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Performance of black rice varieties under integrated nutrient management practices in the Gangetic Alluvial Region of West Bengal

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Abstract
Black rice (*Oryza sativa* L.) is well known for its superior nutritional quality and high anthocyanin content. A two-year field experiment (2023–2025) was conducted at the Agricultural Experimental Farm, University of Calcutta, Baruipur, South 24 Parganas, West Bengal, to evaluate the growth and yield of four black rice varieties under seven integrated nutrient practices using a factorial randomized block design with three replications. Results revealed significant varietal and nutrient effects on growth, yield attributes, and yield. The results demonstrated that varietal performance varied significantly across parameters, with Kalabati excelling in plant height, harvest-stage dry matter accumulation, and straw yield, while Chak Hao showed superiority in panicle length and test weight. Kaala Malliphulo consistently outperformed the other varieties in filled grains panicle^{-1} and grain yield; therefore, it emerged as the most suitable variety for farmers in terms of grain productivity in the Gangetic alluvial region of West Bengal. Among the nutrient regimes, the application of 50% recommended dose of fertilizers (RDF) + Vermicompost @ 1.5 t ha^{-1} constantly surpassed all other INM treatments, producing the highest grain yield and straw yield, along with enhanced growth and yield attributes. However, further investigations are required under diverse agro-ecological conditions to confirm and refine these findings.

Keywords: Black rice, Boro season, gangetic, integrated nutrient management, Kaala Malliphulo, Vermicompost

1. Introduction
Rice (*Oryza sativa* L.) is an ancient cereal cultivated in 117 countries, earning the name "Global Grain." It ranks first among cereals, with India holding the largest cultivated area and second only to China in production. As a staple food for over 60% of the world's population, this Poaceae member is classified by grain colour into white, red, and black types. Black rice is a glutinous type of rice rich in nutrients and primarily cultivated across Asia (Wang *et al*., 2007). Also referred to as purple rice, forbidden rice, heaven rice, imperial rice, king's rice, and prized rice, it comprises numerous varieties with a long history of cultivation in countries such as China, India, and Thailand (Kong *et al*., 2008) [29]. Globally, more than 200 black rice varieties have been identified, with China accounting for about 62% of total production and developing over 54 high-yielding, multi-resistant modern varieties. Major producers include China, Sri Lanka, Indonesia, India, and the Philippines. The characteristic dark purple hue of black rice results from its abundant anthocyanin pigments concentrated in the pericarp layers (Takashi *et al*., 2001). Black rice possesses a superior nutritional profile compared with other rice types, being naturally cholesterol-free and low in sugar, salt, and fat, while serving as a whole-grain source of high-quality protein, fiber, anthocyanins, antioxidants, B-complex vitamins, vitamin E, iron, thiamine, magnesium, niacin, and phosphorus (Kushwaha, 2016) [31]. A 50 g serving can provide around 35% of the recommended daily allowance (RDA) of selenium, copper, zinc, and magnesium, and one-half cup of cooked grain delivers approximately 160 kcal of energy, 1.5 g of fat, 34 g of carbohydrates, 2 g of fiber, and 7.5 g of protein (Kushwaha, 2016) [31]. Recognized as a "super food," black rice has demonstrated therapeutic potential in numerous studies: its bran suppresses dermatitis and may help treat chronic inflammatory conditions (Choi *et al*., 2010) [10],

