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MITIGATING ADVERSE EFFECTS OF SALT STRESS USING EXOGENOUS PROLINE IN RICE (*Oryza sativa*)

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Abstract

Salt stress is certainly one of the most serious environmental factors limiting the productivity of rice plants, particularly in the coastal and salt-affected regions of Bangladesh. The present study was undertaken to investigate the effect of exogenous proline on the morphological, physiological, and biochemical responses of two rice (*Oryza sativa* L.) genotypes, namely BINA dhan23 and Sadamota under salt stress conditions (6 dS m⁻¹). The experiment was conducted in a net-house and laboratory of the Department of Biochemistry and Molecular Biology at Patuakhali Science and Technology University. The experimental treatments consisted of four combinations: T₁-control, T₂-proline spraying, T₃-salt stress and T₄-salt stress with proline spraying. A Randomized Complete Block Design (RCBD) with three replications was used. Data on plant parameters including plant height, tiller number, panicle and grain characteristics were recorded. The physiological and biochemical traits such as proline content, chlorophyll content, total sugar, and K⁺/Na⁺ ratios were analyzed in leaves. Results revealed that salinity significantly reduced yield-contributing traits such as panicle length, grain number, grain yield, and straw yield, BINA dhan23 produced substantially higher grain yield (21.8 g pot⁻¹) than Sadamota (5.58 g pot⁻¹), indicating its stronger reproductive resilience under salinity. The grain yield decreased under salt stress (10.6 g pot⁻¹) was partially recovered by proline spraying (11.4 g pot⁻¹). Similarly salt stress reduced straw yield (26.2 g pot⁻¹), while proline improved it under saline conditions (29.0 g pot⁻¹). Exogenous proline further enhanced leaf proline content (up to 114.9 mg 100 g⁻¹ fresh leaf), total sugar (9.06 mg 100 g⁻¹), and chlorophyll (5.04 mg 100 g⁻¹), while improving the K⁺/Na⁺ ratio (0.78 vs. 0.69 in Sadamota). The findings suggest that the combined use of salt-tolerant genotypes and foliar proline treatment offers a promising approach for enhancing rice productivity in salinity-prone areas. Further field-level validation is recommended to confirm these effects under diverse agro-ecological conditions.

Keywords: Chlorophyll, K⁺/Na⁺ ratios, Proline, Salt stress.

Introduction

Salinity is one of the most critical abiotic stresses constraining rice (*Oryza sativa* L.) production worldwide, particularly in deltaic and coastal ecosystems where soil and water salinity are recurrent problems (Haque *et al.*, 2008). Globally, over 1381 million

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hectares of land are affected by salinity, with an estimated 20% of irrigated agricultural lands suffering yield losses due to excess salt (FAO, 2024). In Bangladesh, about 1.05 million hectares of coastal land are salt-affected, predominantly during the dry season, severely reducing the productivity of rice-based cropping systems (Haque 2018; Khanam *et al.*, 2020). The adverse impacts of salinity include osmotic stress, ionic toxicity, nutrient imbalance, chlorophyll degradation, and disruption of physiological and metabolic processes (Sharmin *et al.*, 2013; Jharna *et al.*, 2001, Haque *et al.*, 2023abc, 2024a). These effects collectively inhibit plant growth, impair reproductive development, and ultimately reduce grain yield (Jharna *et al.*, 2017a; Akter *et al.*, 2020; Dutta *et al.*, 2025).

Rice, as a glycophyte, is highly sensitive to salt stress, particularly during early seedling and reproductive stages (Barman *et al.*, 2025). Salinity-induced yield loss can exceed 64% in susceptible cultivars (Zheng *et al.*, 2023). Thus, developing and deploying salt-tolerant rice varieties and complementary management practices is a priority for sustaining rice production in coastal regions. While genetic improvement for salinity tolerance remains a long-term goal, physiological interventions such as the exogenous application of proline have emerged as promising, immediate strategies for enhancing stress resilience (Farooq *et al.*, 2023).

Proline, one of the mostly studied multifunctional amino acid, due to its roles in osmotic adjustment, stabilization of proteins and membranes, protection of photosynthetic pigments, and scavenging of reactive oxygen species (Jharna *et al.*, 2013, 2017b). Khanam *et al.* (2025) reported that proline content increases with increasing salinity stress; proline level is therefore act as an indicator of salt tolerance. Under salinity stress increasing proline accumulation effectively increases the osmotic pressure of the cell cytoplasm (Yan *et al.*, 2025). Although under saline conditions, plants naturally accumulate proline as part of their stress response; however, the endogenous levels are often insufficient to counteract severe stress which seeks additional supplementation of proline in plants (Verbruggen & Hermans, 2008). Recent studies have demonstrated that foliar application of proline can significantly improve plant water status, photosynthetic efficiency, ion homeostasis, and yield under salinity stress in cereals, including rice (Hayat *et al.*, 2012). However, the complex inter-relation of exogenous proline spraying with various rice genotypes under salinity stress is not well understood. The difference in genetic makeup among improved and traditional rice genotypes may respond differently to applied proline under salt stress, which needs thorough investigation. Despite growing evidence on the benefits of exogenous proline, its effectiveness varies with genotype, growth stage, and environmental conditions (Zhang *et al.*, 2025). Moreover, comparative assessments of high-yielding salt-tolerant varieties and traditional landraces under proline supplementation remain limited, particularly in the context of the South-Central coastal region of Bangladesh. This knowledge gap is critical, as genotype-specific responses can determine the practical applicability of proline-based interventions. The present study was therefore undertaken to evaluate the morphological, physiological, and biochemical responses of two

contrasting rice genotypes BINA dhan23 (a high-yielding salt-tolerant variety) and Sadamota (a traditional landrace) to exogenous proline application under salinity conditions.

Methodology

Experimental site and duration

The experiment was conducted in the net-house and laboratory of the Department of Biochemistry and Molecular Biology, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh. The study was carried out during the Aman season 2024 under open sunlight. The natural temperature and humidity were maintained in the study site.

Experimental materials

Two contrasting rice (*Oryza sativa* L.) genotypes were selected for the experiment (BINA dhan23 and Sadamota). BINA dhan23 is a high-yielding salt-tolerant rice variety, developed by Bangladesh Institute of Nuclear Agriculture. The Sadamota is a traditional local landrace which is very much adapted in the coastal environment.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with two factors and three replications. Factor 1 was variety ($V_1 =$ BINA dhan23, $V_2 =$ Sadamota), and Factor 2 was treatment, comprising four combinations: T_1 : control (no salinity, no proline), T_2 : proline spraying (75 mM), T_3 : salt stress (6 dS m^{-1} NaCl) and T_4 : salt stress + proline spraying (75 mM). A total of 24 pots were used, with each pot containing 8 kg of air-dried, sieved soil. Using 25-days old seedlings transplanting was done on 10 September 2024.

Fertilization

Basal fertilizers were applied at the rates of 100 mg N kg^{-1} soil, 25 mg P kg^{-1} soil, 40 mg K kg^{-1} soil, and 25 mg S kg^{-1} soil, using urea, triple superphosphate (TSP), muriate of potash (MOP), and gypsum, respectively. All fertilizers except urea were incorporated during final pot preparation, while urea was applied in two equal splits.

Imposition of salt stress and proline application

Salinity stress (6 dS m^{-1}) was imposed 20 days after transplanting by submerging the designated pots in a saline water tank. On the same day, 75 mM proline (Sigma-Aldrich, analytical grade) was sprayed as a foliar treatment, mixed with 0.1% Tween-20 as a surfactant. Second spraying of proline was done 35 days after transplanting during the morning hours to ensure optimum absorption.

Data collection on morphological parameters

At maturity all the plants were harvested at ground level. The BINA dhan23 was harvested on 16 November 2024 and Sadamota was on 7 December 2024. The parameters recorded were plant height (cm), number of tillers per pot, leaf length (cm) and width (cm), panicle length (cm), grains per panicle (no.), grain yield per pot (g) and straw yield per pot (g).

Physiological and biochemical parameters

Samples for physiological and biochemical analysis were collected 15 days after treatment application. Chlorophyll content was determined using the method of Coombs *et al.* (1985) by extracting fresh leaves with 80% acetone and measuring absorbance by spectrophotometer at 645 nm and 663 nm wavelength. The proline content was estimated by the method of Bates *et al.* (1973) using acid ninhydrin, with absorbance measured at 520 nm. Similarly, the total sugar content was determined following Dubois *et al.* (1956) using the anthrone method, with absorbance at 620 nm. The leaf Na⁺ and K⁺ content was measured with a flame photometer after wet digestion of dried leaf samples (Yoshida *et al.*, 1976). The K⁺ /Na⁺ ratio was calculated from the measured ion concentrations.

Statistical analysis

Data were statistically analyzed using the STAR (Statistical Tool for Agricultural Research) software developed by the International Rice Research Institute (IRRI). Analysis of variance (ANOVA) was performed, and treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% probability level.

Result and Discussion

Effect of proline spraying and salt stress on growth parameters of rice genotypes

The single effect of genotype on plant height was highly significant ($p < 0.001$). Among the varieties, Sadamota showed the tallest plants (132 cm), which was 18% higher than BINA dhan23 (112 cm), reflecting genotypic variability in growth response under the given conditions (Table 1). The taller nature of traditional rice genotype Sadamota also reported by Sume *et al.* (2023). Likewise, the single effect of salinity and proline application was also highly significant ($p < 0.001$). The tallest plants (126 cm) were observed in proline spraying, closely followed by the control (125 cm). In contrast, plant height declined under salt stress, registering only 117 cm. However, the application of proline under saline conditions improved plant height to 120 cm, suggesting a partial mitigative effect of proline against salt-induced growth inhibition. The interaction between genotype and treatment was statistically significant ($p < 0.05$). Under control and only proline conditions, Sadamota maintained a consistent height of 135 cm, significantly higher than BINA dhan23 (115-116 cm; Table 2). Under salt stress, both genotypes showed reduced height, but Sadamota (126 cm) still outperformed BINA dhan23 (108 cm). Notably, under salt stress with proline application, plant height in Sadamota increased to 132 cm, while BINA dhan23 reached 109 cm, indicating that exogenous proline mitigated salt-induced reductions in plant growth for both genotypes.

Salinity inhibits plant growth by disrupting water balance, nutrient uptake, and cell elongation processes (Shila *et al.*, 2016). In this study, salt stress (6 dS m^{-1}) significantly reduced plant height in both rice genotypes, consistent with earlier reports that ionic toxicity and osmotic stress under saline conditions lead to stunted plant development (Sikder *et al.*, 2016; Kumar *et al.*, 2018). Exogenous application of proline showed a beneficial effect under both normal and saline conditions. The improved plant height in salt stress with proline spraying treatment suggests that proline supplementation helps mitigate the adverse effects of salt stress (Khanam *et al.*, 2025).

Table 1. Plant growth parameters of rice genotypes as influenced by proline spraying under salt stress condition

Treatment combinations	Plant height (cm) ©	Tiller pot-1 (no.)	Leaf width (cm)	Leaf length (cm) ©
Single effect of variety				
V1: BINA dhan23	112	14.6 B	1.49 A	37.4
V2: Sadamota	132	16.8 A	1.15 B	50.9
Significance level	***	***	***	***
SE (±)	0.61	0.416	0.416	0.77
Single effect of salinity and proline				
T1: Control	125	16.0 A	1.35 AB	46.5
T2: Proline spraying	126	16.8 A	1.37 A	43.5
T3: Salt stress (6 dS m ⁻¹)	117	13.7 B	1.26 C	40.7
T4: Salt stress+Proline spraying	120	16.2 A	1.29 BC	45.9
Significance level	***	***	**	***
SE (±)	0.86	0.589	0.589	1.09
Variety:treatments interaction				
Significance level	*	NS	NS	***
SE (±)	1.21	0.833	0.833	1.54
CV (%)	1.22	6.51	4.58	4.27

Similar capital letter in a column was not significantly different at 5% probability level

©According to STAR software, when interaction effect was significant, the lettering was given in interaction table, rather than single effects

Table 2. Interaction effect between variety and treatments on different plant parameters of rice

Treatments	Rice varieties	
	BINA dhan23	Sadamota
Plant height of rice (cm)		
T ₁ : Control	115 A b	135 A a
T ₂ : Proline spraying	116 A b	135 A a
T ₃ : Salt stress (6 dS m ⁻¹)	108 B b	126 C a
T ₄ : Salt stress+Proline spraying	109 B b	132 B a
Leaf length (cm) of rice		
T ₁ : Control	38.6 AB b	54.4 A a

Treatments	Rice varieties	
	BINA dhan23	Sadamota
T ₂ : Proline spraying	39.9 A b	47.1 B a
T ₃ : Salt stress (6 dS m ⁻¹)	34.8 C b	46.5 B a
T ₄ : Salt stress+Proline spraying	36.1 BC b	55.7 A a
Number of grain panicle ⁻¹ of rice		
T ₁ : Control	98.73 A a	54.9 A b
T ₂ : Proline spraying	99.13 A a	55.3 A b
T ₃ : Salt stress (6 dS m ⁻¹)	94.80 A a	5.42 B b
T ₄ : Salt stress+Proline spraying	98.40 A a	6.08 B b

Similar capital letter in a column or similar small letter in a row was not significantly different at 5% probability level

The single effect of variety on tiller production was highly significant ($p < 0.001$). Sadamota produced a significantly higher number of tillers per pot (16.8) compared to BINA dhan23 (14.6) (Table 1). The single effect of salinity and proline treatment was also statistically significant ($p < 0.001$). Among the treatments, the highest number of tillers (16.8) was observed under only proline spraying, followed closely by salinity with proline spraying (16.2) and control (16.0). In contrast, the lowest tiller number (13.7) was recorded under salt stress, indicating a substantial reduction in tillering due to salinity. The application of proline under salt stress restored tiller number close to control levels. However, the interaction effect between variety and treatment was not significant, suggesting that the influence of treatment on tiller number was similar across both genotypes. In this study, salt stress significantly reduced tiller number per pot, likely due to osmotic and ionic toxicity that inhibit cell division and tiller initiation (Ahmed *et al.*, 2017; Sultana *et al.*, 2021; Kumar *et al.*, 2017). Application of exogenous proline significantly enhanced tiller production compared to salt stress alone, supporting its role as a protective osmolyte. The recovery of tiller number under salt stress with proline to levels comparable with the control suggests that foliar proline application can mitigate the inhibitory effects of salinity on vegetative growth.

