Research Article

Agro-Morphological Characterization and Diversity Studies of Local and Modern Rice Genotypes in the Coastal Region of Bangladesh

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Abstract | As a primary food of majority global population, rice is essential to maintain steady and reliable production. However, soil conditions, especially in the coastal region and salinity level, pose threats to achieving optimum productivity. Therefore, it is essential to evaluate morpho-genetic variability finding an appropriate genotype in rice breeding for these regions. This study focused on evaluating the morphological differences among ten local and modern genotypes in Noakhali, a coastal region of Bangladesh, using a randomized complete block design (RCBD). ANOVA results indicated a significant variation ($P \leq 0.001$) among the genotypes. The local variety (Rajashail) was relatively early maturing among all. Whereas, for the other morphological traits (number of tillers, number of effective tillers, panicle length, grains per hill and yield), comparatively modern varieties outperformed. Binadhan-10, a modern variety, showed the highest yield of 5.23 tons/ha, demonstrating superior performance in the coastal region due to its adaptability to saline conditions. In the principal component analysis (PCA), the first two PCs explained 68.01% of the total variation between genotypes. Additionally, PC1 separated high-yielding genotypes from low-yielding suggests the studied moderns are high-yielding than locals for coastal regions. These insights might help further rice breeding programs to develop a suitable variety for coastal regions.

Received | June 05, 2024; **Accepted** | October 25, 2024; **Published** | January 03, 2025
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Citation | Alam, I., B. Das, K.M.Y. Tanim, R. Zannat, A.D. Hridoy, H.M.F. Hossain, T. Islam and M.A.R. Bhuiyan. 2025. Agro-morphological characterization and diversity studies of local and modern rice genotypes in the coastal region of Bangladesh. *Sarhad Journal of Agriculture,* 41(1): 01-11.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.1.1.11
Keywords | Local, Modern, Rice, Coastal region, Salinity, Diversity

Introduction

Rice (*Oryza sativa* L.) is the main food crop for over half of the world's population, which supplies approximately 27% of essential nutrients and 20% protein intake in developing regions (Sikirou *et al*., 2024; Kennedy *et al*., 2002). In Bangladesh, approximately 38.14 million metric tons of rice

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are produced annually, cultivated on nearly 28.89 million acres of land. This makes rice the most important food crop, accounting for 95% of all cereals consumed in the country (BBS, 2022). It is responsible for 50% of the total agricultural income and 60% of the national revenue (BBS, 2018). The production of rice is expected to increase a factor four by the year 2050 to meet hunger of this rapidly expanding global population (Fischer *et al*., 2009). Bangladesh's population is expected to hit 215.4 million by 2050, with corresponds to a demand of 44.6 million tons rice (Kabir *et al*., 2015). Therefore, adequate rice production is crucial to ensure food security in Bangladesh. Indeed, the concept of 'rice security' is equivalent to 'food security' in Bangladesh, as it is in main rice-growing nations (Brolley, 2015). Enhancing the production of rice is poised to become a significant challenge in coming years owing to the burgeoning global population and escalating demand for worldwide rice production (Mata *et al*., 2023; Rahman and Connor, 2022).

In this situation, soil characteristics of coastal regions pose a significant threat to crop production where salinity is predominant. Soil salinity is a major environmental stressor worldwide, impacting more than 77 million hectares or 5% of the arable land (Yang *et al*., 2004). The coastal region of Bangladesh covers an area of around 29,000 km^2, which is about 20% of the country's total land area. Additionally, more than 30% of the arable land in Bangladesh is located along the coast (Haque, 2006). Elevated levels of sodium chloride (NaCl) in these regions induced salinity stress, mainly by inhibiting osmosis and causing toxicity due to excessive ions (Sarma *et al*., 2023; Parida and Das, 2005). This stress hampers the process of crop photosynthesis, resulting in to decrease production and to have a substantial effect on storage, composition, and physical properties of starch in cereals (Sarma *et al*., 2023; Parida and Das, 2005). Rice is given priority for improvement on such soils due to the negative influence of salts on numerous components, such as stand establishment, leaf area index, panicle and tiller number, spikelets, floret sterility, heading time, and individual grain size (Xu *et al*., 2024; Meng *et al*., 2021). Majority of rice cultivars have a threshold electrical conductivity (EC) of 3 dS/m, making them sensitive to salinity stress. Salinity of most coastal regions ranges from 4 to 16 dS/m, and this variation in soil salinity levels depends on the season and location of rivers entering the basin from North and the Bay of Bengal (Dasgupta *et al*., 2018). Being moderately salt-sensitive to salt resistance, rice exhibits a complex reaction to salinity stress that differs depending on species, stage of growth and development, and length of stress duration. Due to its adverse effects, rice yield potentially decreases 50% (Lokeshkumar *et al*., 2023; Bray *et al*., 2000). An estimation made by Dasgupta *et al*. (2018) indicated that yield of high-yielding rice variety (HYV) was notably reduced 15.6% in coastal regions having soil salt levels 4 dS/m.

To meet the rising food requirements of a growing population, it is crucial to develop rice genotype that can tolerate high levels of salt. By utilizing a combination of conventional and modern breeding methods, it is possible to improve rice production to fulfil world demand (Lu *et al*., 2020; Khush, 2005). To understand it, it is crucial to thoroughly examine phenotypic variation present in exotic and native germplasms. to investigate this diversity, it is possible to speed up the process of rice development by identifying new genes. Morphological traits are crucial for assessing genetic variability and trait associations in rice, particularly for developing varieties suited to coastal regions. In saline environments, where salt stress hampers growth and yield, correlation and multivariate analyses have been widely used to identify stress-tolerant genotypes (Megloire, 2005). Previous studies have shown the value of screening rice varieties, including local and modern cultivars, for stress tolerance using morphological evaluations (Pranaya *et al*., 2024; Muntha *et al*., 2024; Lokeshkumar *et al*., 2023; Chowdhury *et al*., 2023). However, the performance of rice varieties on saline soils varies significantly. Local varieties, in particular, possess unique traits, including salt tolerance and adaptability, that are less common in modern high-yielding varieties (Sogir *et al*., 2024). This lack of integration has limited the discovery of gene combinations that enhance salinity tolerance. While studies have focused on either local or modern varieties, few have explored their combined potential in saline soils. This presents a missed opportunity to harness the genetic variability of local varieties alongside the yield advantages of modern lines. Therefore, the present study aims to evaluate both local and modern rice genotypes in the coastal region of Noakhali, Bangladesh, where soil electrical conductivity (EC) ranges from 4 to 8 dS/m (Dasgupta *et al*., 2018; Ahmed *et al*., 2024; Das *et al*., 2024). By utilizing morphological traits, this research seeks to establish an effective foundation for selection and breeding programs, ultimately generating rice varieties better suited to saline soils.