while its principal anthocyanin, cyanidin-3-glucoside (C3G), effectively inhibits inflammatory responses (Min *et al*., 2010) [37]. Regular consumption has been linked to weight reduction through suppression of adipogenesis and decreased fatty acid synthesis without affecting fatty acid oxidation, thereby reducing intracellular lipid accumulation (Kim *et al*., 2016) [50]. The anthocyanins also lower LDL cholesterol reduces atherosclerosis risk, help control blood pressure, and protect cardiovascular health (Zawistowski *et al*., 2009) [60]. In addition, these antioxidants mitigate free-radical damage associated with cancer development, support diabetes prevention due to high fiber and low sugar content, and alleviate inflammation in allergic and other disease conditions. Black rice is a rich source of iron and is therefore beneficial for individuals with anemia (Kushwaha, 2016) [31]. Regular intake is further associated with enhanced overall health, increased longevity, improved digestion, better eye health with reduced risk of cataracts and macular degeneration, protection against osteoporosis, and a lower risk of asthma. Rice in India is cultivated in three seasons- *kharif* (June-July sowing, 84% of production), *rabi*/*boro* (November-February sowing, 9% of production), and pre-*kharif*/autumn (May-August sowing, 7% of production). Although *kharif* is the main season, farmers increasingly prefer *boro* cultivation due to its higher productivity, better water and fertilizer management under irrigated conditions, lower pest pressure, and favorable temperature regime that enhances photosynthate accumulation and grain filling. Transplanting remains the most common method of establishment, ensuring uniform plant stands and early weed suppression. Rice plant requires essential macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) to support growth, chlorophyll formation, and the synthesis of starch, anthocyanin, and vitamin B that determine grain quality. To obtain high yields with superior grain characteristics, plants must receive a balanced supply of nutrients from both organic and inorganic sources. Efficient use of organic manures through appropriate application methods and timing, in combination with inorganic fertilizers, has been emphasized as part of integrated nutrient management (INM) practices (Khan *et al*., 2006) [28]. Such integrated approaches improve rice yield by reducing nutrient losses, optimizing nutrient supply, and enhancing nutrient-use efficiency (Parkinson, 2013) [44]. Biofertilizers such as phosphate-solubilizing bacteria (PSB) and potassium-solubilizing bacteria (KSB) further enhance nutrient uptake by converting insoluble phosphorus and potassium into plant-available forms, thereby promoting root growth, dry matter accumulation, and higher yield while improving soil microbial health. Integrated nutrient management that combines organic manures with inorganic fertilizers is widely regarded as the most effective strategy for sustaining soil fertility, increasing crop productivity, and ensuring long-term food security (Jenssen, 1993; Palm *et al*., 1997; Bisht *et al*., 2002) [26, 43, 7]

2. Materials and Methods

The experiment was carried out during the *boro* seasons of 2023–2024 and 2024–2025 at the Agricultural Experimental Farm of the University of Calcutta, Baruipur, South 24 Parganas, West Bengal. The site, located in the Gangetic alluvial region (88°26′ E, 22°22′ N, 9 m MSL), has clay loam soil and a tropical wet-dry climate with mild winters (minimum >15°C), hot summers (38–45°C), and about 1,400 mm annual rainfall, 75% of which occurs during June-September. The soil was slightly acidic (pH 6.15), medium in organic carbon (0.89%), non-saline (EC 0.05 dS m^{-1}), with moderate CEC (15.76 cmol p^+ kg^{-1}), low N (174 kg ha^{-1}), medium phosphorous (30.18 kg ha^{-1}), and high potassium (262.53 kg ha^{-1}). A factorial randomized block design with three replications was adopted, involving four varieties- Chak Hao (V_1), Kalabati (V_2), Krishna (V_3), and Kaala Malliphulo (V_4); and seven integrated nutrient practices: Control (N_1), 100% RDF (NPK 40:20:20) (N_2), FYM @8 t ha^{-1} + PSB + KSB (N_3), 50% RDF + FYM @4 t ha^{-1} (N_4), VC @3 t ha^{-1} + PSB + KSB (N_5), 50% RDF + VC @1.5 t ha^{-1} (N_6), and FYM @4 t ha^{-1} + VC @1.5 t ha^{-1} + PSB + KSB (N_7). Seeds were pre-soaked, incubated, treated with *Trichoderma viride*, and sown each variety at 50 kg ha^{-1} in nurseries. The main field was ploughed, harrowed, leveled, and divided into 84 plots with bunds and irrigation channels. Fertilizers were applied as per treatments, with half nitrogen (N) and full phosphorous (P_2O_5) and potassium (K_2O) at final land preparation, and the remaining nitrogen in two splits at mid-tillering and heading. PSB (10 kg ha^{-1}) and KSB (10 kg ha^{-1}) were incorporated with farmyard manure (FYM) or vermicompost (VC) as per treatments. Forty-five-days-old seedlings were transplanted at 20 × 20 cm spacing with three seedlings $hill^{-1}$. Harvesting was done at physiological maturity when about 85% of spikelets ripened and grain moisture was below 16%. Net plots were harvested separately, sun-dried, threshed, cleaned, and winnowed, and grain yield was recorded. Straw yield was calculated by subtracting grain from biological yield, and both yields were expressed in t ha^{-1}.