A highly significant ($p < 0.001$) variation in leaf width and leaf length was observed between the genotypes (Table 1). BINA dhan23 recorded a significantly wider leaf (1.49 cm) than Sadamota (1.15 cm), while Sadamota showed markedly longer leaves (50.9 cm) compared to BINA dhan23 (37.4 cm), reflecting inherent varietal differences. The effect of salinity and proline treatments on those parameters were also significant ($p < 0.01$). The widest leaves were observed under treatment proline spraying (1.37 cm) and control (1.35 cm), while the narrowest leaves were under salt stress (1.26 cm). Leaf width slightly improved under salt stress with proline spraying (1.29 cm), suggesting that proline application partially mitigated the negative effect of salinity. Moreover, the longest leaves were found in control (46.5 cm) and salt stress with proline spraying (45.9 cm), followed by proline spraying (43.5 cm). The shortest leaves were recorded in salt stress (40.7 cm), confirming that salinity adversely affected leaf elongation. The

application of proline under salt stress helped in restoring leaf length close to the control condition. The interaction between variety and treatment was also significant ($p < 0.001$), as detailed in Table 2. Under salt stress, leaf length reduced in both genotypes, with BINA dhan23 showing 34.8 cm and Sadamota 46.5 cm. However, the application of proline under salinity improved leaf length, especially in Sadamota, which recorded the longest leaves (55.7 cm), surpassing even the control. In contrast, BINA dhan23 remained comparatively shorter (36.1 cm) across all treatments. However, the application of proline (T_2 and T_4) significantly improved both parameters. Proline likely mitigates salinity effects by maintaining cell turgor, scavenging free radicals, and protecting cellular structures (Nguyen *et al.*, 2021).

Effect of proline spraying and salt stress on yield and yield components of rice genotypes

As shown in Table 3, a highly significant ($p < 0.001$) difference was observed in panicle length between the two rice genotypes. BINA dhan23 exhibited a longer panicle (24.7 cm) than Sadamota (20.4 cm). Salinity and proline treatments also had a significant ($p < 0.001$) effect on panicle length. The highest panicle length was recorded under T_2 (Proline spraying, 23.6 cm) and T_1 (Control, 23.2 cm), while the lowest was under T_3 (Salt stress, 21.5 cm). Application of proline under salt stress (T_4) increased panicle length to 21.9 cm. However, the interaction effect was not significant (NS), indicating consistent treatment effects across both genotypes. Table 3 further shows that grains per panicle were significantly influenced ($p < 0.001$) by variety, treatment, and their interaction. BINA dhan23 produced significantly more grains per panicle (97.8) than Sadamota (30.4). Among treatments, the maximum grain count was recorded in T_2 (77.2) and T_1 (76.8). Salt stress drastically reduced grain number (T_3 : 50.1), while proline application under stress (T_4 : 52.2) offered slight improvement. The interaction effect was highly significant (Table 2). Under control and only proline conditions, BINA dhan23 maintained a high grain count (~99 grains panicle⁻¹), while Sadamota showed moderate values (~55 grains panicle⁻¹). Under salt stress, grain production in Sadamota dropped sharply to only 5.42 grains, while BINA dhan23 still retained 94.8 grains. Similar trends continued under salinity and proline spraying; proline showing a protective effect in both varieties but particularly in BINA dhan23, which retained high productivity under stress.

Grain yield data (Table 3) revealed a highly significant varietal difference ($p < 0.001$). BINA dhan23 produced substantially higher grain yield (21.8 g pot⁻¹) than Sadamota (5.58 g pot⁻¹). Salinity and proline application also had a significant impact ($p < 0.01$). The highest yield was recorded in control (17.3 g pot⁻¹), followed by only proline (15.5 g pot⁻¹). Yield decreased under salt stress (10.6 g pot⁻¹) but was partially recovered by proline spraying (T_4 : 11.4 g pot⁻¹). Straw yield (Table 3) further showed a significant ($p < 0.001$) difference between genotypes, with Sadamota outperforming BINA dhan23 (40.8 vs. 22.6 g pot⁻¹). Treatment effects were also significant ($p < 0.01$). The highest straw yield was observed in only proline spraying, 36.6 g pot⁻¹ and control (35.1 g pot⁻¹). Salt stress reduced straw yield (T_3 : 26.2 g), while proline improved it under saline conditions (T_4 : 29.0 g pot⁻¹). The interaction effect was not significant for both grain and straw yield, indicating similar response patterns across genotypes.

Salinity adversely affected several yield-contributing traits such as panicle length, grain number, grain yield, and straw yield, which is consistent with previous findings (Haque *et al.*, 2024b, 2025ab). Salt stress likely caused reproductive failure, pollen sterility, and poor grain filling, contributing to yield reduction (Jodder *et al.*, 2016; Haque and Hoque 2023, Haque *et al.*, 2025c). BINA dhan23 consistently outperformed Sadamota in grain-related traits under all conditions, indicating its stronger reproductive resilience under salinity. Notably, grains per panicle and grain yield were drastically reduced in Sadamota under salt stress, reflecting its higher sensitivity. These observations are in line with reports suggesting that varietal tolerance plays a crucial role in maintaining reproductive output under saline environments (Chen *et al.*, 2024).

The application of proline significantly mitigated the negative effects of salt stress across all measured traits. Particularly under T₄ (salt stress + proline), BINA dhan23 maintained high grain number and yield, indicating that proline can enhance salt stress tolerance more effectively in stress-tolerant genotypes. In contrast, Sadamota, although superior in straw yield and vegetative vigor, performed poorly in reproductive traits under salt stress. This indicates that vegetative growth does not always correlate with reproductive success under salinity, highlighting the importance of stress-resilient reproductive physiology. The results emphasize that selection of tolerant varieties (like BINA dhan23) combined with foliar proline supplementation can significantly improve yield performance in saline conditions. Grain yield of rice was strongly dependent of the number of grain production per panicle (Fig. 1).

Table 3. Yield and yield components of rice genotypes as influenced by proline spraying under salt stress condition

Treatment combinations	Panicle length (cm)	Grain panicle ⁻¹ (no.)	Grain yield pot ⁻¹ (g)	Straw yield pot ⁻¹ (g)
Single effect of variety				
V ₁ : BINA dhan23	24.7 A	97.8	21.8 A	22.6 B
V ₂ : Sadamota	20.4 B	30.4	5.58 B	40.8 A
Significance level	***	***	***	***
SE (±)	0.332	1.39	1.24	2.39
Single effect of salinity and proline				
T ₁ : Control	23.2 A	76.8	17.3 A	35.1 AB
T ₂ : Proline spraying	23.6 A	77.2	15.5 A	36.6 A
T ₃ : Salt stress (6 dS m ⁻¹)	21.5 B	50.1	10.6 B	26.2 C
T ₄ : Salt stress+Proline spraying	21.9 B	52.2	11.4 B	29.0 BC
Significance level	***	***	**	**
SE (±)	0.470	1.97	1.75	3.37

Variety: treatments interaction

Treatment combinations	Panicle length (cm)	Grain panicle ⁻¹ (no.)	Grain yield pot ⁻¹ (g)	Straw yield pot ⁻¹ (g)
Significance level	NS	***	NS	NS
SE (±)	0.664	2.79	2.47	2.47
CV (%)	3.61	5.32	12.10	4.77

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According to STAR software, when interaction effect was significant, the lettering was given in interaction table, rather than single effects

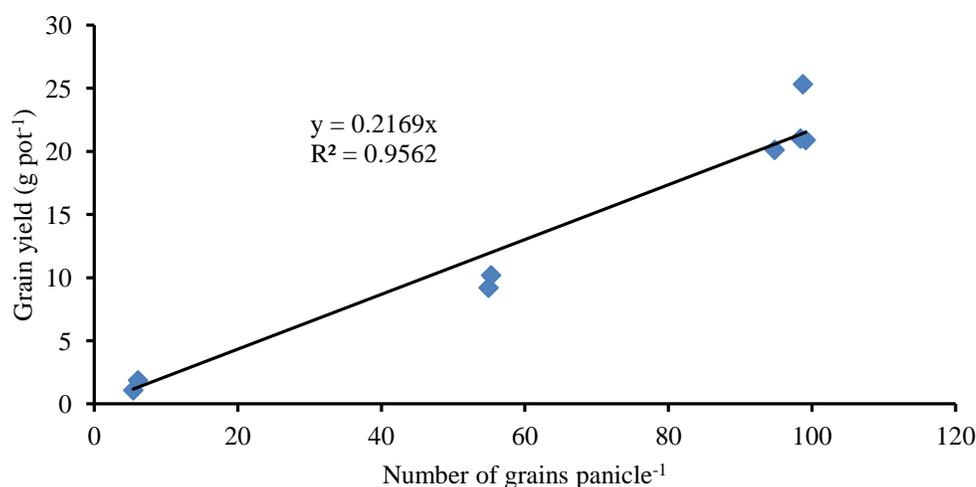


Fig. 1. Regression relation of number of grains panicle⁻¹ with grain yield of rice

Effect of proline spraying and salt stress on proline accumulation in rice genotypes

Proline, a key osmoprotectant, accumulated significantly in rice leaves in response to genotypic variation and treatment conditions, as well as their interaction (Table 4). The proline content was significantly higher ($p < 0.001$) in Sadamota (91.3 mg 100g⁻¹) compared to BINA dhan23 (61.9 mg 100g⁻¹). Among the treatments lowest proline level was found in control plants at 14.3 mg 100g⁻¹, representing basal metabolic levels. Salt stress alone increased proline to 105.3 mg 100g⁻¹, while proline spraying without stress raised it to only 72.1 mg 100g⁻¹, confirming the effectiveness of foliar proline application. The highest proline accumulation was observed in the combined salt stress and proline spraying treatment at 114.8 mg 100g⁻¹, indicating a synergistic effect where both endogenous synthesis (from salt stress) and exogenous application contribute to proline buildup. A highly significant ($p < 0.001$) interaction between genotype and treatment was observed (Table 5). Notably in control conditions, Sadamota accumulated more proline (17.3 mg 100g⁻¹) than BINA dhan23 (11.2 mg 100g⁻¹). Under salt stress

alone, both genotypes showed substantial increases, but Sadamota still maintained a slightly higher level ($109.7 \text{ mg } 100\text{g}^{-1}$) than BINA dhan23 ($100.8 \text{ mg } 100\text{g}^{-1}$). In proline spraying alone, Sadamota showed a dramatic spike in proline ($126.3 \text{ mg } 100\text{g}^{-1}$), far exceeding that of BINA dhan23 ($17.9 \text{ mg } 100\text{g}^{-1}$), indicating possible differences in foliar absorption or conversion efficiency. Interestingly, under combined salt stress + proline, BINA dhan23 ($117.7 \text{ mg } 100\text{g}^{-1}$) slightly exceeded Sadamota ($111.9 \text{ mg } 100\text{g}^{-1}$), though the difference was not statistically significant. Several studies also indicated that salt-tolerant rice cultivars accumulated higher proline than salt-sensitive rice under salinity stressed conditions (El-Banna and Mosa, 2024).

Table 4. Proline and total sugar content of rice genotypes as influenced by proline spraying under salt stress condition

Treatment combinations	Proline content mg 100g^{-1} fresh leaf ©	Total sugar content mg 100g^{-1} fresh leaf
Single effect of variety		
V ₁ : BINA dhan23	61.9	8.10
V ₂ : Sadamota	91.3	8.08
Significance level	***	NS
SE (\pm)	1.01	0.433
Single effect of salinity and proline		
T ₁ : Control	14.3	7.44 B
T ₂ : Proline spraying	72.1	7.10 B
T ₃ : Salt stress (6 ds m^{-1})	105.3	8.75 A
T ₄ : Salt stress + Proline spraying	114.9	9.06 A
Significance level	**	**
SE (\pm)	1.43	0.613
Variety:treatments interaction		
Significance level	***	NS
SE (\pm)	2.03	0.867
CV (%)	3.24	13.14

Similar capital letter in a column was not significantly different at 5% probability level

©According to STAR software, when interaction effect was significant, the lettering was given in interaction table, rather than single effects

Table 5. Interaction effect between variety and treatments on proline content (mg 100g⁻¹ fresh leaf) of rice

Treatments	Rice varieties	
	BINA dhan23	Sadamota
T ₁ : Control	11.2 D b	17.3 Ca
T ₂ : Proline spraying	17.9 C b	126.3 Aa
T ₃ : Salt stress (6 dS m ⁻¹)	100.8 Bb	109.7 Ba
T ₄ : Salt stress+Proline spraying	117.7 Aa	111.9 Bb

Similar capital letter in a column or similar small letter in a row is not significantly different at 5% probability level

Effect of proline spraying and salt stress on total sugar content in rice genotypes

The total sugar content (mg 100g⁻¹ fresh leaf) in rice plants was analyzed under varying treatments of salinity and proline application (Table 4). The results revealed that genotypic differences between BINA dhan23 and Sadamota were not statistically significant (NS), as both varieties recorded nearly identical total sugar levels (8.10 mg 100g⁻¹ and 8.08 mg 100g⁻¹, respectively). In contrast, the effect of salinity and proline treatments on total sugar content was statistically significant, indicating that stress and exogenous treatments played a major role in altering sugar metabolism. Among the treatments, the highest total sugar content was observed in salt stress combined with proline spraying at 9.06 mg 100g⁻¹, followed by salt stress alone at 8.75 mg 100g⁻¹. This increase in sugar under saline conditions could be attributed to osmotic adjustment and stress response mechanisms, where sugars act as compatible solutes to protect cellular structures and maintain turgor (Joseph *et al.*, 2018).

Chlorophyll content

Chlorophyll a content in rice leaves varied significantly ($p < 0.01$) between the two genotypes studied (Table 6). Sadamota recorded significantly higher chlorophyll a (4.08 mg 100g⁻¹) compared to BINA dhan23 (3.99 mg 100g⁻¹), suggesting a genotypic tendency toward higher pigment concentration. However, the effect of salinity and proline treatments on chlorophyll a was not statistically significant, with salt stress slightly reduced chlorophyll a content, while proline spraying under salt stress marginally improved it, but not at a significant level. A notable increase in chlorophyll b was observed in the salt stress with proline spraying treatment (1.10 mg 100g⁻¹), while salt treatment reduced it to 1.04 mg 100g⁻¹).

Total chlorophyll content was also not significantly different between genotypes. The treatment effect was, however, highly significant ($p < 0.001$). When salt was not imposed, the proline spraying had no significant effect on total chlorophyll content. However, under salt applied condition spraying had a significant effect to increase total chlorophyll content of rice, suggesting positive effect of proline on mitigating salinity stress in rice. This dramatic rise suggests that proline application under salt stress significantly enhanced chlorophyll synthesis or prevented its degradation, possibly due to proline's role in membrane and pigment stabilization (Pranto *et al.*, 2025).