Materials and Methods

Experimental site

The study was carried out in 2023 to assess the performance of rice genotypes during the Aman season (July to December, 2023) at Noakhali Science and Technology University's Agricultural Experiment Farm which belongs to the Young Maghna estuary flood plain (AEZ-18) in Bangladesh. The geographical area is distinguished by its medium-depth sandy loam-textured soil, which is moderately alkaline and predisposed to salinity with a pH of 7.5 and EC 4.32 dS/m. It demonstrates moderate fertility but contains low organic matter, with a soil nitrogen content of 0.09%. The area experiences an average annual temperature of 25.6 °C and receives approximately 3,302 mm of annual rainfall.

Experimental design and planting material

Three replications of the RCBD were used in this experiment. Planting materials included six local genotypes (Rajashail dhan, Tulshimala, Birui, Hail dhan, Swarna and Lal paika) and four modern genotypes (BRRI dhan-34, BRRI dhan-52, BRRI dhan-100 and Binadhan-10). Seeds of these varieties were collected from diversified sources around Noakhali, Bangladesh. The sources of collection and key characteristics of these genotypes are given in Table 1.

Seed treatment and seedbed preparation

After collection, seeds were sun-dried for one day and stored at room temperature. Seeds were subsequently immersed in water for 24 hours, placed within moist gunny bags, and left to sprout for approximately thirty hours. The sprouted seeds of genotypes were evenly distributed in a well-prepared nursery bed. Proper precautions were taken to protect seeds in the nursery-bed and ensured the cultivation growth of healthy seedlings for 30 days.

Land preparation and fertilizer

To prepare the land, it was initially tilled with a tiller, followed by ploughing and levelled. After removing residues from field, the plots were laid out according to design specifications. Three days prior to transplanting, field received broadcast applications of triple super phosphate (TSP), muriate of potash (MOP), and gypsum at the rate specified in Table 2. Urea was applied in three equal doses as top dressing at 15, 30, and 45 days after transplanting. Chelated zinc was also applied to the plants at 25 and 50 days after transplanting meeting their zinc requirements.

Table 1: *Selected genotypes with their key features and sources of collection.*

	Main features	Sources of collection
Modern varieties		
BRRI dhan34	Aromatic and heat-sensitive cultivar	Bangladesh Rice Research Institute (BRRI), Regional Sstation, Sonagazi, Feni
BRRI dhan52	Flood-tolerant (12-14 days), clean rice medium slender, Aman cultivar	BRRI, Regional-Station, Sonagazi, Feni.
BRRI dhan100	Zinc-enriched, high-yielding, medium-slim grain, irrigated ecosystem	BRRI, Regional-Station, Sonagazi, Feni.
Binadhan-10	Early maturing, salt-tolerant variety	Bangladesh Institute of Nuclear Agriculture, Subarnachar, Noakhali.
Local varieties		
Rajashail dhan	Indigenous, saline and flood-tolerant.	Farmers of Noakhali sadar, Noakhali.
Tulshimala	Photosensitive Aman rice variety	Bangladesh Institute of Research and Training on Applied Nutrition (BIRTAN), Subarnachar, Noakhali.
Birui	Indigenous and most prevalent	BIRTAN, Subarnachar, Noakhali
Lal Paika	red grains, high fibre, rich in antioxidants, drought-tolerant, nutrient-dense, adaptable to diverse environments	BIRTAN, Subarnachar, Noakhali
Hail dhan	Popular coastal regions (Noakhali, Laxmipur, Chandpur) in Aman	Farmers of Companyganj, Noakhali.
Swarna	Indian cultivar, popular in the northern region.	Farmers of Subarnachar, Noakhali.

Table 2: *Fertilizer dosage used for this experiment.*

Fertilizer	Dose/Ha
Urea	200 kg
TSP	100 kg
MOP	70kg
Gypsum	60 kg

Data collection and parameters

Nine parameters (i.e., days to maturity (DM), plant height (PH), panicle length (PL), number of tillers per plant (NT), number of effective tillers per plant (NET), number of grains per hill (NG), number of unfilled grains per hill (NUG), 1000-grain weight (1000GW), and Yield) were recorded from ten randomly selected plants within each plot. PH and PL were measured using a measuring tape, while number of tillers and grains (both filled and unfilled) were manually counted. The 1000GW weight was ascertained after drying collected grains from each plot. Subsequently, the grain yield per plot was quantified and converted to ton/ha.

Data analysis

Data on yield-related numerical features were analyzed using MINITAB 17 statistical software (Minitab Inc., State College, Pennsylvania, USA) and R studio version 4.3.0. Analyses of variance (ANOVA) and Tukey's test were conducted using MINITAB 17 following the application of the general linear model (GLM) to identify significant differences between genotypes for the studied traits. Additionally, correlation analysis and principal component analysis were also performed using R Studio to examine associations among traits.

Results and Discussion

Analysis of variance

The analysis of variance (ANOVA) results for the growth and yield contributing traits, including days to maturity (DM), plant height (PH), panicle length (PL), number of tillers per plant (NT), number of effective tillers per plant (NET), number of grains per hill (NG), number of unfilled grains per hill (NUG), 1000-grain weight (1000GW), and yield, revealed a highly significant ($p < 0.001$) variation among the genotypes (Table 3).

Mean performance of nine different traits of rice genotypes

The mean performance of eight studied traits of all genotypes is presented in Table 4 and their distribution is illustrated in Figures 1 and 2. In this study, days to maturity showed significant variation among genotypes in coastal region. BRRI dhan100 exhibited the maximum days to maturity (148 days), while Rajashail expressed the minimum (122.33 d) to reach maturity (Table 4, Figure 1a).