Observations and Procedures of Data Recorded

Biometric observations were systematically recorded to assess crop growth, yield components, and productivity. Five hills $plot^{-1}$ were randomly selected and tagged for regular measurement. Growth parameters such as plant height (cm) and dry matter accumulation (g $hill^{-1}$) were recorded at 30, 60 days after transplanting (DAT), and at harvest following standard procedures. Yield attributes, including panicle length (cm), filled grains $panicle^{-1}$, and test weight (g), were assessed from randomly selected hills in each plot. At maturity, the crop was harvested from the net plot area, and grain yield and straw yield (t ha^{-1}) were recorded.

Statistical Analysis

The data on various parameters were analyzed using OPSTAT software, developed at CCS Haryana Agricultural University, Hisar, in accordance with the principles of Factorial Randomized Block Design (FRBD). Analysis of variance (ANOVA) was performed to test the significance of treatment effects and their interactions, with four black rice cultivars considered as factor A and seven integrated nutrient treatments as factor B. The data from two years were pooled for combined analysis, and the differences among treatment means were compared at the 5% level of significance using Least Significant Difference (LSD) test after a significant F-test in the ANOVA.

3. Results and Discussion

3.1 Growth Parameters

Plant Height (cm)

Plant height (cm) of black rice increased steadily from 30 DAT to harvest, attaining the maximum at physiological maturity because the height of rice plant showed a sigmoid pattern of growth of rice in all the treatments characteristics of many living plants (Gallston, 1968) [17]. The growth rate took a gradual declining trend from flower initiation onwards and the crop underwent further elongation of the main axis following anthesis (Loechning, 1961; Yoshida, 1981) [34, 59].

Significant differences were observed among varieties and nutrient management practices across all growth stages (Table 3.1). Among the varieties, Kalabati (V_2) consistently recorded the tallest plants at 30 DAT (90.90 cm), 60 DAT (136.69 cm), and harvest (156.99 cm). This superior vegetative growth is likely due to its genetically vigorous growth habit (Fageria and Baligar, 2005) [16] and better responsiveness to nutrient uptake (Liu *et al*., 2009) [32], particularly nitrogen, which plays a crucial role in cell division and elongation (Luo *et al*., 2020) [35]. Kaala Malliphulo (V_4) produced the minimum plant height at corresponding stages (61.42 cm, 98.01 cm, and 120.99 cm, respectively), which may be due to its relatively shorter growth stature, reflecting its genetic limitations for vertical growth. Similar opinions were also recorded by Liu *et al.* (2018) [33], who observed that rice plant height is controlled by genes that lie within a complex regulatory network, primarily involved in the biosynthesis or signal transduction of phytohormones such as gibberellins, brassinosteroids, and strigolactones.

Nutrient management treatments exerted a significant influence on plant height, with the highest values being obtained under 50% RDF + vermicompost @ 1.5 t ha^{-1} (N6) at 30 DAT (78.99 cm), 60 DAT (119.82 cm), and at harvest (142.50 cm). This enhanced performance may be attributed to the synergistic effect of combining chemical fertilizers with organic sources (Abbasi and Yousra, 2012) [1]. Vermicompost may have provided a slow and steady release of macro- and micronutrients, while also improved soil physical structure (Singh *et al*., 2024) [52], increased microbial activity, and enhanced nutrient availability (Rehman *et al*., 2023; Tammam *et al*., 2023) [47, 55]. When applied in combination with a reduced dose of chemical fertilizers, vermicompost could have ensured a more balanced nutrient supply throughout the crop growth stages (Hoque *et al*., 2022) [21]. These findings are in close agreement with those of Aruna and Mohhamad (2005) [3] and Barik *et al*. (2006) [5]. The minimum plant height was consistently recorded under the control (N_1) across all growth stages (73.34 cm, 113.06 cm, and 135.75 cm, in 30 DAT, 60 DAT, and harvest, respectively) likely due to the absence of any external nutrient input, which may have resulted in poor soil fertility status and limited nutrient availability.

Dry Matter Accumulation (g hill^{-1})

Dry matter accumulation (g hill^{-1}) in black rice increased progressively with crop age, showing a relatively slow rate of increase up to 30 DAT, followed by a sharp rise between 30 and 60 DAT, and thereafter a comparatively slower increase until harvest. This trend might be attributed to contributions from increased plant height and other physiological growth parameters, which are generally more pronounced at the later growth stages and particularly at maturity (Zhai *et al*., 2022) [61].