Table 6. Chlorophyll content of rice genotypes as influenced by proline spraying under salt stress condition

Treatment combinations	Chlorophyll a content (mg 100g ⁻¹ fresh leaf)	Chlorophyll b content (mg 100g ⁻¹ fresh leaf)	Total chlorophyll content (mg 100g ⁻¹ fresh leaf)
Single effect of variety			
V ₁ : BINA dhan23	4.08 B	1.16	5.24
V ₂ : Sadamota	3.99 A	1.14	5.13
Significance level	**	NS	NS
SE (±)	0.159	0.065	0.166
Single effect of salinity and proline			
T ₁ : Control	4.28	1.26 A	5.54 A
T ₂ : Proline spraying	4.24	1.20 A	5.44 A
T ₃ : Salt stress (6 dS m ⁻¹)	3.68	1.04 C	4.71 C
T ₄ : Salt stress+Proline spraying	3.94	1.10 B	5.04 B
Significance level	NS	***	***
SE (±)	0.225	0.09	0.235
Variety:treatments interaction			
Significance level	NS	NS	NS
SE (±)	0.318	0.13	0.332
CV (%)	9.55	6.34	6.21

Similar capital letter in a column was not significantly different at 5% probability level

Effect of proline spraying and salt stress on potassium (K⁺) and sodium (Na⁺) content in rice genotypes

The potassium content of rice plants was significantly influenced by rice genotype, salinity and proline treatments, and their interactions (Table 7). Among the genotypes, BINA dhan23 showed significantly higher K⁺ (3.09%) compared to Sadamota (1.25%) under the tested conditions. Regarding treatment effects, the highest mean K⁺ was recorded in the proline spraying (T₂) treatment (2.41%), followed by the control (T₁) (2.36%), while the lowest K⁺ was observed under salt stress (T₃) (1.94%) and salt stress combined with proline spraying (T₄) (1.97%). The application of proline slightly improved the K⁺ under salt stress compared to salt stress alone, although the effect was modest. The significant interaction emphasizing those genotypic responses varied across treatments (Table 8). In the control condition (T₁), BINA dhan23 had the highest K⁺ (3.38%) compared to Sadamota (1.33%). Under salt stress (T₃), K⁺ dropped substantially in both varieties, but the reduction was more severe in Sadamota. Interestingly, proline spraying under salt stress (T₄) led to a slight improvement in K⁺ in BINA dhan23 (2.80%) compared to salt stress alone (2.75%), but the difference was not statistically significant as per letter annotations. These results are consistent with previous findings that potassium plays a key role in osmotic adjustment and salt tolerance, and that tolerant genotypes often maintain higher K⁺ levels under salt stress (Haque 2020).

Table 7. Potassium and sodium content of rice genotypes as influenced by proline spraying under salt stress condition

Treatment combinations	K ⁺ content (%) ©	Na ⁺ content (%) ©
Single effect of variety		
V ₁ : BINA dhan23	3.09	2.93
V ₂ : Sadamota	1.25	1.36
Significance level	***	***
SE (±)	0.059	0.053
Single effect of salinity and proline		
T ₁ : Control	2.36	1.69
T ₂ : Proline spraying	2.41	1.67
T ₃ : Salt stress (6 dS m ⁻¹)	1.94	2.63
T ₄ : Salt stress+Proline spraying	1.97	2.61
Significance level	***	***
SE (±)	0.084	0.075
Variety:treatments interaction		
Significance level	**	***
SE (±)	0.119	0.106
CV (%)	6.76	6.05

Similar capital letter in a column was not significantly different at 5% probability level

According to STAR software, when interaction effect was significant, the lettering was given in interaction table, rather than single effects

Table 8. Interaction effect between variety and treatments on K⁺% of rice

Treatments	Rice varieties	
	BINA dhan23	Sadamota
Potassium (%)		
T ₁ : Control	3.38 A a	1.33 A b
T ₂ : Proline spraying	3.44 A a	1.38 A b
T ₃ : Salt stress (6 dS m ⁻¹)	2.75 B a	1.14 A b
T ₄ : Salt stress+Proline spraying	2.80 B a	1.15 A b
Sodium		
T ₁ : Control	2.31 B a	1.07 B b
T ₂ : Proline spraying	2.23 B a	1.10 B b
T ₃ : Salt stress (6 dS m ⁻¹)	3.60 A a	1.66 A b
T ₄ : Salt stress+Proline spraying	3.60 A a	1.63 A b

Similar capital letter in a column or similar small letter in a row is not significantly different at 5% probability level

The sodium content was also significantly affected by genotype, treatment, and their interaction (Table 7 & 8). BINA dhan23 exhibited a significantly higher Na^+ content (2.93%) than Sadamota (1.36%). Treatment-wise, salt stress and salt stress with proline significantly increased Na^+ (2.63% and 2.61%, respectively), compared to the control and proline alone (1.69% and 1.67%, respectively). Under salt stress (T_3), BINA dhan23 showed a dramatic increase in Na^+ (3.60%) compared to Sadamota (1.66%) (Table 8). Similar patterns were observed in T_4 . The consistent pattern of lower Na^+ accumulation in Sadamota may be attributed to lower Na^+ uptake but at the cost of overall reduced growth and ion balance, as indicated by its lower K^+ values. This suggests that while BINA dhan23 accumulates more Na^+ , it maintains a better K^+/Na^+ ratio, which may contribute to its higher salt tolerance. Exogenously sprayed proline on rice under salt stress reduces its sodium concentration by inhibiting Na^+ uptake and translocation, which helps to maintain a higher K^+/Na^+ ratio, that contributes to the overall improvement of growth and yield in salt-affected rice plants (Koc *et al.*, 2024).

The K^+/Na^+ ratio is a critical indicator of salt tolerance, as a higher ratio reflects a plant's ability to maintain potassium uptake while restricting sodium accumulation. Under control and proline spraying alone, both genotypes maintained relatively high K^+/Na^+ ratios, with BINA dhan23 consistently outperforming Sadamota (Fig. 2). Salt stress significantly reduced the K^+/Na^+ ratio in both genotypes. However, BINA dhan23 retained a higher ratio (0.76) than Sadamota (0.69), suggesting better ionic regulation under stress. Proline application under salt stress slightly improved the K^+/Na^+ ratio in both genotypes (0.78 and 0.71, respectively), indicating a mild mitigated effect. The graph clearly shows that BINA dhan23 maintains a higher K^+/Na^+ ratio across all treatments. Salt stress sharply reduces this ratio, but proline helps buffer the decline, more noticeably in BINA dhan23. This confirms that BINA dhan23 is more salt-tolerant, and proline can moderately support ionic balance under stress.

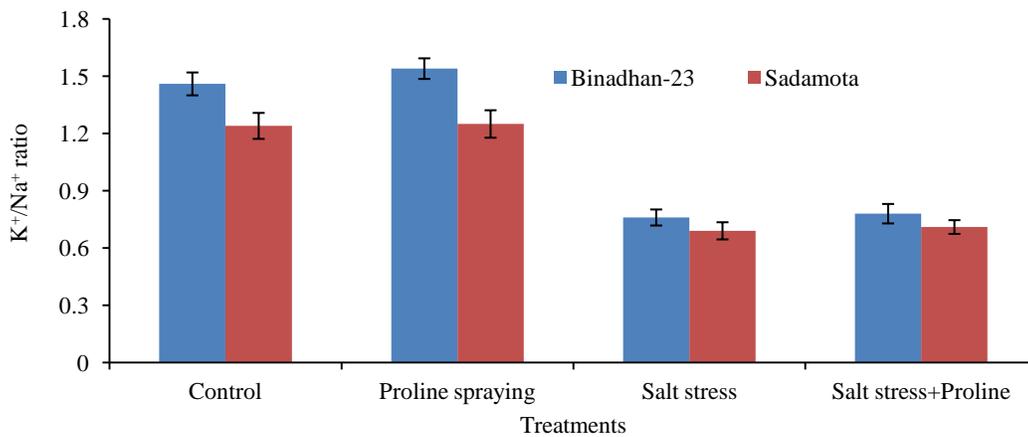


Fig. 2. K^+/Na^+ Ratio under different treatments of rice genotype Single and interaction effects were significant at 0.10% probability level

Conclusion

The findings of this study demonstrate that exogenous proline application can significantly mitigate the adverse effects of salt stress on rice growth and yield. Both BINA dhan23 and Sadamota responded positively to proline application under saline conditions, with improvements observed in key agronomic traits such as plant height, leaf development, grain number, and yield. Notably, proline application enhanced the accumulation of proline and helped maintain chlorophyll and ion balance, contributing to better stress tolerance. BINA dhan23 performed better in terms of grain yield and potassium retention, whereas Sadamota showed superior vegetative growth and proline accumulation under stress. These varietal differences suggest that proline's effectiveness may vary depending on genetic background. Overall, the results support the use of exogenous proline as a potential strategy to improve rice resilience in salt-affected areas. However, the main limitation of the current research; it was done in pot culture condition with only one induced salinity level (6 dS m^{-1}). The findings of the study are suggested to validate in field conditions under varying degree of salinity.

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Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

Authors' contribution

Study conception, research program formulation, materials supply, statistical analysis of data, tables and graph preparation, manuscript writing and editing, and research project funding was accomplished by Dilruba Easmin Jharna. Field activities, chemical analysis, data collection and manuscript writing were done by Md Mobarak Hossain. Fazla Rabbi helped in chemical analysis and data collection. All authors read and approved the final manuscript.

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EFFECTS OF FOLIAR APPLICATION OF ZINC AND BORON ON THE YIELD OF TOMATO

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Abstract

Zinc and Boron deficiencies in Bangladeshi soil is remarkable which is a major cause of yield loss of tomato. However, foliar spray of these micronutrients can be a cure of this problem. Field experiments were carried out during Rabi season of 2021-2022, 2022-2023 and 2023-2024 to evaluate the effect of foliar application of zinc (Zn) and boron (B) on the yield and yield attributes of tomato (var. BARI tomato21). Treatments included various combinations of Zn and B application at 300 ppm and 600 ppm. The experiment followed a Randomized Complete Block Design (RCBD) with three replications. The Zn and B were sprayed three times at 20, 40 and 60 days after transplanting (DAT). The treatment T₈, containing 600 ppm Zn and 300 ppm B foliar application showed the most significant impact on plant height (140.5 cm), number of branches per plant (3.23), number of fruits per plant (54.1), individual fruit weight (56.6 g) and marketable fruit yield (101.4, 88.8 and 91.3 t ha⁻¹, respectively in 2021-22, 2022-23 & 2023-24 cropping years). Over the span of three years, the T₈ treatment consistently outperformed other Zn-B combinations individual Zn or B application and the control in terms of fruit yield.

Keywords: Boron, Foliar application, Tomato, Yield, Zinc.

Introduction

Tomato (*Solanum lycopersicum*) is one of the most important vegetable crops in Bangladesh, contributing significantly to household nutrition and national agriculture. However, tomato production in the country is often constrained by nutrient-related challenges, particularly deficiencies of essential micronutrients such as zinc (Zn) and boron (B). These micronutrients play critical roles in plant growth and fruit development zinc is involved in various enzymatic activities and protein synthesis (Patel *et al.*, 2007), while boron is essential for cell wall formation (Dong *et al.*, 2018) as well as flower and fruit development (Rerkasem *et al.*, 2020). In many soils of Bangladesh, Zn and B deficiencies are widespread, leading to reduced crop vigor, lower yields, and poor fruit quality. To overcome these limitations, foliar application has emerged as an efficient method for supplying micronutrients directly to plants and enhances the yield and yield attributes of tomato crop. Previous studies suggest that foliar sprays of zinc and boron

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can significantly improve plant growth, fruit size, and overall yield of tomato (Bhujel et al., 2024). Therefore, evaluating the impact of foliar applications of zinc and boron on the yield and quality of tomato is essential for developing improved nutrient-management practices that enhance tomato productivity in Bangladesh (Sultana *et al.*, 2016). In this context, the present study was undertaken to assess the effects of different foliar concentrations of zinc and boron on the yield and yield attributes of tomato.

Materials and Methods

Description of the experimental site

Field experiments were set up during rabi season of consecutive three years from 2021-2024 at the Regional Agricultural Research Station (RARS) of BARI, Jashore. The site belongs to AEZ 11 i.e High Ganges River Floodplain. Before starting the first season trial, Soil samples from all treatments were collected at 0-15 cm depths. The soil samples were collected from the experimental field for analysis of soil properties (Tables 1 and 2). Soil texture was measured by hydrometer method (Black, 1965), soil bulk density (BD) was measured by core method (Karim *et al.*, 1988), Soil pH was measured by a glass electrode pH meter (Ghosh *et al.*, 1983), Soil Organic Carbon (SOC) was measured by the wet oxidation method (Jackson, 1973) and SOM was calculated by multiplying percent SOC with the van Bemmelen factor, 1.73 (Piper, 1942). Total N was measured by micro-Kjeldahl method (Bremner, and Mulvaney, 1982), available P by the 0.5 M NaHCO₃ (Olsen et al. 1954), exchangeable K by NH₄OAc extraction (Black, 1965), available S by CaCl₂ extraction (Fox *et al.*, 1964), available Zn by DTPA extraction (Lindsay and Norvell, 1978) and Available B content of soil was determined by the mono-calcium biphosphate [Ca(H₂PO₄)₂] extraction method (Page *et al.*, 1982). The analysis revealed that the textural class of the experimental soil was sandy clay loam with bulk density value was 1.40 g cm⁻³. Soils were slightly alkaline in nature with low levels of SOM (1020%) and P (15.0 mg kg⁻¹). On the other hand, the soils had very low levels of N (0.60%), K (0.15 meq 100 g soil⁻¹), Zn (0.52 mg kg⁻¹) and B (0.16 mg kg⁻¹).

Treatments and design

The experimental design was Randomized Complete Block Design (RCBD) with three replications of each treatment. The seedlings were raised in a seedbed and 30-days old tomato seedlings were transplanted into a 4- row 10 m² (4.0 m × 2.5 m) plot with planting spacing of 60 cm × 50 cm. The experiment included nine treatments with two micronutrients (Zn and B), applied through foliar spray as needed to thoroughly wet the entire plants in the plots, either individually or in combination, along with a control, at concentrations of 300 ppm and 600 ppm for each micronutrient. The treatments were as T₁ = control (no spray), T₂ = Foliar application of 300 ppm Zn at 20, 40 and 60 DAT, T₃ = Foliar application of 600 ppm Zn at 20, 40 and 60 DAT, T₄ = Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₅ = Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₆ = Foliar application of 300 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₇ = Foliar application of 300 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₈ = Foliar application of 600 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT and T₉ = Foliar application of 600 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT.