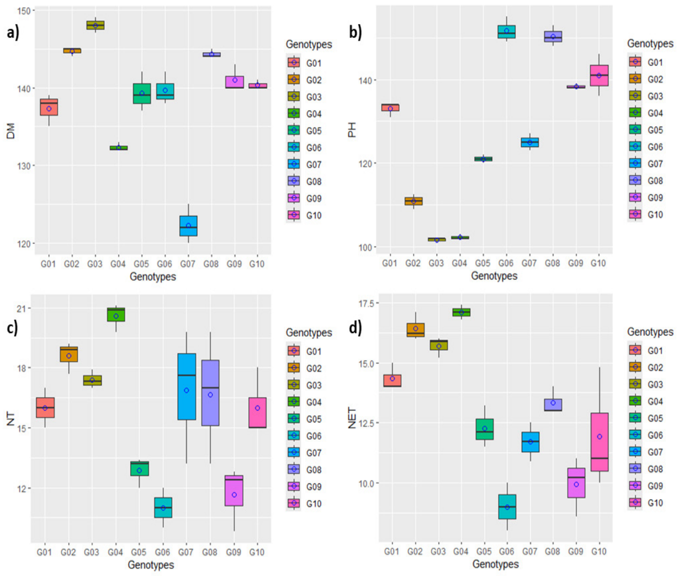

Figure 1: *Boxplots illustrating the distribution of (a) Days of maturity, (b) Plant height, (c) Number of tillers per plant, (d) Number of effective tillers per plant values. The blue points are mean values, and the horizontal lines dividing the box represent the medians. The lower and upper box boundaries, as well as the lower and higher whiskers, reflect the Q1 (25th percentile), Q3 (75th percentile) and Interquartile Range expressing middle 50% scores. Note: G1 (BRRI dhan34), G2 (BRRI dhan52), G3 (BRRI dhan100), G4 (Binadhan-10), G5 (Swarna), G6 (Tulshimala), G7 (Rajashail), G8 (Birui), G9 (Hail dhan), G10 (Lal paika).*

Table 3: *Analysis of variance (mean square) for different growth and yield contributing traits of ten rice genotypes.*

Source of variation	DM	PH	NT	NET	PL	NG	NUG	1000GW	Yield
Genotype	157.61***	1020.75***	28.042***	22.07***	11.53***	5820.23***	101.92***	92.57***	5.52***
Replication	8.23	0.16	5.95	3.43	1.82	171.86	3.80	0.36	0.093
Error	2.048	5.84	2.88	0.90	0.62	74.16	3.24	0.81	0.021

*Notes: ***Significance at P<0.001; DM = days of maturity, PH = plant height, DM = plant height, NT =number of tillers per plant, NET = number of effective tillers per plant PL = length of panicle, NG = no. of grains per hill, NUG = no. of unfilled grains per hill, 1000GW= 1000 grains weight.*

Table 4: *Mean performance of nine different traits of ten rice genotypes.*

Genotypes	DM	PH	NT	NET	PL	NG	NUG	1000GW	Yield
BRRI Dhan52	144.66AB	110.83 E	18.6 A	16.43 A	24.1 BC	188.73A-C	13.46 DE	41DE	5.033A
BRRI dhan100	148A	101.66 F	17.4 AB	15.69 AB	23.06A	156D	9.46EF	35.4GH	4.23B
BRRI dhan34	137.3D	133C	16A-E	14.33 ABC	26.82 A	200.66AB	18.13B-D	38FG	4.03 BC
Sarna	139.33D	121D	12.86 B-D	12.26 CD	26.6 ABC	175.96B-D	21A-C	44.33C	3.9 BC
Tulshimala	139.66D	151.66 A	11D	9E	24.58 C	124.33E	13.33 DE	33.56H	1.42F
Binadhan-10	132.33E	102.33 F	20.6A	17.1 A	23.05 AB	205.33A	13DE	43CD	5.23A
Rajashail	122.33F	125D	16.86 AB	11.7C-E	25.67 A-C	89.26F	25.13A	47.56B	3.27D
Birui	144.33A-C	150.33 A	16.66 A-E	13.33 BC	25.17 D	116.86E	6.33F	52A	3.77C
Hail Dhan	141BCD	138.33 BC	11.66 C-E	9.93 DE	20.16 A-C	87.13 F	16.33 CD	42.83CD	1.43 F
Lal Paika	140.33CD	141B	16A-C	11.93 CD	24.54 C	165.26CD	21.86AB	39EF	2.26E
SEM	2.29	5.83	0.79	0.59	0.62	13.49	1.84	4.22	0.43
CV	0.05	0.14	0.16	0.15	0.08	0.29	0.37	0.38	0.42

Notes: *DM = days of maturity, PH = plant height, DM = plant height, NT =number of tillers per plant, NET = number of effective tillers per plant PL = length of panicle, NG = no. of grains per hill, NUG – no. of unfilled grains per hill, 1000GW= 1000 grains weight.*

Plant height (cm) also exhibited significant variations, ranging from 101.66 cm to 151.66 cm (Table 4, Figure 1b). The local cultivar Tulshimala was the tallest (151.66 cm), whereas BRRI dhan100 was the shortest (101.66 cm). Regarding tiller number, Binadhan-10 had the maximum (20.6), whereas local variety (Tulshimala) was the lowest (11) (Table 4, Figure 1c). The maximum NET was found in Binadhan-10 (17.1), while the minimum in Tulshimala (9) (Table 4, Figure 1d). PL showed significant variation, ranging from 20.16 cm to 26.82 cm. The highest PL was observed in BRRI dhan34 (26.82 cm), and lowest in Hail dhan (Table 4, Figure 2e).

The number of grains per hill varied from 87.13 to 205.33 (Table 4, Figure 2f). Binadhan-10 had the highest NG, followed by BRRI dhan34, BRRI dhan52, Swarna, Lal Paika, BRRI dhan100, Tulshimala, Birui, Rajashail, and Hail dhan, respectively. Among these, local cultivar Rajashail had the maximum number of unfilled grains (25.13), whereas, minimum was found in Birui (6.33) (Table 4, Figure 2g). The genotypes also showed significant variation in 1000-GW, ranging from 33.56 g to 52 g. Birui had the maximum 1000 GW, while Tulshimala had the lowest (Table 4).

Considering yield, the modern variety Binadhan-10 (5.23 t/ha) yielded the maximum, followed by BRRI dhan52 (5.033 t/ha), BRRI dhan100 (4.23 t/ha), BRRI dhan34 (4.03 t/ha), Swarna (3.9 t/ha), Birui (3.77 t/ha), Rajashail (3.27 t/ha), Lal Paika (2.26 t/ha), Hail dhan (1.43 t/ha), and Tulshimala (1.42 t/ha), respectively (Table 4, Figure 2h).