Significant differences were observed among varieties as well as nutrient management practices across all growth stages (Table 3.1). Among the varieties, Kalabati (V_2) recorded the maximum values at 30 DAT (20.72 g hill^{-1}) and at harvest (122.33 g hill^{-1}). In the early stages, differences in seedling vigor and root architecture appeared to play a crucial role. Kalabati, being a tall genotype, may have exhibited a deeper and more extensive root system, which could have enabled more effective nutrient foraging, particularly of nitrogen and phosphorus (Chithrameenal *et al*., 2018) [9]. Both of these nutrients are essential for leaf development and, consequently, for increases in dry matter accumulation. The shift in superiority at the reproductive stage suggests that Kalabati might possess genotype-specific traits such as prolonged photosynthetic duration and delayed senescence (Deng *et al*., 2023) [12]. However, Chak Hao (V_1) recorded the highest DMA at 60 DAT (73.86 g hill^{-1}) could be attributed to its good tillering ability and sustained photosynthetic activity. Chak Hao is known for its dense canopy architecture, which could favor higher light interception during the vegetative peak, thereby enhancing assimilate production (Dou *et al*., 2021) [13]. In contrast, Kaala Malliphulo (V_4) consistently exhibited the lowest DMA throughout the growth stages (15.01 g hill^{-1} at 30 DAT, 57.52 g hill^{-1} at 60 DAT, and 82.28 g hill^{-1} at harvest). The relatively lower biomass accumulation in Kaala Malliphulo may be attributed to inherently weaker vegetative vigor, smaller leaf area, and reduced plant height, traits that likely contributed to diminished light interception and photosynthetic efficiency (Colomb *et al*., 2000) [11].

Nutrient management practices also had a marked effect on dry matter production. The treatment 50% RDF + vermicompost @ 1.5 t ha^{-1} (N_6) outperformed other treatments (22.62 g hill^{-1} at 30 DAT, 76.26 g hill^{-1} at 60 DAT, and 116.04 g hill^{-1} at harvest) reflects a highly synergistic and optimized nutrient environment conducive to plant growth. The results have got close conformity with the findings of Krishna *et al*. (2008) [30], Dutt and Chauhan, (2010) and Murthy, (2012) [41]. This treatment remained statistically comparable with 50% RDF + FYM @ 4 t ha^{-1} (N_4) across all stages, suggests that both vermicompost and FYM, when applied in conjunction with RDF, could provide a balanced and sustained nutrient supply that supports improved growth parameters and potentially enhanced dry matter production. On the other hand, the control (N_1) produced the minimum values (14.24 g hill^{-1} at 30 DAT, 51.37 g hill^{-1} at 60 DAT, and 82.41 g hill^{-1} at harvest) reflecting restricted physiological activity, possibly due to nutrient limitations arising from a broad C:N ratio.

Interaction Effect of Variety and Nutrient Management on Growth Parameters

The interaction effect between black rice varieties and integrated nutrient management on plant height and dry matter accumulation was statistically non-significant (Table 3.1).

3.2 Yield Attributing Characters

Panicle length (cm), number of filled grains panicle^{-1}, test weight (g) were significantly influenced by varietal differences and nutrient practices, although the effect of nutrient treatments was more pronounced than genotypic variation. All the treatments produced markedly higher values compared to the control (Table 3.2).

Panicle Length (cm)

Among the varieties, Chak Hao (V_1) exhibited the maximum panicle length (22.54 cm), followed by Kaala Malliphulo (V_4) (21.75 cm), appears to possess an inherent genetic predisposition for enhanced inflorescence elongation (Bai *et al*., 2021) [4]. This trait is likely regulated by its ability to maintain efficient assimilate partitioning towards panicle axis expansion during the critical stages of reproductive differentiation (Adriani *et al*., 2016; Reig-Valiente *et al*., 2018) [2, 48]. Krishna (V_3) produced the minimum panicle length (20.90 cm), which could be attributed to its limited genetic potential for reproductive axis expansion. The reduced panicle development may also result from lower nutrient partitioning to reproductive structures, possibly constrained by physiological limitations.