Table 1. Particle size distribution, textural class and bulk density of initial soil of the experimental field, RARS, Jashore

Soil depth (cm)	Particle size distribution			Textural class	Bulk density g cm ⁻³
	Sand%	Silt%	Clay%		
0-15	52.00	25.28	22.72	Sandy clay loam	1.40

Table 2. Initial soil nutrients status of the experimental field, RARS, Jashore

Soil depth (cm)	pH	SOM	Total N	Available level of nutrients				
		(%)	(%)	K meq 100 g soil ⁻¹	P	S	Zn mg kg ⁻¹	B
0-15	7.6	1.20	0.060	0.15	15.0	18	0.52	0.16
Interpretation	Slightly alkaline	Low	Very low	Very low	Low	Medium	Very low	Very low

Solution preparation

Prepared 1 liter of 300 ppm Zn solution by dissolving 1.32 grams of ZnSO₄·7H₂O in distilled water and made the volume up to 1 liter. Similarly, by dissolving 2.64 grams of ZnSO₄·7H₂O was in 1-liter distilled water for 600 ppm Zn solution. In addition, 2.65 grams of Borax (Na₂B₄O₇·10H₂O) was dissolved in 1-liter distilled water for 300 ppm B solution. Likewise, 5.30 grams of Borax (Na₂B₄O₇·10H₂O) was dissolved in 1-liter distilled water for 600 ppm B solution.

Fertilizer dose and method of application

The micronutrients were supplied in the form of borax and zinc sulphate, which are the sources of boron and zinc, respectively. Zinc and boron were applied through foliar spray, either individually or in combination, three times at vegetative stages (20 DAT), flowering stage (40 DAT) and early fruiting stage (60 DAT). A 300 ppm Zn and B foliar spray in tomato required 600 L ha⁻¹, total 180 g of Zn and B was needed per hectare. Similarly, 1200 L ha⁻¹ solution was needed for 600 ppm Zn and B solution where a total 360 g Zn and B was needed for 1 hectare of land. Zinc and boron were applied through foliar spray as needed to thoroughly wet the entire plants in the plots. On the other hand, a blanket dose of cow dung (10 t ha⁻¹), urea (300 kg ha⁻¹), TSP (200 kg ha⁻¹), and MoP (210 kg ha⁻¹) were applied. During final land preparation, the full amounts of cow dung and TSP, along with half of the MoP, were applied to soil. The remaining half of MoP and the entire urea were applied in two equal installments: the first at 15 DAT and the second at flowering stage (45 DAT).

Data collection and analysis

Ten plants from each plot during the harvest were selected randomly to collect the data on plant height, number of branches per plant, total and marketable fruits per plant, single fruit weight, and fruit yield per hectare. These data were statistically analyzed using Statistix 10 software. The mean values were calculated, and analysis of variance for each treatment was performed using the F-test. Differences between treatments were assessed using the Least Significance Difference (LSD) test at a 5% significance level (Gomez and Gomez, 1984).

Results and Discussion

Effects of zinc and boron on growth parameters

Spraying zinc and boron as a foliar application significantly increased the plant height of tomato. The tallest plant (140.5 cm) was observed in T₈ treatment (600 ppm Zn and 300 ppm B foliar application) during 2023-2024 year which is 26.9% higher than T₁ control treatment (Table 3). The T₈ treatment was statistically comparable to the T₇, T₆, and T₉ treatments. The number of branches per plant exhibited a similar pattern. The T₈ treatment recorded the highest number of branches per plant (3.23), followed by T₉ (3.03) and T₇ (3.02), as shown in Table 3 and the T₈ exhibited a 38.6% increase relative to the control. Our findings align closely with those of several other researchers. Sharma (1999) reported the tallest plants (70.6 cm) and the highest branch count (5.9) with 20 kg ha⁻¹ of borax, while the control had the shortest plants (59 cm) and fewest branches (4.8). Hamsaveni *et al.* (2003) observed a significant height increase (140.7 cm) in tomatoes with a 0.5% boron spray at 50% flowering. Hussain *et al.* (1989) found the greatest height improvement with 0.1% zinc and boron foliar spray. Bhatt *et al.* (2004) achieved 9.61 branches per plant due to 100 ppm each of boron and zinc. Barche *et al.* (2011) recorded the highest height (80.4 cm) and branch count (34.7) with H₃BO₃ and ZnSO₄ at 250 ppm. Ejaz *et al.* (2011) showed 6% zinc and 5% boron sprays significantly improved plant height and branches of tomato plants.

Effects of zinc and boron on the yield and yield attributes of tomato

Foliar application of Zn and B positively influenced tomato growth and yield. It also remarkably influenced the total and marketable fruit count per plant as well as the individual fruit weight. During 2023-2024, the T₈ treatment yielded the highest total number of fruits per plant (54.1), followed by the T₉ treatment (51.5 fruits). This represented a 36.9% increase for T₈ compared to the control treatment (T₁), which recorded 39.5 fruits, as detailed in Table 3. The T₈ treatment also produced the maximum number of marketable fruits (41.5), closely followed by T₉ (39.0). In contrast, the control treatment resulted in the lowest number of marketable fruits (27.9). The highest individual fruit weight was observed in the T₈ treatment (56.6 g), which was comparable to T₉ (54.4 g). Moreover, the yield per plant in the T₈ treatment was significantly higher at 2.75 kg compared to the other treatments. Our findings are consistent with many previous research results. Barche *et al.* (2011) highlighted the superior yield from combined boron (H₃BO₃) and zinc (ZnSO₄) sprays at 250 ppm, increasing fruit yield per plant (1.18 kg) and total yield (20 t ha⁻¹). Ali *et al.* (2013) confirmed similar findings,

noting the maximum yields from boron and zinc sprays (5 g per 100 ml each). Singh and Tiwari (2013) observed optimal yields using boric acid, zinc sulphate, and copper sulphate at 250 ppm each. Singh *et al.* (2014) reported tomato yields of 23.1 t ha⁻¹ with boron (0.2%) and zinc (0.4%) compared to the 14.5 t/ha control. Shnain *et al.* (2014) documented the highest fruit clusters (7.17), fruits per plant (88.3), and total yield (113.6 t ha⁻¹) with boron and zinc sprays (1.25 g per litre each). Combined application of micronutrients consistently demonstrated more effective than individual micronutrient treatments.

Table 3. Effects of zinc and boron as foliar spray on the yield contributing characters of tomato during 2023-24

Treat.	Plant height (cm)	No. of branches/plant	Total number of fruits/plant	Marketable fruits/plant	Individual fruit weight (g)	Fruit yield/plant (kg)
T ₁	110.7 d	2.33 f	39.5 e	27.9 g	37.2f	1.79 d
T ₂	114.9 d	2.40 ef	42.0 e	29.9 fg	41.8 e	1.93 cd
T ₃	116.3 cd	2.60 de	47.1 cd	30.9 efg	45.3de	2.22 bc
T ₄	119.5 cd	2.67 d	46.1 d	33.9 cde	44.6 de	2.22 bc
T ₅	126.6 bc	2.93 bc	48.1 bcd	35.3 cd	48.1 cd	2.12 bcd
T ₆	133.1 ab	2.77 cd	47.9bcd	32.7 def	51.4 bc	2.34 b
T ₇	133.3 ab	3.02 ab	50.5 abc	36.7 bc	52.4 b	2.22 bc
T ₈	140.5 a	3.23 a	54.1 a	41.5 a	56.6 a	2.75 a
T ₉	132.9 ab	3.03 ab	51.5 ab	39.0 ab	54.4 ab	2.39 b
LSD	10.91	0.25	3.8	3.4	4.14	0.35
CV%	5.03	5.28	4.63	5.71	4.99	9.07

Legend: T₁ = control (no spray), T₂ = Foliar application of 300 ppm Zn at 20, 40 and 60 DAT, T₃ = Foliar application of 600 ppm Zn at 20, 40 and 60 DAT, T₄ = Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₅ = Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₆ = Foliar application of 300 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₇ = Foliar application of 300 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₈ = Foliar application of 600 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT and T₉ = Foliar application of 600 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT.

Over three years of observation, tomato yields increased with foliar sprays of zinc and boron at different concentrations. Significant yield differences were seen among treatments, with the highest yield recorded in the T₈ treatment (foliar application of 600 ppm Zn + 300 ppm B). In the first year, the highest yield (101.4 t ha⁻¹) was obtained from T₈ (600 ppm Zn + 300 ppm B foliar application) treatment which was statistically comparable to T₇ (300 ppm Zn + 600 ppm B foliar application) and T₉ (600 ppm Zn + 600 ppm B foliar application) treatments. In the 2nd year, the highest yield (88.7 t ha⁻¹) of tomato was found in T₈ treatment which was statistically similar with T₄ and T₉ treatments (84.5 t ha⁻¹). The 2nd year showed slightly lower yields, possibly due to late sowing. In the 3rd year, the T₈ treatment produced the highest tomato yield which was

identical and followed by T₉ (89.9 t ha⁻¹), T₃ (91.5 t ha⁻¹), T₂ (84.6 t ha⁻¹), T₅ (83.6 t ha⁻¹), T₂ (84.6 t ha⁻¹) and T₆ (81.1 t ha⁻¹). The T₈ treatment achieved yields of 101.4, 88.7, and 91.3 t ha⁻¹ in the first, second, and third years, respectively, representing 34%, 18%, and 25% increases over the control yields of 75.4, 75.0, and 73.3 t ha⁻¹. The BARI tomato-21 variety also showed a 26% yield increase with foliar applications of Zn and Boron (Ullah *et al.*, 2015). Foliar application of 600 ppm Zn and 300 ppm B optimized plant physiological functions. Zinc is crucial for carbonic anhydrase enzyme synthesis, aiding CO₂ transport in photosynthesis (Alloway, 2008), enhancing photosynthetic efficiency and strengthening the antioxidant system in tomatoes (Faizan and Hayat, 2019).

Table 4. Effect of zinc and boron as foliar spray on the fruit yield of tomato over the years

Treatments	Fruit yield (t ha ⁻¹)		
	2021-22	2022-23	2023-24
T ₁	75.4 e	75.0 c	73.3 b
T ₂	77.2 de	75.5 c	84.6 ab
T ₃	76.8 de	83.3 b	91.5 a
T ₄	85.8 cd	84.5 ab	81.9 ab
T ₅	89.0 bc	80.6 b	83.6 ab
T ₆	91.1 bc	81.3 b	81.1 ab
T ₇	96.6 ab	83.2 b	72.3 b
T ₈	101.4 a	88.7 a	91.3 a
T ₉	98.0 ab	84.5 ab	89.9 a
LSD	9.5	5.1	2.1
CV%	6.23	3.57	9.41

Legend: T₁ = control (no spray), T₂ = Foliar application of 300 ppm Zn at 20, 40 and 60 DAT, T₃ = Foliar application of 600 ppm Zn at 20, 40 and 60 DAT, T₄ = Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₅ = Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₆ = Foliar application of 300 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT, T₇ = Foliar application of 300 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT, T₈ = Foliar application of 600 ppm Zn + Foliar application of 300 ppm B at 20, 40 and 60 DAT and T₉ = Foliar application of 600 ppm Zn + Foliar application of 600 ppm B at 20, 40 and 60 DAT.

Correlation matrix of yield and yield components

The correlation analysis revealed significant positive associations among all measured growth and yield attributes (Table 5). Plant height exhibited strong correlations with number of branches per plant ($r = 0.82$), total number of fruits per plant ($r = 0.84$), individual fruit weight ($r = 0.83$), and fruit yield per plant ($r = 0.75$), indicating its contribution to overall plant productivity. Number of branches per plant showed very strong correlations with total number of fruits per plant ($r = 0.97$) and marketable fruits per plant ($r = 0.97$), suggesting that branching is a major determinant of fruit-bearing capacity.

Total number of fruits per plant displayed the strongest correlations with individual fruit weight ($r = 0.97$) and fruit yield per plant ($r = 0.92$). Likewise, marketable fruits per plant was highly correlated with total fruits ($r = 0.94$), individual fruit weight ($r = 0.92$), and fruit yield per plant ($r = 0.86$). Individual fruit weight also showed a strong association with fruit yield per plant ($r = 0.90$), emphasizing its direct influence on yield.

Fruit yield per plant demonstrated the strongest correlation with fruit yield per hectare ($r = 0.88$), confirming that yield per plant is a reliable predictor of overall productivity. Fruit yield per hectare also correlated positively with total number of fruits per plant ($r = 0.85$) and number of branches ($r = 0.81$), although the correlation with plant height was relatively weaker ($r = 0.46$).

Table 5. Pearson correlation matrix of tomato yield and yield contributing characters during 2023-24 as affected by zinc and boron foliar spray

Parameters	Plant height	No. of branches/plant	Total number of fruits/plant	Marketable fruits/plant	Individual fruit weight	Fruit yield/plant	Fruit yield (t/ha)
Plant height	1						
No. of branches/plant	0.82	1					
Total number of fruits/plant	0.84	0.97	1				
Marketable fruits/plant	0.78	0.97	0.94	1			
Individual fruit weight	0.83	0.95	0.97	0.92	1		
Fruit yield/plant	0.75	0.85	0.92	0.86	0.90	1	
Fruit yield (t/ha)	0.46	0.81	0.85	0.79	0.78	0.88	1

Conclusion

Foliar application of zinc and boron notably improved tomato growth and yield. The T₈ treatment (foliar application of 600 ppm Zn + 300 ppm B) consistently produced the highest fruit yield and including the greatest number of fruits per plant, the most marketable fruits, and the heaviest individual fruit. Over a 3-year period, the T₈ treatment demonstrated consistent yield increases of 34%, 18%, and 25% compared to the control. These results highlight the beneficial effects of micronutrient application on tomato yield, suggesting that optimal levels of zinc and boron can significantly improve tomato production.

Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

Authors' contribution

N.U. Mahmud, N. Salahin and K.U. Ahammad conceptualized the study and designed the experiments. N. Salahin and N.U. Mahmud collected and analyzed the data as well as interpreted the results. Roknuzzaman drafted the text. N. Salahin and M.S. Kobir reviewed the results and finalized the manuscript.

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CHEMICAL SCARIFICATION UNLOCKING CASHEW NUT GERMINATION POTENTIAL

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Abstract

The Seed Technology Division of BARI, Gazipur carried out a lab test to identify the best chemical scarification agent for improving germination and seedling performance of cashew nut. Water and vinegar at 25% and 50% concentrations were used as chemical scarification means. The seeds were soaked into water and vinegars for 0, 24, 48, 72, and 96 hours following completely randomized design (CRD) with three replications. The results of the study reveal that germination percentage of cashew nut went up due to priming over varying times. Among the treatments, soaking cashew nut seeds in water for 72 hours was found as the most effective method for enhancing seed germination.