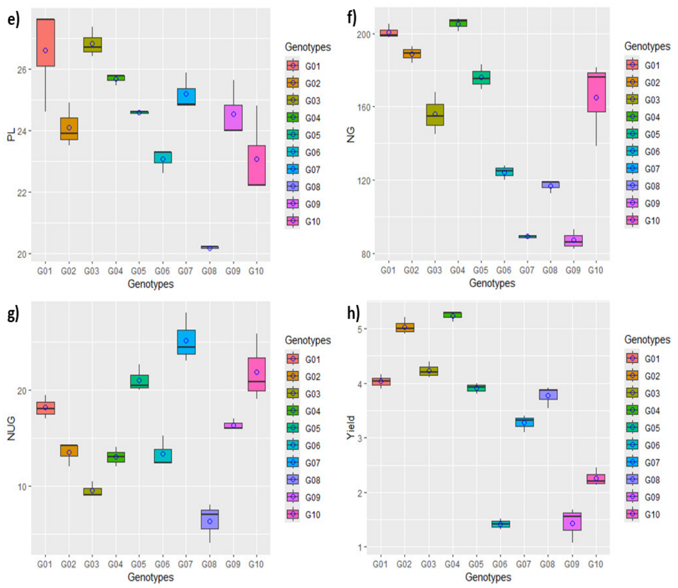

Figure 2: *Boxplots illustrating the distribution of (e) Length of panicle, (f) No. of grains per hill, (g) No. of unfilled grains per hill, (h) yield values. The blue points are mean values, and the horizontal lines dividing the box represent the medians. The lower and upper box boundaries, as well as the lower and higher whiskers, reflect the Q1 (25th percentile), Q3 (75th percentile) and Interquartile Range expressing middle 50% scores. Note: G1 (BRRI dhan34), G2 (BRRI dhan52), G3 (BRRI dhan100), G4 (Binadhan-10), G5 (Swarna), G6 (Tulshimala), G7 (Rajashail), G8 (Birui), G9 (Hail dhan), G10 (Lal paika).*

Correlation studies

Pearson correlation coefficients between all yield and yield-attributing morphological traits are shown in Figure 3. In the study, out of 36 associations, 10 significantly correlated associations were found. Yield showed a significant positive correlation with NET ($p < 0.001$), as well as positive correlations with NT ($p < 0.01$) and NG ($p < 0.05$). Conversely, yield had a negative correlation with PH (p < 0.05). NET was positively associated with NT (p < 0.001) and NG (p < 0.05). Additionally, PH also had in negative correlation with NET at $p < 0.01$ but with NT and PL at $p < 0.05$ (Figure 3).

Principal component analysis

Principal component analysis (PCA) was applied to analyze the experimental dataset comprising ten rice cultivars for 9 parameters, aiming to reduce data dimensionality and explore relationships among measured traits (Figure 4). The results of PCA indicated that first three principal components (PCs) with eigenvalues exceeding 1 explained 86.33% of total variance (Figure 4b). Notably, first two PCs, which collectively explained 68.01% of variance, were used to construct a PCA biplot (Figure 4a). PC1, contributing 46.8% total variability, was primarily associated with traits such as NET, Yield, PH, NT, NG, PL, and NUG (Figure 4a, c). PC2 explained an additional 21.2% of variability and predominantly linked with NUG, DM, PL, PH, NET, Yield, and 1000-GW (Figure 4a, d). Interestingly, PC1 notably separated high-yielding genotypes G01, G02, G03, and G04 from the low-yielding genotypes G06, G09, and G10 (Figure 4a).

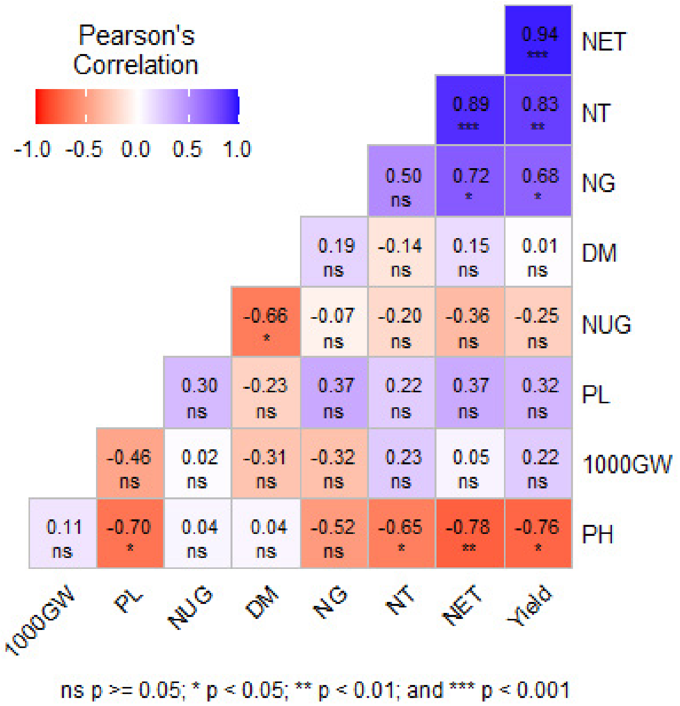

Figure 3: *Correlation analysis among the studied parameters. DM= Days of maturity; PH= Plant height; NT = number of tillers per plant; NET= number of effective tillers per plant; PL= length of panicle; NG= no. of grains per hill; NUG= no. of unfilled grains per hill; 1000GW= 1000 grains weight.*