Across nutrient practices, the integrated treatment 50% RDF + VC @ 1.5 t ha^{-1} (N_6) recorded the highest panicle length (23.75

cm), which remained statistically at par with 50% RDF + FYM @ 4 t ha^{-1} (N_4) (23.26 cm). This outcome may be attributed to the steady nutrient release and soil-conditioning effects of manures, which possibly supported a gradual nutrient supply throughout the reproductive phase (Ranjan *et al.*, 2023) [46]. These integrated approaches seems to have ensured sustained nutrient availability, improved soil physical structure, and enhanced enzymatic and microbial activity (Mohanty *et al.*, 2013) [39]. Similar observations have also been reported by Mondal *et al.* (2015) [40]. The lowest panicle length (18.52 cm) was recorded under the control treatment (N_1), indicating that the absence of nutrient supplementation likely restricted the plant's reproductive development.

No. of Filled Grains Panicle^{-1}

Among the varieties, Kaala Malliphulo (V_4) recorded the maximum filled grain count (116.50 grains panicle^{-1}), which suggests a likely intrinsic efficiency in assimilates partitioning toward reproductive sinks, potentially governed by superior spikelet fertility and synchronized grain filling. This genotypic advantage may be attributed to its ability to maintain a favorable balance between source capacities and sink strength, thereby ensuring a sustained carbohydrate supply during the grain-filling phase (Jiang *et al.*, 2023) [27], whereas Kalabati (V_2) exhibited the lowest (96.44 grains panicle^{-1}), could be due to suboptimal spikelet fertility or a weakened assimilates flow, resulting in a reduced grain set (Chen *et al.*, 2019) [8].

Across integrated nutrient regimes, the treatment 50% RDF + VC @ 1.5 t ha^{-1} (N_6) proved most effective, producing the highest number of filled grains (121.50 grains panicle^{-1}), and was significantly superior to all other treatments. The synergistic effect of this integrated nutrient strategy may have promoted consistent nutrient availability, hormonal equilibrium, and enhanced rhizospheric microbial activity throughout the reproductive phase, thereby optimizing conditions for pollination success and grain development (Gupta *et al.*, 2022) [19]. The control (N_1) recorded the minimum filled grains (88.95 grains) panicle^{-1}.

Test Weight (g)

Among the genotypes, Chak Hao (V_1) exhibited the highest test weight (23.83 g), which could be attributed to its inherent genetic potential (Islam *et al.*, 2016) [24] to accumulate greater dry matter per grain, indicating a robust photosynthetic capacity and efficient biomass partitioning. The vegetative vigor exhibited by Chak Hao likely ensured a consistent supply of assimilates during the grain-filling phase, even though the total grain number was comparatively moderate (Huang *et al.*, 2017) [22]. In contrast, Kalabati (V_2) recorded the lowest test weight (22.34 g) could be attributed to its limited efficiency in assimilate allocation during the grain filling stage, despite its relatively longer panicles (Chen *et al.*, 2019) [8].

The integrated nutrient application of 50% RDF in combination with vermicompost @1.5 t ha^{-1} (N_6) resulted in the maximum test weight (24.42 g) may be attributed to the complementary interaction between inorganic and organic nutrient sources, which potentially ensured both immediate and sustained nutrient availability. Similar outcomes were previously reported by Islam *et al.* (2015) [25] and Suresh *et al.* (2013) [54]. Conversely, the lowest value (21.61 g) was obtained under the control (N_1).

Interaction Effect of Variety and Nutrient Management on Yield Attributes

The interaction effect between black rice varieties and integrated nutrient management on panicle length and no. of filled grains panicle^{-1} was statistically non-significant but for test weight (g), it was found significant (Table 3.2). Test weight was registered significantly higher (25.04 g) under Chak Hao (V_1) with integrated fertilizers treatment 50% RDF + VC @ 1.5 t ha^{-1} (N_6) and lowest test weight (20.09 g) was found from Kalabati (V_2) with control treatment (N_1).

3.3 Yield (t ha^{-1})

The grain and straw yield (t ha^{-1}) recorded from each plot at maturity were analysed statistically and presented (Table 3.3). Different black rice varieties and integrated nutrient management showed significant effect on yields of black rice.