Keywords: Chemical scarification, Cashew seed germination, Dormancy breaking, Hydropriming, Vinegar.

Introduction

Cashew nut (*Anacardium occidentale L.*) is a rapidly expanding evergreen tree that is indigenous to northeastern Brazil. Cashew can be cultivated in various soil types, except wetlands. Subasinghe (2004) views that it requires minimal maintenance and helps protect soil erosion. Major cashew-producing countries include Brazil, Nigeria, India, Vietnam, and Cambodia (Ferreira-Silva *et al.*, 2009). In India, it grows well in states along the Bay of Bengal, particularly in coastal areas like West Bengal, Tamil Nadu, and Orissa (Rejani *et al.*, 2013). Although Bangladesh has a similar climate, it has not fully capitalized on its cashew production potential; the tree was introduced in Chittagong Division about 50 years ago (DAE, 2020). The Ministry of Agriculture is now prioritizing cashew planting in mountainous districts. However, seed dormancy poses challenges for successful seedling establishment, necessitating strategies to overcome this issue. There are two types of dormancy: chemical dormancy, caused by inhibitory substances in the fruit and seed covering, and physical dormancy, resulting from hard

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seed coats that block light, gases, and water (Fasidi *et al.*, 2000). Both types can occur simultaneously, and seeds with immature embryos may also not sprout (Nikolaeva, 2004). Bajehbaj (2010) states that chemical scarification improves seed vigor, accelerates germination, and enhances seedling growth in challenging conditions. Although there is limited research on osmotically treated seeds in field conditions, chemical scarification has shown promising results in okra seeds (Sanjay *et al.*, 2000). This method provides benefits for various crops, such as quicker emergence, uniform stands, reduced reseeded, stronger plants, drought resistance, earlier flowering, and increased seed yield (Chavan *et al.*, 2014; Harris *et al.*, 2001; Assefa *et al.*, 2008). Vinegar, which contains acetic acid, the one chemical used for scarification and is considered eco-friendly and promising for seed treatment (Tóbiás *et al.*, 2007). Studies have presented effective seed treatment techniques for ecological vegetable production, including antagonistic microorganisms, aerated steam and hot water treatments (Roberts *et al.*, 2006), plant extracts (Hartman *et al.*, 1995), essential oils, and natural acids (Tinivella *et al.*, 2004). Vinegar can also alter pH, making the environment unsuitable for germs. Borgen (2001) notes that acetic acid is a naturally occurring substance that poses minimal oral hazards to humans and animals. In order to promote cashew nut seed germination and advance the region's underdeveloped cashew plantation culture, this study was undertaken to determine the most effective chemical scarification therapy.

Materials and Methods

A two-factor Complete Randomized Design (CRD) with three replications of each treatment was followed. The experiment was set up in the Seed Technology Division research laboratory of BARI, Joydebpur, Gazipur. Cashew nuts (M-23 variety) were sourced from LA Agro Limited, Bandarban. Water, 25% vinegar, and 50% vinegar were used as chemical scarification (Factor A) and Soaking durations were 0, 24, 48, 72, and 96 hours (Factor B). All cashew nut seeds were cleaned three times using distilled water before vinegar treatments and were then disinfected for three minutes with 70% ethanol. Six beakers were labeled according to the vinegar concentrations after being cleaned with distilled water and a 10% bleach solution. The first beaker was filled with 100 milliliters of pure vinegar. The second beaker, labeled as 50%, received 50 milliliters of the 100% vinegar solution, followed by the addition of 50 milliliters of distilled water, which was then gently swirled. Similarly, the third beaker, designated as 25%, was filled with 25 milliliters of the 100% solution and then diluted with 75 milliliters of pure water, after which it was also swirled gently. Using soil media, seed germination was carried out at room temperature (25°C). Water and 25% and 50% vinegar solutions were used to soak the seeds for 24, 48, 72, and 96 hours. After soaking the seeds for each time duration their weights were taken and the initial weight of the seeds was recorded. The original weight was compared with the weight after soaking to calculate the amount of water absorbed. Total ten seeds were used for each solution, with three replications, in order to calculate an average percentage. The number of seeds that germinated was counted daily over a period of 30 days. The following formula was used to assess the seedlings' survival rate after 60 days.

$$\text{Survival rate (\%)} = \frac{\text{Total number of emerged seedlings} - \text{Total number dead seedlings}}{\text{Total number of emerged seedlings}} \times 100$$

Data analysis

Open-source R software was used to perform two-way analysis of variance (ANOVA) on the data collected to evaluate the impact of priming types and soaking duration on germination and associated parameters. The significant means were separated using the Least Significant Difference (LSD) test.

Results and Discussion

Effects of chemical scarification and soaking duration on the germination characteristics of cashew nut seeds

The germination capability of a single seed, which is based on a binary respond (germinated/non-germinated), is one qualitative aspect of the germination process that is commonly converted into a quantitative feature, typically given as a percentage. Figure 1 showed that there were variations (at the 5% level) between the treatments on germination characteristics and it resulted in significant changes in germination quality. The results of the study showed that the percentage of cashew nuts that germinated increased when chemical scarification was imposed for different duration of time. The results showed that the most effective treatment for improving seed germination was water with a 72-hour soaking time (73%), which was statistically different from all other treatments. Until the 72-hour soaking period, the germination percentage increased; after that, it began to decline for water. Germination went up quickly for 48 hours in a 25% vinegar solution before declining. Germination for a 50% vinegar solution only happens after a 24-hour soaking period. The findings showed that vinegar inhibited cashew nut germination. Mere *et al.* (2021) reported similar results.

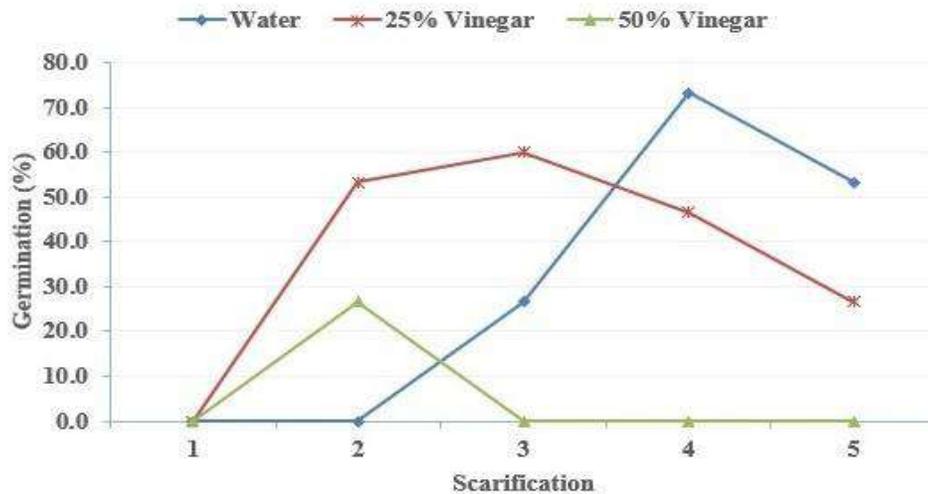


Fig. 1. Interaction effect of scarification types over time (1=0 h, 2=24 h, 3=48h, 4=72h and 5= 96 h) on germination

Similar to the aforementioned, Yao *et al.* (2022) observed that neem seed aqueous extract was efficient against the majority of pests. These aqueous extracts can be utilized in an integrated control program to combat key crop pests like cabbage. In align with this, Ndour *et al.* (2021) suggest that seed treatment is crucial to the survival of the species. Using 25% vinegar for 24 and 48 hours of priming yielded the highest survivorship value (Table 1a), which was statistically equal to all other treatments.

Every treatment had a survivorship rate of 80% or higher, indicating that treatments had no effect on survivability. According to Table 1b, hydration and priming for 72 hours with 25% vinegar hours resulted in the greatest number of leaves (11.0), whereas hydration for 96 hours and 25% vinegar for 48 hours produced the lowest number (7.0). According to Table 1c, the 72-hour soaking period produced the most leaf length (6.93 cm), which was statistically equivalent to the 96-hour soaking period. The 25% vinegar treatment produced the smallest leaf length (4.23 cm) after 96 hours of soaking.

The leaves with the largest diameter, measuring 3.43 cm, were soaked in a 25% vinegar solution for 24 hours. This treatment yielded results that were statistically similar to those of leaves soaked for 48 hours, as indicated in Table 1d. For the leaves with the smallest diameter, measuring 2.67 cm, a 25% vinegar solution was applied for 96 hours; this treatment was statistically equivalent to hydration over the same duration. The highest seedling length recorded was 17.00 cm after a 72-hour hydration period. This length was statistically comparable to the lengths observed after 24 and 96 hours of soaking in 25% vinegar, as well as 24 hours in a 50% vinegar solution, as shown in Table 1e. These results indicate that seedling length was not significantly affected by priming. The seeds that were soaked for 96 hours in all three combinations—hydration, 25%, and 50% vinegar solution-absorbed the most water, as shown by the results in Table 1f (6.17g, 5.79g, and 6.11g, respectively). The rate of water absorption increased with time.

Table 1a. Survivability (%)

Chemical Scarification/ Soaking duration	0h	24h	48h	72h	96h
Water	0	0	0	80.7	78.0
25% Vinegar	0	89.0	89.0	83.3	83.3
50% Vinegar	0	83.0	0	0	0
CV (%)			41.1		
LSD (0.05)			26.8		

Table 1b. Number of leaves

	0	24h	48h	72h	96h
Water	0	0	0	11.0	7.0
25% Vinegar	0	7.0	8.0	11.0	8.0
50% Vinegar	0	9.0	0	0	0
CV (%)			11.4		
LSD (0.05)			1.1		

Table 1c. Leaf length (cm)					
Water	0	0	0	6.93	6.27
25% Vinegar	0	5.70	6.00	5.63	4.23
50% Vinegar	0	5.10	0	0	0
CV (%)			11.9		
LSD (0.05)			0.75		

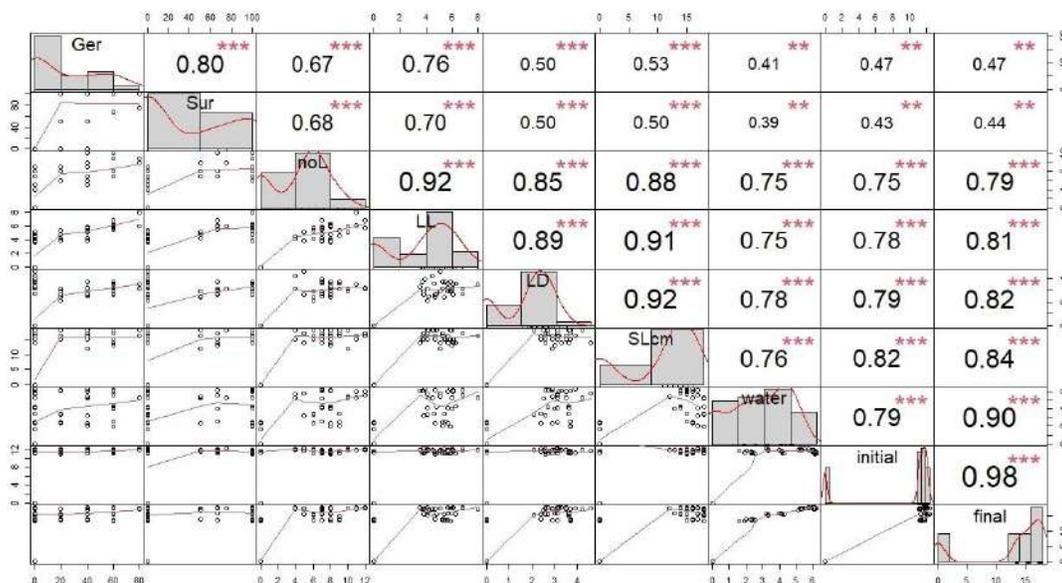
Table 1d. Leaf diameter (cm)					
Water	0	0	0	3.23	2.73
25% Vinegar	0	3.43	3.40	3.20	2.67
50% Vinegar	0	3.07	0	0	0
CV (%)			15.4		
LSD (0.05)			0.59		

Table 1e. Seedling length (cm)					
Water	0	0	0	17.0	15.3
25% Vinegar	0	16.3	13.7	14.3	16.0
50% Vinegar	0	16.3	0	0	0
CV (%)			10.4		
LSD (0.05)			2.00		

Table 1f. Amount of water absorbed after soaking (g)					
Water	0	2.12	3.28	5.34	6.17
25% Vinegar	0	2.25	4.12	5.73	5.79
50% Vinegar	0	2.26	3.90	5.60	6.11
CV (%)			7.71		
LSD (0.05)			0.45		

Correlation matrix

A linear link between different features was investigated using phenotypic correlation analysis, and the correlation matrix (Figure 1) illustrates this relationship. All of the parameters in this analysis showed a substantial positive connection with Germination (Ger). The majority of the metrics showed a high degree of positive association with one another. The amount of water absorbed during the soaking phase, leaf diameter (LD), and seedling length (SL) all showed somewhat positive significant connection with germination and survival. The strongest positive association was found between seedling length (SL) and leaf length (LL) and leaf diameter (LD).



*Ger-Germination, Sur-Survivability, noL-Number of leaves, LL-Leaf length, LD-Leaf diameter, SL-Seedling length, Water-Amount of water absorbed during soaking, Initial-Initial seed weight, Final-Final seed weight

There was positive significant correlation between seed germination and its survival and the amount of water absorbed during soaking period, leaf diameter (LD), and seedling length (SL). Seedling length (SL), leaf length (LL), and leaf diameter (LD) showed the strongest positive correlation.

Conclusion

The study suggests that vinegar can inhibit the germination of cashew nuts. It was noted that maintaining 72 hours' hydration period yielded the best results, exhibiting a seed germination rate of 73% which was significantly higher than vinegar treatments. The results suggest that vinegar had no influence on seed germination and simply adequate hydration is important for improving seed germination of cashew nut.

Conflicts of interest

The authors declare no conflicts of interest regarding publication of this manuscript.

Authors' contribution

The experiment's conception and design, field testing, data collection, and report writing were all done by M. S. Rahman. P. C. Sarkar helped the fieldwork, evaluated the text, and helped analyze the results. S. E. Akter and S. A. Mahmud revised the work and assisted in the literature review. T. Jahan and M. S. Reza helped performing the statistical analysis, and offering technical advice throughout the study.