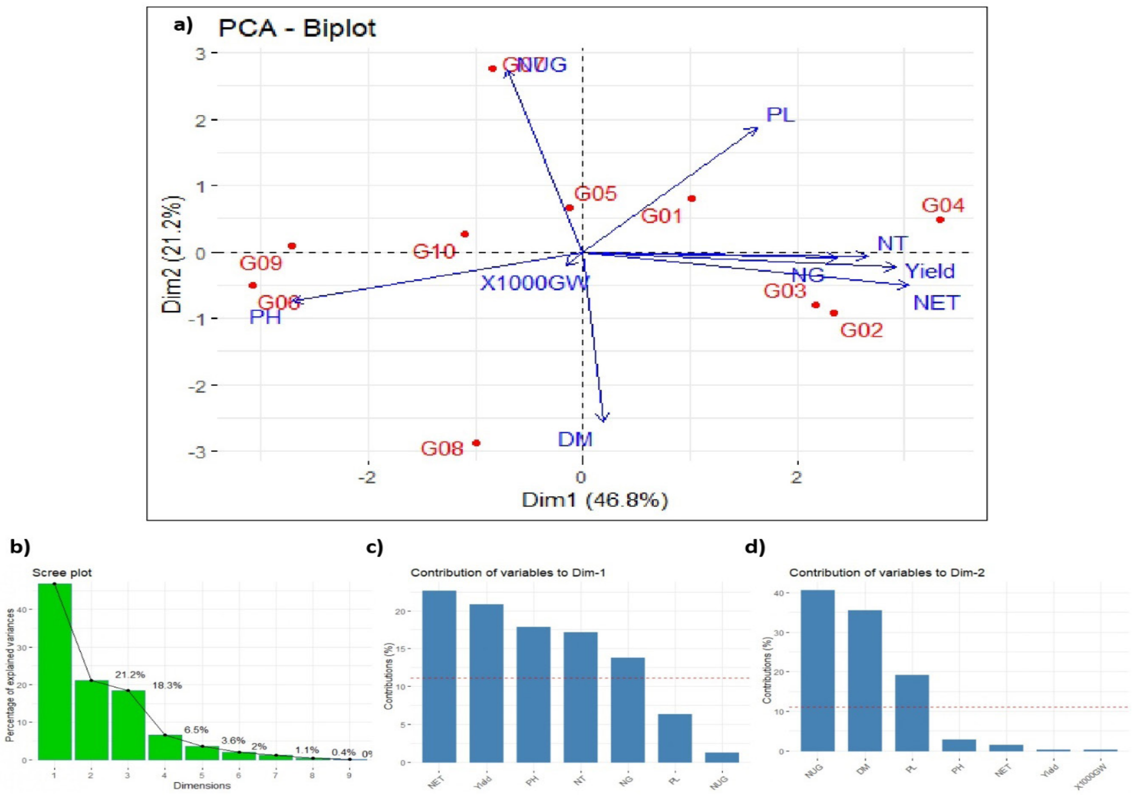

Figure 4: *(a) Principal component analysis of all the studied traits among the 10 genotypes. (b) The proportion of the dimensions (PCs). (c) Contribution of traits in dim-1. (d) Contribution of traits in dim-2. Note: G1 (BRRI dhan34), G2 (BRRI dhan52), G3 (BRRI dhan100), G4 (Binadhan-10), G5 (Swarna), G6 (Tulshimala), G7 (Rajashail), G8 (Birui), G9 (Hail dhan), G10 (Lal paika). DM = days of maturity; PH = plant height; DM = plant height; NT =number of tillers per plant; NET = number of effective tillers per plant; PL = length of panicle; NG = no. of grains per hill; NUG – no. of unfilled grains per hill; 1000GW= 1000 grains weight.*

Analysis of variance

The ANOVA performed on ten rice genotypes across nine quantitative traits revealed significant differences (P ≤ 0.001) for all traits assessed (Table 3). This indicates substantial variability among the genotypes, suggesting that each genotype possesses unique genetic traits that contribute to their performance. This variability presents rice breeders with the opportunity to select and combine genotypes with desirable traits through selective breeding and hybridization. Such approaches can enhance the suitability of rice varieties for saline soils in coastal regions, ultimately improving crop resilience and yield in challenging environments (Chowdhury *et al.*, 2023; Hannan *et al.*, 2020; Osundare *et al.*, 2017).

Mean performance of eight different traits of 8 rice genotypes

The mean performance of all the studied traits showed a significant amount of variability among the genotypes, enhancing potential for selection in breeding programs. The mean performance of genotypes plays a crucial role in determining genotypic diversity (Iqbal *et al.*, 2018). Developing early-maturing rice varieties is a critical research priority for sustainable rice production in the salt-affected coastal regions of Bangladesh. These varieties are crucial for protecting rice cultivation from prolonged salinity exposure. Additionally, plant growth and maturity phases significantly impact rice production. In this study, Rajashail emerged as an early-maturing variety, maturing 10 to 25 days earlier than the modern varieties, indicating its potential to avoid prolonged saline conditions. Other researchers have reported similar variations in days to maturity among their studied rice genotypes (Sabouri *et al.*, 2008). The early maturity of Rajashail aligns with the goal of selecting varieties suitable for short-season environments where salinity is a major concern. Plant height is an important crop growth characteristic as it influences yield-contributing traits and impacts grain production (Sandhu *et al.*, 2019). In rice breeding, height is significant due to its connection with effective carbon assimilation. Breeding programs typically prefer shorter plants since tall, thin-stemmed plants often have lower yield potential and are more susceptible to lodging (Ni *et al.*, 2000; Luz *et al.*, 2016). However, taller plants with thicker stems should not be overlooked. In this study, shorter plants were associated with higher yields (Figure 3). Among all the genotypes, the modern cultivar BRRI dhan100 was the shortest. This finding supports the trend in modern breeding, where semi-dwarf varieties like BRRI dhan100 are selected for their higher yield and resilience to lodging, making them ideal for intensive farming systems. The number of tillers, especially effective tillers, is crucial in rice breeding. Effective tillers, being panicle-bearing, significantly contribute to the final yield. The study observed significant variability in the number of effective tillers (NET) among the genotypes. All the modern cultivars (Binadhan-10, BRRI dhan34, BRRI dhan52, and BRRI dhan100) had comparatively more effective tillers than the local cultivars. These findings align as well as contradict in some extent with previous researchers (Hannan *et al.*, 2020; Chowdhury *et al.*, 2023). Higher NET among modern cultivars suggests enhanced resource use efficiency, while local varieties may exhibit lower tillering capacity, limiting their yield potential under improved management practices. Panicle length serves as a crucial trait in yield-related research for rice breeders, as longer panicles with higher numbers of filled grains typically correlate with increased yield potential. Previous studies have consistently shown that rice yield is influenced significantly by factors such as panicle density per unit area, the proportion of filled grains per panicle, and the weight of 1000 grains (Garcia *et al.*, 2015). In this study, the modern genotype BRRI dhan34 exhibited longer panicles compared to other genotypes. Although, except for the local variety Hail dhan, the other genotypes had panicle lengths similar to BRRI dhan34.

