Bay leaf (10 g in 100 ml) recorded the highest response score (22), followed by the treatment with 200 ppm $MnSO_4$ **(Table 4a).**

Table 4(a): The highest response traits of the varieties at maximum tillering to heading (70 DAS) and harvest stages of the rice crop

Stages	Maximum tillering to heading and harvest stages			
Varieties \ Traits	Inglongkiri	Dehangi	Lachit	Luit
SLW at MT		✓		
SLW at heading stage		✓		
Plant height		✓		
Shoot biomass		✓		
No. of tillers		✓		
No. of effective tillers		✓		
No. of Leaves		✓		
Root biomass		✓		
Chlorophyll Content at MT		✓		
Chlorophyll content at heading stage		✓		
NR activity at MT		✓		

table cont....

Stages	Maximum tillering to heading and harvest stages			
NR activity at heading stage		✓		
Manganese Content at harvest			✓	
Carbohydrate Content at harvest		✓		
Cation Leakage at MT			✓	
Cation Leakage at Heading stage			✓	
Lipid peroxidation at MT			✓	
Lipid peroxidation at heading stage			✓	
Panicle length		✓		
Panicle weight		✓		
Panicle number per plant		✓		
No. of seeds per panicle		✓		
Test weight		✓		
HD grains		✓		
Sterility Percent		✓		
Economic Yield		✓		
Biological Yield		✓		
Grain Harvest Index		✓		
Total response score of the varieties at maximum tillering to Heading stages (70DAS) and harvest stage	00	23	05	00

Based on morphological, physiological, biochemical, and yield-attributing traits, Dehangi consistently showed manganese tolerance, the strongest overall performance with a top response score of 23, regardless of the treatment used. Interestingly, across all varieties, the combination of 200 ppm $MnSO_4$ and an aqueous Bay leaf extract (10 g in 100 ml water) yielded the next highest response score of 22 **(Table 4b)**. According to the findings, bay leaf played a significant role in promoting root growth, noticeably boosting root biomass, which in turn improved nutrient uptake and the production of carbohydrates. This led to improvements across nearly all of the physiological traits.

Table 4(b): Response scores of the treatment at maximum tillering (MT) to Heading (70 DAS) and harvest stages of rice crop

Treatments / Variety	200ppm $MnSO_4$ (control)	200 ppm $MnSO_4$ + aqueous Bay leaf (10 g in 100 ml)	200ppm $MnSO_4$ + aqueous Banana peel (10 g in 100 ml)	200 ppm $MnSO_4$ + aqueous Potato peel (10 g in 100 ml)	Natural soil
SLW at MT		✓			
SLW at heading stage		✓			
Plant Height at harvest		✓			
Shoot Biomass at harvest		✓			
No. of tillers at MT		✓			
No. of effective tillers at MT		✓			
No. of leaves at MT		✓			

table cont....

Treatments / **Variety**	**200ppm $MnSO_4$ (control)**	**200 ppm $MnSO_4$ + aqueous Bay leaf (10 g in 100 ml)**	**200ppm $MnSO_4$ + aqueous Banana peel (10 g in 100 ml)**	**200 ppm $MnSO_4$ + aqueous Potato peel (10 g in 100 ml)**	**Natural soil**
Root biomass at harvest		✓			
Total chlorophyll content at MT		✓			
Total chlorophyll content at heading stage		✓			
NR activity at MT		✓			
NR activity at heading stage		✓			
Manganese content at harvest	✓				
Carbohydrate content at harvest		✓			
Cation leakage at MT	✓				
Cation leakage at heading stage	✓				
Lipid Peroxidation at MT	✓				
Lipid Peroxidation at heading	✓				
Panicle length		✓			
Panicle Weight		✓			
Panicle No. per plant		✓			
No. of seeds per panicle		✓			
Test weight		✓			
HD grains		✓			
Sterility percent	✓				
Economic Yield		✓			
Biological yield		✓			
Grain Harvest Index		✓			
Total response score of the varieties at maximum tillering to Heading stages (70DAS) and harvest stage	06	22	00	00	00

Correlation studies between economic yield and yield-attributing parameters under different stress conditions are frequently used to link physiological parameters obtained at phonological stages for crop variety identification (Fageria *et al*., 2008; Gaddameedi *et al*., 2021). Grain yield and 1000-grain weight were found to be positively related in wheat (Shahryari *et al.*, 2011; Jaisi *et al.*, 2021; Gao *et al.*, 2023**)**. All discovered positive connections between grain yield and the number of grains per spike, plant height, and 1000-grain weight. Wheat grain yield is primarily determined by yield parameters such as tillers per plant, grains per spike, and grain weight per thousand. The findings presented highlight that under high manganese stress condition, the application of natural extracts derived from bay leaf, potato peel, and banana peel positively influenced the physiological and biochemical performance of rice. Among the three, bay leaf extract consistently demonstrated the most pronounced benefits across various growth and yield parameters. Notably, the indigenous highland Ahu (Summer) rice varieties exhibited differential responses to these treatments, with the Dehangi variety showing the greatest resilience to manganese stress conditions. Soil analysis revealed an increase in pH levels and a reduction in exchangeable Mn content, suggesting more efficient nutrient uptake by the rice plants. Favorable climatic conditions further supported crop development throughout the study period. Physiological indicators such as SLW, plant height, shoot and root biomass, number of tillers and effective tillers, and leaf count per plant improved significantly, particularly in response to bay leaf extract treatment. The enhanced SLW and greater plant height point to improved photosynthetic efficiency and structural development, while increased shoot biomass and tiller numbers reflect robust vegetative growth. Additionally, the substantial increase in root biomass in bay leaf-treated plants suggests improved nutrient acquisition and greater adaptability to stress, contributing to overall plant vigor and productivity.

Test weight, panicle length, panicle weight, and seed count per panicle were all significantly enhanced by bay leaf extract. The extract's ability to improve grain quality and setting is supported by the rise in high-density grains and decrease in sterility percentage. Economic and biological yields also improved dramatically, commensurate with higher grain harvest index values. The findings demonstrate how effectively bay leaf extract supports stress resistance mechanisms, glucose translocation, and grain filling.

CONCLUSION

The study highlights the importance of bay leaf extract as a potential bio-stimulant capable of enhancing rice growth, yield performance, and tolerance to iron toxicity. The observed positive associations between the parameters are largely attributed to its rich composition of phenolic compounds, flavonoids, and potassium. Because, bay leaf greatly increased root biomass and multiplication, which improved nutrient absorption. Finally, these findings contribute to the development of eco-friendly, economically viable strategies for improving rice cultivation in regions affected by iron and manganese stress.

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Conflict of Interest: The authors declare that there is no conflict of interest in publishing the manuscript elsewhere.

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