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STRATEGIC ANALYSIS FOR SUSTAINING PRODUCTION AND SAVING WATER THROUGH INCREASING *T. AUS* AND *T. AMAN* RICE CULTIVATION IN BANGLADESH

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Abstract

Rice is a water-loving crop. Among the three rice growing seasons of Bangladesh, water demand is met in *Boro* through intensive irrigation largely utilizing underground water. Increasing pressure on underground water can cause water crisis in future hindering irrigation coverage of the entire production area in the season. With this background, this study explored revised seasonal land allocation between the rice growing seasons aiming probable land release from *Boro* season to sooth water crises. Options were also included in utilizing fallow land in their process. A conceptual framework was developed to address the issue. For the analysis, published and unpublished data were used. A model was developed and applied to simulate rice area, yield and production under four different scenarios. The results shows that the area under *T. Aus* can be increased from 1.28 to 2.0 mha in 2030 by utilizing 15% fallow land and shifting 5% of *Boro* area to *T. Aus*. Utilization of better varieties and proper management practices would ensure the target of rice production equilibrium in the proposed change scenarios, whereas mitigate potential water crisis by 4725 million liters. To establish these potentials, the study highlighted a number of pre-requisites to be looked into by various stakeholders.

Keywords: *T. Aman*, *T. Aus*, Cropping pattern, Intensive irrigation, Simulation.

Introduction

Rice is the staple food for Bangladeshi people and will continue to remain so in the future. In the year 2019, the net cultivated area was about 8.83 million hectares (mha), among them 7.88 mha land was irrigated (BBS, 2023). Bangladesh is the 3rd largest country in the world with respect to rice production (FAO, 2022). Because, rice is grown in all the three crop growing seasons of a year and it occupies about 11.68 mha land where production is 40.697 million metric tons (mmt) of the year 2023-24 (BBS, 2024). All modern *Boro* varieties are cultivated as irrigated rice, whereas only a small proportion of the *T. Aus* and *T. Aman* crops (7% and 5%, respectively) receive either full

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or supplemental irrigation. Production of 1 kg of irrigated rice mainly *Boro* type requires about 1606 liters of water as estimated in the north western region (Amin & Tuhin, 2025). With respect to natural water availability, about 96% of the total rainfall occurs during the period of April to October, statistically 13% of total rainfall occurs during post-monsoon (October and November) and only 7% of total rainfall occurs during dry season (December to February) (DoE, 2024). Drought conditions prevail over most areas of Bangladesh during the period of November to April. A rice crop cannot sustain during this period with rainfall alone. Due to very limited availability of rain water during dry season (November-April) the *Boro* rice is fully dependent on irrigation.

Area irrigated by groundwater has jumped to 80% from 16% (BADC, 2013). About 79% of the total cultivated area in Bangladesh is irrigated by groundwater, whereas the remaining is irrigated by surface water (Contaminants, 2023). So, groundwater is the major source of rice irrigation, as surface water is scarce during dry season. Groundwater is extensively used as a reliable and dependable source of irrigation. Large number of Deep Tube Wells (DTWs), Shallow Tube Wells (STWs) and Hand Tube Wells (HTWs) have been installed for this purpose in the country. Due to excessive and unplanned water uplifting, groundwater level constantly declines which is heading to imbalance of local biodiversity in near future. Ali *et al.* (2012) mentioned that, water-table depths could shrink by double by 2030 in the Barind area if current trend of withdrawal continue. Karim, N. N. *et al.* (2025) figured out the supply of and demand for thirty-five crops using ARIMA model for the period of 2025-2050 with base year of 2021, which escaped a focus on water crises or saving water in future.

Targeting high yield by providing irrigation facility with a higher cropping intensity is the most logical way of raising the total rice production at the national level. So, side by side the rational way should be to bring more fallow land under cultivation in *T. Aus* season with growing modern varieties because we still have almost 0.431 mha of land are being fallowed. We need to utilize it. So, rice area can be increased in *T. Aus* and *T. Aman* season adopting techniques of using rain water or partial irrigation which will allow groundwater saving to a large extent. This study was carried out to support policy guidelines for increasing *T. Aus* rice production and thereby reducing pressure on irrigation using groundwater in *Boro* season. This will contribute to strategy development for sustaining the rice production to match the demand with the limited land and water resources of Bangladesh.

Approaches and Methods

Conceptual framework

Sustaining rice production by using underground irrigation water from underground is a major driver of irrigated rice cultivation where irrational uplifting poses a great challenge of water security in future. Saving water is an option to mitigate the future challenges of water crises. There are a number of alternative options sketched in the Fig.1.

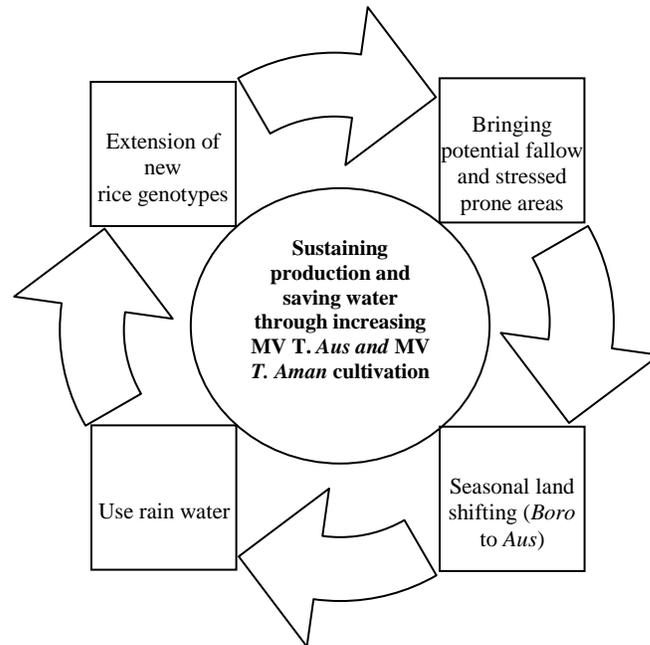


Fig. 1. Conceptual framework of the study

Continuous effort for development of stress tolerant varieties and improved rice genotype has been made but many of the technologies are still not in practice or underutilized. Necessary investment and for extension of those varieties in *T. Aus* and *T. Aman* season would enormously contribute to national rice security. Many stress prone areas remains fallow due to lack of proper attention and policy execution and those will be the options of increasing *T. Aus* and *T. Aman* cultivation and reduce *Boro* cultivation area. Therefore, rice area should be increased in *T. Aus* season by adopting techniques of using rain water or partial irrigation which will allow groundwater saving to a large extent. On the other hand, natural calamity is the potential risk.

Terminology

Terminologies used in this study includes Rabi season for dry season-irrigated or *Boro* cultivation, Kharif-I or upland rice for *T. Aus* and wetland rice or Kharif-II for *T. Aman*. Modern variety is abbreviated as MV and local variety as LV. Million hectare is abbreviated as mha, tons per hectare as t/ha and million metric tons as mmt. Planted area and harvested area represents the area devoted to rice cultivation during transplanting and harvesting, respectively.

Data collection

This study used secondary data gathered from published and unpublished sources, notably Bangladesh Bureau Statistics (BBS), Bangladesh Agricultural Census (BAC) and Bangladesh Rice Research Institute (BRRI). Farm and retail prices were collected from World Rice Statistics (WRS). Exports, imports, and stock change of rice

were gathered from the Food and Agriculture Organization (FAO) as well as GDP and GDP deflator are from World Data Bank (World Bank). Climatic data of temperature, rainfall, and solar radiation were collected from the Data Distribution Centre of the IPCC. Forecast climatic variables from 2010 to 2030 was used from Model for Interdisciplinary Research on Climate (MIROC5), General Circulation Model (GCM) of the University of Tokyo, NIES (National Institute for Environmental Studies) and JAMSTEC (Japan Agency for Marine-Earth Science and Technology).

Analytical models

In order to carry out simulation under the strategies of *T. Aus* rice increasing and adaptation of climate change, a rice supply and demand model was developed to understand the future situation of rice under climate change in Bangladesh. Supply and demand model for rice in Bangladesh consists of sixteen structural equations and nine identities, including temperature, rainfall and solar radiation as climatic variables. The basic structure of the simulation model for supply and demand structure for market equilibrium condition was adopted from Furuya and Meyer (2008), Furuya *et al.* (2010), and Salam *et al.* (2017).

The market equilibrium condition was defined as

$$SS_{Rt} = DD_{Rt} \dots \dots \dots (1)$$

Where, SS_{Rt} stands for supply and DD_{Rt} is demand for rice

$$times t = 1, 2, 3, \dots \dots \dots n$$

Breakdown of Market Supply of Rice (SS_{Rt})

$$SS_R = 0.67 * \sum(YR_{ivt} * AR_{ivt}) + Import_t - (Seed_t + Feed_t + Exp_t + STC_t + Wastage_t + UO_t) \dots \dots (2)$$

Where:

YR_{ivt} = Yield per unit area in year t	Exp_t = Export of rice in year t
AR_{ivt} = Harvested area in year t	STC_t = Stock changes in year t
$Import_t$ = Quantity of rice imported in year t	OU_t = Other usage
$Seed_t$ = Quantity of rice used as seed in year t	i = different seasons
$Wastage_t$ = post-harvest and storage losses in year t	and v = types of varieties
$Feed_t$ = Feeds for livestock in year t	0.67 is conversion rate of rice from paddy

Given that the climate is one of the influential factors, the yield function was built up by taking time trends and climatic factors (rainfall, temperature, and sun radiation) as explanatory variable along with technology advancements (modern genotypes, various machinery, and nutrients). To predict how farmers will react to market prices and previous season climate, the area function was developed using the combined assumptions of partial adjustment and adaptive expectations (Nerlove, 1958). Therefore,

product of rice yields and areas by variety and season finally generated national rice production in the simulated model (Salam et al. 2017).

$$QR_t = \sum(YR_{ivt} * AR_{ivt}) \dots \dots \dots (3)$$

Where, QR_t = total rice production from different season.

In this study, harvested area of three different seasons was applied in the model. Grain yield and production of different rice varieties (modern and local) in different seasons (*T. Aus*, *T. Aman* and *Boro*) was taken for analyzing with this model.

The ‘harvested’ area (used instead of ‘planted’ area in this model) functions were specified based on the Nerlovian adaptive expectation (Nerlove, 1958) model where the exogenous variable was rainfall as proxy for irrigation.

If the area function responded to the expected price and the yield did not respond to the expected price, the explanatory variables of the area function was harvested area, price, and exogenous variable in the previous year.

Development of Area function

$$AR_{ivt} = \alpha_{ivAR} + \beta_{ivAR1} * AR_{iv(t-1)} + \beta_{ivAR2} * Price_{t-1} + \beta_{ivAR3} * Rain_{t-1} \dots \dots (4)$$

Where AR_{ivt} is the harvested area and $AR_{iv(t-1)}$ is the lagged area. $Price_{t-1}$ is the lagged farm price and $Rain_{t-1}$ is the lagged of seasonal rainfall in months (m) as proxy for irrigation. α_{ivAR} , β_{ivAR1} , β_{ivAR2} and β_{ivAR3} are estimated parameters, respectively which need to be estimated.

At the same time, the yield function is independent from the expectation model because the yield does not respond to the price.

Development of Yield function

$$YR_{ivt} = \alpha_{ivYR} + \beta_{ivYR1} * Trend_{iv} + \beta_{ivYR2} * Temp_{ivt} + \beta_{ivYR3} * Rain_{ivt} + \beta_{ivYR4} * srad_{ivt} \dots \dots (5)$$

Where YR_{ivt} is specific rice varieties yield; $Trend_{iv}$ is trend used as proxy for technological advancement. Climate variable such as $Temp_{ivt}$, $Rain_{ivt}$ and $srad_{ivt}$ are seasonal temperature, rainfall and solar radiation respectively in months. α_{ivYR} , β_{ivYR1} , β_{ivYR2} , β_{ivYR3} and β_{ivYR4} are estimated parameters, respectively which needs to be estimated. In Bangladesh, *T. Aus* (upland rainfed) season begins from the beginning of March and it is harvested in mid-August. *T. Aman* (wet season) starts from July and ends at late December and *Boro* (dry season-irrigated) begins from the mid-November of previous year and harvested in late April. In every season farmer used to grow modern variety and local varieties in their plots. The modern varieties are those, which plant height is dwarf (short/strong), leaf erect (straight), nutrient up taking capacity is high and finally those are higher yielder. On the other hand, local variety’s plant heights are long and weak, leaf is flat and nutrient uptake efficiency is comparatively lower. So, those varieties provide lower yield.

Estimated area function:

$$AR_{ivt} = \hat{\alpha}_{ivAR} + \hat{\beta}_{ivAR1} * AR_{iv(t-1)} + \hat{\beta}_{ivAR2} * Price_{t-1} + \hat{\beta}_{ivAR5} * Rain_{t-1} \dots (6)$$

Now, assume a percentage growth in area (r):

$$rAR_{ivt} = \hat{\alpha}_{ivAR} + \hat{\beta}'_{ivAR1} * AR_{iv(t-1)} + \hat{\beta}_{ivAR2} * Price_{t-1} + \hat{\beta}_{ivAR5} * Rain_{t-1} \dots (7)$$

Where, r = percentage increase of $T. Aus$ area of rice in year t

To get new parameter by subtracting eq (6) - eq (7):

$$AR_{ivt} - rAR_{ivt} = \hat{\beta}_{ivAR1} * AR_{iv(t-1)} - \hat{\beta}'_{ivAR1} * AR_{iv(t-1)}$$

$$\text{Or } (1 - r) * AR_{ivt} = (\hat{\beta}_{ivAR1} - \hat{\beta}'_{ivAR1}) * AR_{iv(t-1)}$$

$$(1 - r) * AR_{ivt} = (\hat{\beta}_{ivAR1} - \hat{\beta}'_{ivAR1}) * AR_{iv(t-1)}$$

When $i = Aus$ season, the new parameter for 15% fallow land shifting to MV $T. Aus$ cultivation as below

$$\hat{\beta}'_{ivAR1} = \frac{(r-1)*AR_{ivt}}{AR_{iv(t-1)}} + \hat{\beta}_{ivAR1} \dots (8)$$

When $i = Boro$ season, the new parameter for 5% of $Boro$ shifting to MV $T. Aus$ of area is as below:

$$\hat{\beta}'_{ivAR1} = \hat{\beta}_{ivAR1} - \frac{(1 - r) * AR_{ivt}}{AR_{iv(t-1)}} \dots (9)$$

The base parameter of lagged area $\hat{\beta}_{ivAR1}$ was replaced in eq (6) by the calculated changed parameter $\hat{\beta}'_{ivAR1}$ in $T. Aus$ and $Boro$ area function, respectively, for re-simulation of the supply and demand model. The iteration of the simulation of eq (1) continued until supply and demand arrived at equilibrium condition. Finally, the re-simulation resulted in the re-adjusted areas allocation for $T. Aus$, $T. Aman$ and $Boro$.