One of the most critical factors influencing yield is the number of grains per panicle, with fully viable grains directly enhancing rice yield (Xu *et al.*, 2024; Gravois and McNew, 1993). However, a higher number of unfilled grains can reduce the overall yield in rice plants. Therefore, selecting a higher number of filled grains and minimizing the number of unfilled grains is essential in rice breeding. In this study, significant variation was observed in these traits, indicating that the modern varieties performed better in both parameters compared to other genotypes. The modern varieties demonstrated a higher proportion of filled grains, highlighting their improved sink capacity and better grain filling, which is crucial for achieving higher grain yield in competitive environments. Like other yield-contributing traits, the 1000-seed weight (1000-GW) is a crucial factor associated with higher yield per plant. Our current research findings indicate a significant variation in 1000-GW, ranging from 33.56 g to 52 g. Grain yield is the ultimate goal for plant breeders, with rice breeders focusing on developing high-yielding cultivars that consistently perform well (Iqbal *et al*., 2018). This study identified notable yield variation among the genotypes, emphasizing that the modern variety Binadhan-10 exhibited the highest yield with 5.23 tons/ha among those examined, with other modern varieties also performing commendably. Overall, modern varieties showed superior yield compared to local cultivars. Other researchers also found significant diversity in agro-morphological traits across their studied rice genotypes (Worede *et al*., 2014; Shrestha *et al*., 2021; Zahid *et al*., 2005). This suggests that breeding efforts focused on modern cultivars are yielding tangible results in terms of productivity, but local varieties still have niche advantages in specific environmental conditions, particularly in stress management.

Correlation analysis

In crop breeding, the primary objective is to boost yield while considering other factors affecting crop growth. Since yield is determined by various genetic factors, solely focusing on it for selection may not be reliable. Correlation analyses shed light on genetic patterns and relationships among plant traits, aiding in the selection of traits for yield enhancement. Therefore, understanding the direction and strength of relationships between yield and related traits is crucial for making informed decisions in breeding programs (Jayasudha and Sharama, 2010; Ratna *et al*., 2015). Yield exhibited strong positive correlations with the number of effective tillers, number of tillers, and number of grains. Similarly, previous studies by Chowdhury *et al*. (2023) and Hannan *et al*. (2020) also reported positive relationships between these traits and yield, as they collectively influence overall yield. It is commonly observed in cereal plants that semi-dwarf varieties tend to have higher yields than taller ones (Luz *et al*., 2016), a pattern reflected in our findings with a negative relationship between yield and plant height. Consistently, plant height also showed negative associations with NT, NET, and NG. Understanding these trait associations will provide valuable insights for plant breeders in optimizing breeding schemes and managing rice germplasm effectively.

Principle component analysis

PCA, a multivariate technique, simplifies complex data into principal components, helping researchers understand trait combinations and genetic relationships among crop varieties (Abdi and Williams, 2010). It aids in identifying trait combinations, assessing morphological variation, and establishing genetic relationships among crop germplasm. Essentially, it's like finding the key factors that shape a crop's characteristics. Higher coefficients in the analysis suggest traits that strongly influence crop distinctions (Sanni *et al*., 2012). In this study, the first two PCs explained most of the variance (68.01%). PC1 contributed 46.8% of the variance, mainly driven by traits such as NET, yield, PH, NT, and NG. PC2 explained 21.2% of the variance, primarily associated with NUG, DM, and PL. These two PCs captured most of the variability observed in rice germplasm collections, consistent with findings by Maji and Shaibu (2012). Furthermore, PC1 divided the genotypes into two groups based on their yield, with G01, G02, G03 and G04 exhibiting high yields and G06, G09, and G10 displaying low yields. Notably, all the high-yielding genotypes were modern varieties, while the low-yielding ones were from local varieties.

Conclusions and Recommendations

Developing rice varieties resilient to coastal conditions is crucial due to the adverse effects of soil salinity. This study conducted a comprehensive evaluation of ten prominent rice genotypes in Bangladesh's coastal regions, identifying significant morphological variability across all examined traits. Notably, Rajashail emerged as the earliest maturing genotype, while BRRI dhan100 and Binadhan-10 exhibited shorter plant heights. Among the evaluated genotypes, Binadhan-10 was identified as the highest-yielding variety, with all modern varieties outperforming local genotypes. The correlation study provided valuable insights, revealing a positive association between yield and the number of tillers, effective tillers, and grains, while indicating a negative correlation with plant height. Additionally, the principal component analysis (PCA) offered significant insights for future breeding programs. For effective crop improvement in coastal regions, breeders should prioritize Rajashail, BRRI dhan100, and Binadhan-10, focusing on enhancing traits such as the number of effective tillers and grains, alongside selecting for shorter plant heights. As a recommendation for farmers in Noakhali, Bangladesh, cultivating modern rice varieties particularly Binadhan-10 during the Aman season is advised to achieve higher yields and improve resilience in saline soils.

Acknowledgements

The authors express their gratitude to all the teachers and staff of the Department of Agriculture, Noakhali Science and Technology University for guiding and helping them throughout the research.

Novelty Statement

This research is significant for its novel findings that modern rice varieties outperform local varieties in saline soils during the Aman season in Noakhali, Bangladesh. Among them, Binadhan-10 emerged as a high-yielding variety. The study recommends the adoption of this high-yielding, salt-tolerant variety by farmers to enhance productivity and resilience in challenging environments.

Author's Contribution

Md. Atiqur Rahman Bhuiyan and Iftakher Alam: Planned and designed the research.
Iftikhar Alam, Biswajit Das and Kazi Md. Younus Tanim: Conducted the fieldwork, collected data and analysed and visualised the data.
Iftikhar Alam, Biswajit Das and Rafiat Zannat: Wrote the manuscript.
Tarikul Islam, Amiya Das Hridoy and H. M. Fahad Hossain: Edited the manuscript.
Md. Atiqur Rahman Bhuiyan: Provided guidance throughout the research process and reviewed the manuscript. Lastly, the final draft was reviewed and approved by all authors.

Availability of data and materials
Data can be provided if needed.

Conflict of interest
The authors have declared no conflict of interest.