Grain Yield (t ha^{-1})

Kaala Malliphulo (V_4) recorded the highest grain yield (2.66 t ha^{-1}), which was significantly superior to all the tested varieties. This performance was likely attributable to its superior yield-contributing traits, indicating a robust sink potential that was probably supported by efficient assimilate translocation. The lowest grain yield (1.68 t ha^{-1}) was observed in Kalabati (V_2). This suggests an inefficiency in converting vegetative vigor into reproductive output, likely due to suboptimal partitioning of assimilates or limited sink strength, where enhanced source activity did not effectively support grain development.

Among the nutrient management practices, the treatment comprising 50% RDF in combination with vermicompost @1.5 t ha^{-1} (N_6) achieved the maximum grain yield (2.70 t ha^{-1}), followed by 50% RDF + FYM @ 4 t ha^{-1} (N_4) (2.53 t ha^{-1}). This superiority was likely attributable to the synergistic interaction between inorganic and organic nutrient sources, which ensured a dual advantage of immediate nutrient release from the inorganic fraction and sustained mineralization from organic inputs. Such a regime probably enhanced rhizosphere health, microbial activity, and root function while improving soil physical, chemical, and biological qualities. Consequently, these improvements promoted better nutrient uptake, higher photosynthetic efficiency, and greater biomass accumulation, all of which collectively contributed to superior grain yield (Yaduvanshi and Swarup, 2005; Wichern *et al.*, 2020; Mao *et al.*, 2022) [57, 56, 36]. Shankar *et al.* (2020) [51] and Moe *et al.* (2019) [38] found an increase in yield with an adequate supply of N through both organic inorganic sources of nutrients. The lowest grain yield (1.68 t ha^{-1}) was obtained from the control (N_1).

Straw Yield (t ha^{-1})

Among the varieties, Kalabati (V_2) recorded the highest straw yield (5.71 t ha^{-1}), which may be attributed to its superior vegetative traits (Oladosu *et al.*, 2014) [42]. These characteristics likely facilitated more effective canopy development and improved photosynthetic efficiency, thereby promoting greater biomass production. The lowest straw yield (4.34 t ha^{-1}) was observed in Kaala Malliphulo (V_4), likely due to its relatively reduced growth characteristics, which may have hindered its ability to effectively intercept solar radiation.

With respect to nutrient management, the application of 50% RDF + vermicompost @ 1.5 t ha^{-1} (N_6) produced the maximum straw yield (5.62 t ha^{-1}). Vermicompost is known to be rich in macro- and micronutrients, plant growth regulators, humic substances, and beneficial microbial populations (Rao *et al.*, 2017) [53], which collectively enhanced root development, photosynthesis (Rekha *et al.*, 2018) [49], microbial activity, and soil structure (Pierre-Louis *et al.*, 2021) [45], key factors influencing vegetative biomass accumulation. Ranjan *et al.*

(2023) [46] have demonstrated that the integration of organic manures with reduced quantities of inorganic fertilizers is correlated with sustained yield levels. In contrast, the control treatment (N_1) resulted in the lowest straw yield (4.60 t ha^{-1}).

Interaction effect of variety and nutrient management

The interaction effect between black rice varieties and integrated nutrient management on grain yield and straw yield was statistically non-significant (Table 3.1).

Table 3.1: Plant height and dry matter accumulation of black rice as influenced by varieties, integrated nutrient management, and their interaction at different growth stages (Pooled mean of 2 years)

Treatments	Plant height (cm)			Dry matter accumulation (g $hill^{-1}$)		
	30 DAT	60 DAT	Harvest	30 DAT	60 DAT	Harvest
A. Variety						
V_1: Chak Hao	86.91	129.07	151.13	20.69	73.86	114.55
V_2: Kalabati	90.90	136.69	156.99	20.72	72.18	122.33
V_3: Krishna	63.81	100.53	126.07	17.14	69.12	100.51
V_4: Kaala Malliphulo	61.42	98.01	120.99	15.01	57.52	82.28
S.Em (±)	0.508	0.711	0.679	0.485	0.804	1.172
CD (P = 0.05)	1.424	1.992	1.903	1.359	2.252	3.286
B. Nutrient						
N_1: Control	73.34	113.06	135.75	14.24	51.37	82.41
N_2: 100% RDF (NPK- 40:20:20)	76.57	116.88	139.92	19.79	72.38	109.44
N_3: FYM @ 8t ha^{-1}+PSB+KSB	74.02	114.22	136.58	15.79	64.57	102.49
N_4: 50% RDF+FYM @4t ha^{-1}	77.48	118.17	140.51	21.00	74.28	112.10
N_5: VC @3 t ha^{-1} + PSB+ KSB	74.47	114.82	137.62	16.52	67.87	104.63
N_6: 50% RDF + VC @ 1.5 t ha^{-1}	78.99	119.82	142.50	22.62	76.26	116.04
N_7: FYM @ 4 t ha^{-1} + VC @ 1.5 t ha^{-1} + PSB+ KSB	75.45	115.56	138.70	18.74	70.46	107.30
S.Em (±)	0.672	0.940	0.898	0.641	1.063	1.551
CD (P = 0.05)	1.884	2.636	2.517	1.798	2.980	4.347
C. Interaction (V×N)						
S.Em (±)	NS	NS	NS	NS	NS	NS
CD (P = 0.05)	NS	NS	NS	NS	NS	NS