Determination of Scenarios

In determining the following scenarios, seasonal fallow land and shifting $Boro$ areas to MV $T. Aus$ were considered by using heuristic simulation of the supply and demand model. Expert opinion was also validated through repeated calibration. The scenarios were as follows:

- a) Scenario 1: Business-As-Usual
- b) Scenario 2: 5% of $Boro$ land shifting to MV $T. Aus$ cultivation
- c) Scenario 3: 15% fallow land shifting to MV $T. Aus$ cultivation
- d) Scenario 4: Combined 15% fallow and 5% of $Boro$ land shifting to MV $T. Aus$ cultivation

Parameters of Area equation

New parameters were estimated following scenarios using eq 8 and eq 9 which is shown in table 1.

Table 1. Estimation of parameters of area equation using scenarios

Season	Parameters		
	Base value of lagged area	5% of <i>Boro</i> area shifting	15% fallow land utilization
MV <i>T. Aus</i>	0.69	Same	0.85
MV <i>T. Aman</i>	0.71	Same	Same
MV <i>Boro</i>	0.73	0.68	Same
LV <i>T. Aus</i>	0.27	Same	Same
LV <i>T. Aman</i>	0.57	Same	Same
LV <i>Boro</i>	0.66	Same	Same

Salam et al. (2017) and author's estimation

The base value of lagged area variable of MV *T. Aus* area function was 0.69 which yielded to 0.85 after imposing 15% increase of area in the MV *T. Aus* area function. Similarly, 5% area shifting from *Boro* to *T. Aus* yielded to 0.68 from 0.73 of the lagged area variables of MV *Boro* area function.

Result and Discussion

Present status of *T. Aus*, *T. Aman* and *Boro* rice

Table 2 presents the overall rice cultivation area and production status in Bangladesh. In 2023, a total of 11.63 mha of land were utilized for rice cultivation. Among this, 9.12% of the area was allocated to *T. Aus* rice, 49.19% to *T. Aman* rice, and 41.70% to *Boro* rice. This indicates that the Rabi season (mainly *Boro*) and Kharif -2 season (mainly *T. Aman*) are the dominant periods for rice cultivation in Bangladesh. Although the cultivated area for *Boro* rice is smaller compared to *T. Aman* rice, its yield is significantly higher. However, *Boro* cultivation requires a much larger amount of irrigation water, making it resource-intensive compared to the other rice season. Therefore, it would be a wise decision to increase the cultivation of *T. Aman* and *T. Aus* rice relative to *Boro* rice, without compromising total production. By allocating comparatively less land to *Boro* and expanding the area under *T. Aman* and *T. Aus*, we can reduce the heavy dependence on irrigation during the *Boro* season. This approach would help ensure more efficient utilization of groundwater resources while maintaining overall rice production.

Table 2. Present status of *T. Aus*, *T. Aman* and *Boro* rice in Bangladesh with respect to variety type, production and yield

Crops	Varieties	Area (mha)	Yield (t/ha)	Production (mmt)	% of total production	% of total area
<i>T. Aus</i>	Local	0.09	1.44	0.12	0.31	0.7
	MV	0.98	2.84	2.78	7.11	8.4
Total <i>T. Aus</i>		1.06	2.73	2.90	7.42	9.1
<i>T. Aman</i>	Broadcast	0.22	1.09	0.24	0.62	1.9
	local	0.69	1.65	1.13	2.89	5.9
	MV	4.82	2.91	14.06	35.95	41.4
Total <i>T. Aman</i>		5.73	2.69	15.43	39.46	49.2
<i>Boro</i>	Local	0.02	1.90	0.05	0.12	0.2
	HYV	3.62	4.14	14.99	38.33	31.1
	Hybrid	1.21	4.74	5.74	14.67	10.4
Total <i>Boro</i>		4.85	4.28	20.77	53.12	41.7
Total Rice		11.64	3.23	39.10	100.00	100.00

Source: FY-2022-23 (BBS, 2024)

Division wise crop cultivation and seasonal fallow land

There are eight administrative division in Bangladesh and each has its unique characteristics. Because of this, their soil quality and climate conditions also vary from one another. There are number of rivers with a plenty of surface water in the Barisal region. The majority of rivers have fresh water that can be used for irrigation. MV rice cultivation is unsuitable during the Kharif-2 (*T. Aman*) season due to tidal flooding and deeper water. As a result, local variety of *T. Aman* is very popular. But in high land and medium high land MV rice can be grown where tidal water depth is within the permissible limit (40-70 cm) (Islam *et al.* 2013). Generally, irrigation is not necessary during Kharif-2 season. During dry season, about 65% land is kept fallow due to lack of irrigation facility and Rahman *et al.* (2019) also depicts that almost 29% farmers leaving most land fallow in the dry season. Some farmers cultivate *T. Aus* rice using tidal water and rain water. If irrigation facility can be developed by re-excavating the existing canals and supplying irrigation pumps on rental basis, *T. Aus* area can be increased easily. Farmers can also purchase the irrigation pumps if micro credit facility is ensured. In Rajshahi division, groundwater is mainly used during *Boro* season, if unplanned withdrawal of groundwater continues; it leads to serious environmental degradation. Recent days in some areas, shallow tubewell does not get water during the peak requirement of *Boro* rice. In considering the situation, a particular portion of *Boro* area shifting to *T. Aus* area reduces extreme pressure on ground water. As the yield of *T. Aus*

rice is less, so the area fixation should be such that there is no change in total annual production. In Khulna division like as Satkhira, Khulna and Jessore areas there are water logging problem. Therefore, these areas remain fallow during the whole year. Severely affected upazilas of water logging are Keshobpur (Jashore), Tala, Satkhira Sadar and Kolaroa (Satkhira). So, it is necessary to study the root causes of water logging problem and identify solutions like rehabilitation of the coastal embankment, excavation and dredging of coastal rivers, construction of water control structure during high tide and low tide and development rice varieties for stagnant water and shallow flooded condition (up to 1.0-meter depth). In Sylhet region vast fields remain fallow during dry season. The main reasons for these fallow lands are absentee land owner and lack of irrigation facilities. There is huge amount of irrigable water in Haors. So, attempts should be made to bring those areas under rice cultivation. From table 3, 4 and 5, it can be viewed that, overall Dhaka and Chattogram division has higher percentage of fallow land which is about 9 and 8% respectively. Though, In Barishal, Chattogram, Khulna and Rangpur region has used more land in *Aman* season compare to *Boro* season because of natural calamities but in Rajshahi, Mymensingh, Sylhet and Dhaka utilized more land for *Boro* cultivation. Because of this, in that particular division we saw water scarcity for *Boro* cultivation. So, we had an opportunity to shift/reduce *Boro* land or used fallow land in *T. Aman* and *T. Aus* season which would be a potential solution to overcome water problem.

Table 3. Division wise land utilization status in Bangladesh (area in mha)

Division	Total	Not available for cultivation	Cultivable waste	Current fallow	Singe cropped	Double cropped	Triple cropped	% of Fallow land used for cultivation
Chattogram	3.39	0.62	0.08	0.07	0.27	0.60	0.20	8.00
Sylhet	1.26	0.38	0.06	0.02	0.36	0.27	0.10	2.00
Dhaka	2.05	0.59	0.07	0.13	0.38	0.58	0.23	9.00
Mymensingh	1.07	0.27	0.02	0.03	0.14	0.43	0.15	5.00
Barishal	1.32	0.25	0.01	0.08	0.38	0.25	0.11	3.00
Khulna	2.23	0.45	0.03	0.10	0.26	0.45	0.33	4.00
Rajshahi	1.82	0.45	0.01	0.05	0.17	0.74	0.38	1.00
Rangpur	1.62	0.37	0.01	0.01	0.08	0.79	0.34	3.00
Bangladesh	14.76	3.38	0.29	0.48	2.04	4.11	1.86	4.00

Source: FY-2022-23 (BBS, 2024)

Table 4. Division wise rice cultivation status in Bangladesh

Rice	Items	Barishal	Chattogram	Dhaka	Khulna	Mymensingh	Rajshahi	Rangpur	Sylhet	Bangladesh
<i>T.</i>	Area (mha)	0.19	0.22	0.05	0.16	0.03	0.19	0.09	0.03	1.06
	Yield (t/ha)	2.40	2.66	2.52	2.85	2.68	2.97	2.87	2.92	2.73
<i>Aus</i>	Production (mmt)	0.45	0.59	0.14	0.46	0.07	0.58	0.25	0.08	2.90
	Area (mha)	0.67	0.84	0.53	0.74	0.59	0.83	1.11	0.41	5.72
<i>T.</i>	Yield (t/ha)	2.24	2.66	2.38	2.91	2.65	2.87	2.86	2.80	2.70
	Production (mmt)	1.50	2.23	1.26	2.15	1.57	2.40	3.16	1.16	15.43
<i>Aman</i>	Area (mha)	0.14	0.60	0.75	0.62	0.66	0.82	0.77	0.49	4.85
	Yield (t/ha)	3.98	4.05	4.45	4.37	4.22	4.35	4.29	4.22	4.28
<i>Boro</i>	Production (mmt)	0.57	2.42	3.36	2.73	2.79	3.57	3.29	2.05	20.77

Source: FY-2022-23 (BBS, 2024)

Table 5. Division wise percentage use of rice is in different season of Bangladesh

Division	Area (million hectare)							
	Net cropped	Gross cropped	<i>T. Aus</i>	% <i>T. Aus</i> area of net cropped	<i>T. Aman</i>	% <i>T. Aman</i> area of net cropped	<i>Boro</i>	% <i>Boro</i> area of net cropped
Barishal	0.74	1.22	0.19	25.00	0.67	91.00	0.14	19.00
Chattogram	1.07	2.08	0.22	21.00	0.84	78.00	0.60	56.00
Dhaka	1.19	2.24	0.05	5.00	0.53	45.00	0.75	63.00
Khulna	1.05	2.18	0.16	15.00	0.74	70.00	0.62	59.00
Mymensingh	0.72	1.46	0.03	4.00	0.59	82.00	0.66	92.00
Rajshahi	1.30	2.82	0.19	15.00	0.83	64.00	0.82	63.00
Rangpur	1.22	2.71	0.09	7.00	1.11	91.00	0.77	63.00
Sylhet	0.73	1.18	0.03	4.00	0.41	57.00	0.49	67.00
Bangladesh	8.02	15.90	1.06	13.00	5.72	71.00	4.85	60.00

Source: FY-2022-23 (BBS, 2024)

Simulation result of area, yield and production: Scenario 1

The simulation reveals that area under MV *Aus* is shrinking meaning that MV *Aus* variety is vulnerable to climate change. Furthermore, area under local *Aus* variety shows moderately constant trend under business-as-usual. In addition, area and yield of all varieties during both *Boro* and *T. Aus* season demonstrate stable performance. From table 6, it would be evident that overall output is rising. It also displayed that total production of clean rice is 39.71 mmt in the year 2030.

Table 6. Simulated area, production and yield of three rice types in Bangladesh under Business-As-Usual scenario

Items	Season	Clean rice Yield (t/ha)					Area (mha)				
		2009	2015	2020	2025	2030	2009	2015	2020	2025	2030
MV rice varieties	<i>T. Aus</i>	2.03	2.33	2.62	2.47	2.93	0.67	0.61	0.62	0.61	0.70
	<i>T. Aman</i>	2.49	3.04	3.08	2.67	3.29	3.85	3.89	3.83	3.95	4.12
	<i>Boro</i>	3.95	4.19	3.75	4.73	4.03	4.57	4.36	4.81	4.92	4.77
LV rice varieties	<i>T. Aus</i>	1.23	1.14	1.50	1.51	1.47	0.40	0.34	0.39	0.36	0.42
	<i>T. Aman</i>	1.48	1.78	1.76	1.67	1.88	2.31	2.29	2.12	2.03	2.03
	<i>Boro</i>	2.00	2.12	2.15	2.29	2.30	0.11	0.24	0.09	0.21	0.25
Total production of cleaned rice (mmt)	<i>T. Aus</i>	1.86	1.80	2.21	2.04	2.67					
	<i>T. Aman</i>	13.01	15.86	15.53	13.94	17.39					
	<i>Boro</i>	18.26	18.78	18.22	23.75	19.75					
	Total	33.13	36.44	35.96	39.73	39.81					

Source: Author's estimation from simulation.

Simulation result of area, yield and production: scenario 2

In the simulation, proxy for technologies is time trend representing technological advancement across the time. All MVs for all three seasons performs consistently meaning that the improved technologies are climate resilient. At 5% MV *Boro* area shifting condition, local varieties also demonstrate the stability capacity side by side. The area under MV *Aus* gradually increase from 0.67 mha in 2009 to 1.27 mha in 2030 under this shifting condition. Total production shows modest decrease from business-as-usual (39.81 mmt in 2030) to 5% MV *Boro* area shifting (38.71 mmt in 2030). Table7 shows that after 5% *Boro* area shifting lead to a slight drop in rice production since yield of MV *Aus* is lower than that of MV *Boro* rice.

Table 7. Simulated area, production and yield of three rice types in Bangladesh under 5% *Boro* area shifting from Simulation

Items	Season	Clean rice Yield (t/ha)					Area (mha)				
		2009	2015	2020	2025	2030	2009	2015	2020	2025	2030
MV rice varieties	<i>T. Aus</i>	2.03	2.33	2.62	2.47	2.93	0.67	1.19	1.19	1.19	1.27
	<i>T. Aman</i>	2.49	3.04	3.08	2.67	3.29	3.85	3.91	3.85	3.98	4.15
	<i>Boro</i>	3.95	4.19	3.75	4.73	4.03	4.57	3.74	4.12	4.20	4.04
LV rice varieties	<i>T. Aus</i>	1.23	1.14	1.50	1.51	1.47	0.40	0.34	0.39	0.36	0.43
	<i>T. Aman</i>	1.48	1.78	1.76	1.67	1.88	2.31	2.31	2.14	2.06	2.06
	<i>Boro</i>	2.00	2.12	2.15	2.29	2.30	0.11	0.24	0.09	0.21	0.25
Total production of cleaned rice (mmt)	<i>T. Aus</i>	1.86	3.15	3.71	3.47	4.32					
	<i>T. Aman</i>	13.01	15.98	15.62	14.08	17.54					
	<i>Boro</i>	18.26	16.17	15.61	20.34	16.85					
	Total	33.13	35.30	34.94	37.89	38.71					

Source: Author's estimation from simulation.

Simulation result of area, yield and production: scenario 3

By converting 15% of cultivable land that remained fallow under MV *Aus* rice cultivation, the area under MV *Aus* increase to 1.28 mha in 2030 and subsequently raises total rice production from 39.81 mmt at business-as-usual to 41.34 mmt at shifting 15% fallow land to MV *Aus* in 2030. The significant advancement results from the increased production, such as the possibility of exporting excess rice soon (table 8).