References

Abdi, H. and L.J. Williams. 2010. Principal component analysis. Wiley Interdiscip. Rev. Comput., 2(4): 433-459. https://doi.org/10.1002/wics.101

Ahmed, S., M. Das, M.R. Sojib, S.K. Talukder, S. Sultana, P. Datta, S. Islam and G.M. Mohsin. 2024. Evaluation of local and exotic hybrid genotypes of Yardlong bean (*Vigna unguiculata*) in Saline Prone Area of Bangladesh. Sarhad J. Agric., 40(2): 347-353. https://doi.org/10.17582/journal.sja/2024/40.2.347.353

Bangladesh Bureau of Statistics, 2018. Yearbook of Agricultural Statistics.

Bangladesh Bureau of Statistics, 2022. Yearbook of Agricultural Statistics.

Bray, E.A., J. Bailey-Serres and E. Weretilnyk. 2000. Responses to abiotic stress. In: (eds. B. Buchanan, W. Gruissem and R. Jones), Biochemistry and molecular biology of plants. Am. Soc. Plant Physiol. Rockville. pp. 158-1203.

Brolley, M., 2015. Rice security is food security for much of the world. Rice today. International Rice Research Institute (IRRI), DAPO Box 7777, Metro Manila, Philippines. pp. 30-32.

Chowdhury, N., S. Islam, M.H. Mim, S. Akter, J. Naim, B. Nowicka and M.A. Hossain. 2023. Characterization and genetic analysis of the selected rice mutant populations. Sabrao J. Breed. Genet., 55(1): 25-37. https://doi.org/10.54910/sabrao2023.55.1.3

Das, B., M.J.H. Jone, K.M.Y. Tanim, H. Kabir, N. Islam, T. Islam, A. Shila and R. Ahmed. 2024. Biochar-assisted amelioration of saline soil for optimal growth and yield of okra (*Abelmoschus esculentus* L.) Moench). J. Agric. Rural Res., 7(2): 19-33.

Dasgupta, S., M.M. Hossain, M. Huq and D. Wheeler. 2018. Climate change, salinization and high-yield rice production in coastal Bangladesh. Agric. Resour. Econ. Rev., 47(1): 66-89. https://doi.org/10.1017/age.2017.14

Fischer, R.A., D.R. Byerlee and G.O. Edmeades. 2009. Can technology deliver on the yield challenge to 2050? Paper prepared for expert meeting on how to feed the world in 2050. FAO, Rome.

Garcia, G.A., M.F. Dreccer, D.J. Miralles and R.A. Serrago. 2015. High night temperatures during grain number determination reduce wheat and barley grain yield: A field study. Glob. Change Biol., 21(11): 4153-4164. https://doi.org/10.1111/gcb.13009

Gravois, K.A. and R.W. McNew. 1993. Genetic relationship among and selection for rice yield and yield components. Crop Sci., 33: 249–252. https://doi.org/10.2135/

cropsci1993.0011183X003300020006x

Hannan, A., M. Islam, M.S. Rahman, N. Hoque, and G.H.M. Sagor. 2020. Morpho-genetic evaluation of rice genotypes (*Oryza sativa* L.) including some varieties and advanced lines based on yield and its attributes. J. Bangladesh Agric. Univ., 18(4): 923-933. https://doi.org/10.5455/JBAU.9328

Haque, M.A., 2006. Salinity problems and crop production in coastal areas of Bangladesh. Pakistan J. Agric. Res., 27(2): 220-225.

Iqbal, T., I. Hussain, N. Ahmad, M. Nauman, M. Ali, S. Saeed, M. Zia and F. Ali. 2018. Genetic variability, correlation and cluster analysis in elite lines of rice. J. Sci. Agric., 2: 85-91. https://doi.org/10.25081/jsa.2018.v2.900

Jayasudha, S. and D. Sharma. 2010. Genetic parameters of variability, correlation and path-coefficient for grain yield and physiological traits in rice (*Oryza sativa* L.) under shallow lowland situation. Electron. J. Plant Breed, 1(5): 1332-1338.

Kabir, M.S., M.U. Salam, A. Chowdhury, N.M.F. Rahman, K.M. Iftekharuddaula, M.S. Rahman, M.H. Rashid, S.S. Dipti, A. Islam, M.A. Latif, A.K.M.S. Islam, M.M. Hossain, B. Nessa, T.H. Ansari, M.A. Ali and J.K. Biswas. 2015. Rice vision for Bangladesh: 2050 and beyond. Bangladesh Rice J., 19(2): 1-18. https://doi.org/10.3329/brj.v19i2.28160

Kennedy, G., B. Burlingame and N. Nguyen. 2002. Nutrient impact assessment of rice in major rice consuming countries. Korea, 165(23.3): 12-15.

Khush, G., 2005. What it will take to feed 5.0 billion rice consumers in 2030. Plant Mol. Biol., 59: 1-6. https://doi.org/10.1007/s11103-005-2159-5

Lokeshkumar, B.M., S.L. Krishnamurthy, S. Rathor, A.S. Warriach, N.M. Vinaykumar, B.M. Dushyanthakumar and P.C. Sharma. 2023. Morphophysiological diversity and haplotype analysis of saltol QTL region in diverse rice landraces for salinity tolerance. Rice Sci., 30(4): 306-320. https://doi.org/10.1016/j.rsci.2023.02.001

Lu, J., D. Wang, K. Liu, G. Chu, L. Huang, X.Y. Tian and Zhang. 2020. Inbred varieties outperformed hybrid rice varieties under dense planting with reducing nitrogen. Sci. Rep., 10(1): 8769. https://doi.org/10.1038/s41598-020-65574-0

Luz, V.K.D., S.F.D. Silveira, G.M.D. Fonseca, E.L. Groli, R.G. Figueiredo, D. Baretta, M.K. Mauricio, A.M.D. Magalhães Junior, L.C.D. Maria and C.D. Oliveira. 2016. Identification of variability for agronomically important traits in rice mutant families. Bragantia, 75(1): 41-50. https://doi.org/10.1590/1678-4499.283

Maji A.T. and A.A. Shaibu. 2012. Application of principal component analysis for rice germplasm characterization and evaluation. J. Plant Breed. Crop Sci., 4(6): 87-93. https://doi.org/10.5897/JPBCS11.093

Mata, C.R.D., A.P. De Castro, A.C. Lanna, J.C. Bortolini, and M.G. De Moraes. 2023. Physiological and yield responses of contrasting upland rice genotypes towards induced drought. Physiol. Mol. Biol. Plants, 29(2): 305-317. https://doi.org/10.1007/s12298-023-01287-8

Megloire, N., 2005. The genetic, morphological and physiological evaluation of African cowpea genotypes. Master's thesis, University of Free State, BIoemrontein, South Africa.