Table 3.2: Panicle length, no. of filled grains panicle-1, and test weight of black rice as influenced by varieties, integrated nutrient management, and their interaction at harvest (Pooled mean of 2 years)

Treatments	Panicle length (cm)	No. of filled grains $panicle^{-1}$	Test weight (g)
A. Variety			
V_1: Chak Hao	22.54	103.54	23.83
V_2: Kalabati	21.62	96.44	22.34
V_3: Krishna	20.90	108.97	23.23
V_4: Kaala Malliphulo	21.75	116.50	23.55
S.Em (±)	0.180	1.195	0.076
CD (P = 0.05)	0.506	3.350	0.213
B. Nutrient			
N_1: Control	18.52	88.95	21.61
N_2: 100% RDF (NPK- 40:20:20)	22.64	110.44	23.73
N_3: FYM @ 8t ha^{-1}+PSB+KSB	20.70	97.59	22.50
N_4: 50% RDF+FYM @4t ha^{-1}	23.26	116.59	24.21
N_5: VC @3 t ha^{-1} + PSB+ KSB	21.19	102.61	22.83
N_6: 50% RDF + VC @ 1.5 t ha^{-1}	23.75	121.50	24.42
N_7: FYM @ 4 t ha^{-1} + VC @ 1.5 t ha^{-1} + PSB+ KSB	21.85	106.85	23.36
S.Em (±)	0.239	1.581	0.100
CD (P = 0.05)	0.669	4.431	0.281
C. Interaction (V×N)			
S.Em (±)	NS	NS	0.201
CD (P = 0.05)	NS	NS	0.563

Table 3.3: Grain yield and straw yield of black rice as influenced by varieties, integrated nutrient management, and their interaction at harvest (Pooled mean of 2 years)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
A. Variety		
V_1: Chak Hao	2.17	5.39
V_2: Kalabati	1.68	5.71
V_3: Krishna	2.43	4.95
V_4: Kaala Malliphulo	2.66	4.34
S.Em (±)	0.019	0.033
CD (P = 0.05)	0.052	0.094

B. Nutrient		
N_1: Control	1.68	4.60
N_2: 100% RDF (NPK- 40:20:20)	2.42	5.27
N_3: FYM @ 8t ha^{-1}+PSB+KSB	1.97	4.82
N_4: 50% RDF+FYM @4t ha^{-1}	2.53	5.44
N_5: VC @3 t ha^{-1} + PSB+ KSB	2.08	4.92
N_6: 50% RDF + VC @ 1.5 t ha^{-1}	2.70	5.62
N_7: FYM @ 4 t ha^{-1} + VC @ 1.5 t ha^{-1} + PSB+ KSB	2.26	5.05
S.Em (±)	0.025	0.044
CD (P = 0.05)	0.069	0.124
C. Interaction (V×N)		
S.Em (±)	NS	NS
CD (P = 0.05)	NS	NS

4. Conclusion

On the basis of the present findings, Kaala Malliphulo emerged as the most suitable black rice variety for farmers in the Gangetic alluvial region of West Bengal owing to its superior grain yield. Among the nutrient management practices, the application of 50% RDF combined with vermicompost @ 1.5 t ha^{-1} proved to be the most effective, ensuring higher yields and promoting sustainable *boro* season cultivation in this region. Further multi-location trials across diverse agro-ecological zones are recommended to validate these results and support wider adoption by farmers.

5. References

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