Meng, T.Y., X.B. Zhang, J.L. Ge, X. Chen, Y.L. Yang, G.L. Zhu, Y.L. Chen, G.S. Zhou, H.H. Wei and Q.G. Dai. 2021. Agronomic and physiological traits facilitating better yield performance of japonica/indica hybrids in saline fields. Field Crops Res., 271: 108255. https://doi.org/10.1016/j.fcr.2021.108255

Muntha, S., R.S. Ratnakumari, M.G. Rani, S. Suneethakota, G.V. Kumar and I.U. Rani. 2024. Screening of rice (*Oryza sativa* L.) genotypes for salinity at reproductive stage. J. Exp. Agric. Int., 46(6): 404–408. https://doi.org/10.9734/jeai/2024/v46i62492

Ni, H., K. Moody, R.P. Robles, E.C. Paller and J.S. Lales. 2000. Oryza sativa plant traits conferring competitive ability against weeds. Weed Sci., 48: 200-204. https://doi.org/10.1614/0043-1745(2000)048[0200:OSPTCC]2.0.CO;2

Osundare, O.T., B.O. Akinyele, L.S. Fayeun and O.S. Osekita. 2017. Evaluation of qualitative and quantitative traits and correlation coefficient analysis of six upland rice varieties. J. Biotechnol. Bioeng., 1(1): 17-27. https://doi.org/10.22259/2637-5362.0101004

Parida, A.K. and A.B. Das. 2005. Salt tolerance and salinity effects on plants: A review. Ecotoxicol. Environ. Saf., 60: 324–349. https://doi.org/10.1016/j.ecoenv.2004.06.010

Pranaya, J., V. Roja, M.G. Rani, P.V.R. Rao, D.

Ramesh and B. Jyothsna. 2024. Evaluation of germplasm for reproductive stage salinity tolerance in rice (*Oryza sativa* L.). Int. J. Environ. Climate Change, 14(3): 465–478. https://doi.org/10.9734/ijecc/2024/v14i34057

Rahman, M.M. and J.D. Connor. 2022. The effect of high-yielding variety on rice yield, farm income and household nutrition: Evidence from rural Bangladesh. Agric. Food Secur., 11(1): 35. https://doi.org/10.1186/s40066-022-00365-6

Ratna, M., S. Begum, A. Husna, S.R. Dey and M.S. Hossain. 2015. Correlation and path coefficients analyses in basmati rice. Bangladesh J. Agric. Res., 40(1): 153-161. https://doi.org/10.3329/bjar.v40i1.23768

Sabouri, H., B. Rabiei and M. Fazalalipour. 2008. Use of selection indices based on multivariate analysis for improving grain yield in rice. Rice Sci., 15(4): 303-310. https://doi.org/10.1016/S1672-6308(09)60008-1

Sandhu, N., R.B. Yadaw, B. Chaudhary, H. Prasai, K. Iftekharuddaula, C. Venkateshwarlu and A. Kumar. 2019. Evaluating the performance of rice genotypes for improving yield and adaptability under direct seeded aerobic cultivation conditions. Front. Plant Sci., 10: 159. https://doi.org/10.3389/fpls.2019.00159

Sanni, K.A., I. Fawole, S.A. Ogunbayo, D.D. Tia, E.A. Somado, K. Futakuchi, M. Sie, F. Nwilene and R.G. Guei. 2012. Multivariate analysis of the diversity of landrace rice germplasm. Crop Sci., 52(2): 494-504. https://doi.org/10.2135/cropsci2010.12.0739

Sarma, B., H. Kashtoh, T. Lama Tamang, P.N. Bhattacharyya, Y.K. Mohanta and K.H. Baek. 2023. Abiotic stress in rice: Visiting the physiological response and its tolerance mechanisms. Plants, 12: 3948. https://doi.org/10.3390/plants12233948

Shrestha, J., S. Subedi, U.K.S. Kushwaha and B. Maharjan. 2021a. Evaluation of growth and yield traits in rice genotypes using multivariate analysis. Heliyon, 7(9). https://doi.org/10.1016/j.heliyon.2021.e07940

Shrestha, J., S. Subedi, U.K.S. Kushwaha and B. Maharjan. 2021b. Evaluation of rice genotypes for growth, yield and yield components. J. Agric. Nat. Res., 4(2): 339–346. https://doi.org/10.3126/janr.v4i2.33967

Sikirou, M., A. Shittu, Y.D. Moukoumbi, A.H. Arouna, C. Zokpon, R. Bocco, A. Najimu and V. Ramaiah. 2024. Field evaluation of rice lines derived from Suakoko 8 X Bao Thai for iron tolerance in the South Saharan African farming system. Plants, 13(12): 1610. https://doi.org/10.3390/plants13121610

Sogir, M.A., A.C. Sharma, S.S. Mithila, M. Rasel and A. Ferdausi. 2024. Morpho-molecular assessment of local rice (*Oryza sativa* L.) genotypes at seedling stage for salinity tolerance. Cereal Res. Commun., 52(2): 423–437. https://doi.org/10.1007/s42976-023-00438-7

Worede, F., T. Sreewongchai, C. Phumichai and P. Sripichitt. 2014. Multivariate analysis of genetic diversity among some rice genotypes using morpho-agronomic traits. J. Plant Sci., 9(1): 14–24. https://doi.org/10.3923/jps.2014.14.24

Xu, Y., W. Bu, Y. Xu, H. Fei, Y. Zhu, I. Ahmad, N.E.A. Nimir, G. Zhou and G. Zhu. 2024. Effects of salt stress on physiological and agronomic traits of rice genotypes with contrasting salt tolerance. Plants, 13(8): 1157. https://doi.org/10.3390/plants13081157

Yang, X.E., J.X. Liu, W.M. Wang, Z.Q. Ye and A.C. Luo. 2004. Potassium internal use efficiency relative to growth vigour potassium distribution and Krbohydrates alloKtion in rice cultivars. J. Plant Nutr., 27(5): 837-852. https://doi.org/10.1081/PLN-120030674

Zahid, A.M., M. Akhtar, M. Sabrar, M. Anwar and A. Mushtaq. 2005. Interrelation-ship among yield and economic traits in fine grain rice. In: Proceedings of the international seminar on rice crop. pp. 2-3.