Table 8. Simulated area, production and yield of three rice types in Bangladesh under 15% *Boro* area shifting to MV *Aus*

Items	Season	Clean rice Yield (t/ha)					Area (mha)				
		2009	2015	2020	2025	2030	2009	2015	2020	2025	2030
MV rice varieties	<i>T. Aus</i>	2.03	2.33	2.62	2.47	2.93	0.67	0.98	1.06	1.16	1.28
	<i>T. Aman</i>	2.49	3.04	3.08	2.67	3.29	3.85	3.88	3.81	3.92	4.09
	<i>Boro</i>	3.95	4.19	3.75	4.73	4.03	4.57	4.36	4.81	4.91	4.76
LV rice varieties	<i>T. Aus</i>	1.23	1.14	1.50	1.51	1.47	0.40	0.33	0.38	0.35	0.42
	<i>T. Aman</i>	1.48	1.78	1.76	1.67	1.88	2.31	2.27	2.10	2.01	2.01
	<i>Boro</i>	2.00	2.12	2.15	2.29	2.30	0.11	0.24	0.09	0.20	0.25
Total production of cleaned rice (mmt)	<i>T. Aus</i>	1.86	2.65	3.35	3.39	4.37					
	<i>T. Aman</i>	13.01	15.80	15.43	13.84	17.26					
	<i>Boro</i>	18.26	18.75	18.19	23.71	19.71					
	Total	33.13	37.20	36.98	40.94	41.34					

Source: Author's estimation from simulation.

Simulation result of area, yield and production: scenario 4

After adjusting 5% of area shifted from MV *Boro* area to MV *Aus* and 15% fallow land in the simulation, the total MV *Aus* area will be about 2.02 mha by the year 2030 and total production of clean rice is 40.69 mmt in 2030 (Table 8). The simulated of MV *Aus* area and production increases by shifting 5% MV *Boro* area and fallow land increases the size of MV *Aus* area as well as technological advancement. However, the simulation at combine scenario shows that consistent level of total production is received with the reduced risk with technological advancement in the course of climate change and future market situation. Improved rice varieties and better management can balance production targets and reduce water use by 4725 million liters by 2030.

Table 9. Simulated area, production and yield of three rice types in Bangladesh under scenario 4

Items	Season	Clean rice Yield (t/ha)					Area (mha)				
		2009	2015	2020	2025	2030	2009	2015	2020	2025	2030
MV rice varieties	<i>T. Aus</i>	2.03	2.33	2.62	2.47	2.93	0.67	1.60	1.77	1.89	2.02
	<i>T. Aman</i>	2.49	3.04	3.08	2.67	3.29	3.85	3.90	3.82	3.95	4.12
	<i>Boro</i>	3.95	4.19	3.75	4.73	4.03	4.57	3.73	4.11	4.19	4.03
LV rice varieties	<i>T. Aus</i>	1.23	1.14	1.50	1.51	1.47	0.40	0.34	0.39	0.36	0.42
	<i>T. Aman</i>	1.48	1.78	1.76	1.67	1.88	2.31	2.29	2.11	2.03	2.03
	<i>Boro</i>	2.00	2.12	2.15	2.29	2.30	0.11	0.24	0.09	0.21	0.25
Total cleaned rice production (mmt)	<i>T. Aus</i>	1.86	4.12	5.21	5.22	6.53					
	<i>T. Aman</i>	13.01	15.90	15.50	13.95	17.36					
	<i>Boro</i>	18.26	16.15	15.58	20.29	16.80					
	Total	33.13	36.17	36.28	39.46	40.69					

Source: Author's estimation from simulation.

On the other hand, about 28 mmt cleaned rice will be needed to feed the population of nearly 190 million by the year 2030 with the decreasing consumption of per capita 146 kg/year (BBS, 2012). A particular portion of remaining amount of about 12.97 mmt by the year 2030 is used for other purposes and stock change. The shift in food habits allows for export access to the global rice market since it reduces rice consumption and consequently creates excess (table 10).

Table 10. Export access, stock change and per capita availability of clean rice in Bangladesh under scenario 4

Items	2009	2015	2020	2025	2030
Export access (mmt)	0	2.92	1.34	1.52	1.55
Stock change (mmt)	2.34	-0.41	-1.91	-1.80	-2.43
Population (million)	144.20	158.96	169.54	180.2	189.85
Per capita availability (kg/yr)	158	207	201	205	205

Source: Author's estimation from simulation.

Suitable rice varieties for *Aus*, *Aman* and *Boro* seasons

BIRRI has developed 121 high yielding varieties including 8 hybrids of rice for different seasons and for different ecosystems. Among them, some varieties are regarded as for promising *T. Aus*, *T. Aman* and *Boro* rice varieties. Those three table highlighting their growth duration, yield potential, and special characteristics. The *Aus* varieties, such as BIRRI dhan65, BIRRI dhan83, BIRRI dhan83 and BIRRI dhan98 etc. are typically short-duration and adaptable to various conditions like drought, salinity, and water-saving cultivation. Along with BIRRI dhan65 has a shorter life span than BIRRI Dhan43 and BIRRI dhan106 and the plants are relatively shorter and tougher so they do not lodge. One

of the characteristics of BRR1 dhan65 variety is that rice does not easily shatter. The field is very attractive as the flag leaves of this variety are upright and the rice grains are high. The *T. Aman* varieties, including BRR1 Hybrid dhan6 and BRR1 dhan87, focus on high yield, submergence tolerance, making them suitable for different environments. The *Boro* season varieties, such as BRR1 dhan89, BRR1 dhan108, BRR1 dhan113 and BRR1 Hybrid dhan5 etc. emphasize high yield, shorter growth duration, and tolerance to salinity and lodging, ensuring better adaptability and profitability for farmers (BRR1, 2025).

Suitable cropping patterns

All crops are not suitable for everywhere. Some crops are especially suitable for some specific locations. It depends on soil type, land topography and water source. *T. Aus* and *T. Aman* based cropping patterns are the potential alternative with respect to saving water in rice cultivation as these rice cultivations are mainly based on rainfed culture.

Table 11. Ecosystem wise BRR1 recommended *T. Aus*-based dominant cropping patterns in Bangladesh

Serial	Ecosystem	Cropping pattern along with varieties/crops
1	Irrigated high land to medium high land	Chickpea-Wet seeded <i>Aus</i> (BR26/BRR1 dhan48 and 55)-Transplanted <i>Aman</i> (BR11, BRR1 dhan51)
2	Rainfed high land to medium high land	<i>T. Aus</i> (BR26, BRR1 dhan48 and 55)- <i>T. Aman</i> (BR10, BR11, BR22, BR23, BRR1 dhan30, BRR1 dhan46, BRR1 dhan49)
3	Irrigated Ecosystem (GK Project area)	<i>T. Aus</i> (BR26/BRR1 dhan48 and 55)- <i>T. Aman</i> (BR10, BR11, BR22, BR23, BRR1 dhan30, BRR1 dhan49)
4	Tidal wetland (Non-saline)	<i>T. Aus</i> (BRR1 dhan48, BRR1 dhan27)- <i>T. Aman</i> (BR22, BR23, BRR1 dhan44)
5	Rainfed Medium High land (Madhupur tract soil)	<i>T. Aus</i> (BR26, BRR1 dhan48 and 55)/ <i>B. Aus</i> (BR21, BR24, BRR1 dhan42, BRR1 dhan43)- <i>T. Aman</i> (BR10, BR11, BRR1 dhan30, BRR1 dhan49)

Source: BRKB, 2024

List of some ecosystem wise *Aus-Aman* based dominant cropping pattern along with varieties/crops are given in Table 11. And some new cropping patterns need to be validated such as Maize-Mungbean-*T. Aus*; Mustard-*T. Aus-T. Aman*; Mustard-Mungbean-*T. Aus-T. Aman*; Wheat-Fallow-*T. Aman* (saline area); *T. Aman*-Sunflower (saline area).

Table 12. Productivity of some tested alternate cropping patterns in Bangladesh

Serial	Cropping pattern	Rice Equivalent Yield (t/ha)	Reference
1	<i>Boro-Fallow-T. Aman</i>	11.79	BRRRI Annual report 2024
2	Potato- <i>T. Aus-T. Aman</i>	16.19	BRRRI Annual report 2011
3	Mustard- <i>T. Aus-T. Aman</i>	12.75	BRRRI Annual report 2011
4	Maize-Mungbean- <i>T. Aman</i>	11.81	BRRRI Annual report 2015

The productivity of different alternative cropping patterns is compared in table 12 based on their Rice Equivalent Yield (REY), and it is clear that diversified cropping patterns are more productive than the traditional *Boro-Fallow-T. Aman* system. Among the tested patterns, Potato-*T. Aus-T. Aman* is found to be most productive, much greater than the others, and Mustard-*T. Aus-T. Aman* and Maize-Mungbean-*T. Aman* offer modest gains. The lower REY of the traditional pattern shows that the addition of high-yielding non-rice crops like potato, maize, or mustard can raise productivity as a whole and optimize land use efficiency.

Conclusion

This study shows potentials of shifting or reallocating rice area between the seasons, thereby releasing some land from *Boro* rice cultivation to release intensive water use pressured, Establish these potentials, a number of prerequisites to be looked into BRRRI could be able to provide a greater number of highly productive rice varieties and thereby making up scaling of the potential *T. Aus* and *T. Aman* varieties and the improved *T. Aus* and *T. Aman* based cropping pattern in collaboration with DAE, international organizations, BADC, BINA and development partners. Narrowing of the rice yield gap will also be possible by adopting the modern rice production technologies in collaboration with the same. Seed tracking of stress tolerant rice varieties such as BRRRI dhan52, BRRRI dhan78 and BRRRI dhan110 for *T. Aman* and BRRRI dhan48, BRRRI dhan83, BRRRI dhan85, BRRRI dhan98 and BRRRI dhan106 for *T. Aus* through taskforce activities. Special capacity build-up program for *T. Aus* and *T. Aman* (extension personnel and farmers) and enhancing the regional research and development activities for rice are crucial.

BRRRI has plan to develop sustainable rice varieties along with cropping pattern and ecosystem-based production technologies, dry direct seeded aerobic rice along with their production technologies for *Boro* season, development of tidal submergence tolerant rice varieties for *T. Aus* and *T. Aman* seasons for southern region. Increasing *T. Aus* and *T. Aman* rice production needs seed purification of local cultivars and to undertake Balam improvement program for future rice varieties. Strategies have to be framed out for developing high yielding water stagnation and shallow flood (up to 1.0-meter depth) water tolerant varieties for enhancing rice productivity of the concern ecosystem. Crop modeling for the support of future research dimensions and policy in the changing climate scenarios is essential for future strategies. To offset these issues, BRRRI will need to conduct scientific assessments before re-allocating *Boro* fields to *T. Aus* cultivation,

promote dry-direct seeded aerobic culture, and offer partial irrigation for *Aus* and supplemental irrigation for *T. Aman* rice. In addition, the establishment of short-duration and high-yielding rice varieties, strengthening research collaboration among institutions, and enhancing infrastructure and human resources will be the most important factors in sustaining rice productivity. With such limitations overcome and the recommended solutions implemented, BRRI can elevate rice yield in Bangladesh towards ensuring long-term food security and adapting to environmental hostilities.

Despite strategic planning to expand *T. Aus* and *T. Aman* rice production, several constraints remain that hinder extensive implementation. For the *Aus* season, the high production cost compared to *T. Aman* and *Boro* rice discourages farmers from using its production, with food security issues caused by the lower yield per unit of area of *T. Aus* rice. Additionally, inadequate irrigation facilities, heavy pest and disease prevalence, and lack of short-duration and high-yielding varieties also hinder its development. Similarly, the *T. Aman* season is hampered by restricted irrigation for early transplanting and critical stages, vulnerability to flash floods and unusual submergence, and the lack of high-yielding, tall-seedling varieties that are tolerant to tidal flooding. To address these issues, scientific assessments should be conducted before the replacement of *Boro* fields by *T. Aus* cultivation and shifting towards dry-direct seeded aerobic rice should be promoted. Alternate wetting and drying (AWD) practices, partial and supplementary irrigation, and stressing on short-duration, stress-tolerant rice varieties need to be implemented. Ecosystem-specific cropping calendars, further development of better agronomic packages, and more BRRI-DAE-BINA, international, and private sector collaboration will also be instrumental. Improved infrastructure, increased regional research stations, and the strengthening of human resource capacity will continue to drive the sustainable development of *T. Aus* and *T. Aman* rice production.

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Conflict of interest

The authors honestly declare no conflicts of interest regarding publication of this manuscript.

Authors' contribution

MAS developed the concept and model; accomplished all parts of the manuscript and wrote this manuscript. The author read and approved the final manuscript. Dr. Moin Us Salam provided support to write the manuscripts. KMI and MMH contributed to improve the calibration and write-up of the manuscript.

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PERFORMANCE NUTRIENT DIGESTIBILITY OF YANKASA SHEEP FED DIETRY LEVELS OF CASSAVA AND MAIZE COMPOSITES

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Abstract

The production of Yankasa sheep serves significant socio-economic purposes and it is one of the most common, abundant, and widely distributed sheep in Nigeria. This sheep breed is unable to reach its full potential due to high feed costs and poor nutrient intake. Therefore, the effect of 82 days of feeding with dietary levels of cassava and maize composites on performance and apparent nutrient digestibility were investigated. To do this, forty, 8–10-months old Yankasa sheep were divided into five groups of eight sheep. Each group was assigned to one of the experimental diets in a completely randomized design labelled, Treatment 1 (100% maize composite), Treatment 2 (75% maize composite and 25% cassava composite), Treatment 3 (50% maize composite and 50% cassava composite), Treatment 4 (25% maize composite and 75% cassava composite) and Treatment 5 (100% cassava composite). The dry matter intake (DMI) g/d, supplement DMI, total DMI, daily weight gain, feed conversion ratio and dry matter digestibility were significantly improved ($p < 0.05$) in 50%MC/50%CC than those fed the other treatments. Dressing percentage and leg weights were higher in 75%MC/25%CC and 50%MC/50%CC treatments. DMI ($\text{g/kgW}^{0.75}$), final body weight, total weight gain, empty weight and crude protein digestibility were better in 75%MC/25%CC, 50%MC/50%CC and 25%MC/75%CC. Combination of varying levels of maize and cassava composites in sheep diets provided nourishable diets. However, Treatment 3 (50%MC/50%CC) gave the most enhanced performance and dry matter digestibility, and is hence recommended for enhanced Yankasa sheep production.

Keywords: Body weight changes, Carcass characteristics, Growth performance, Nutrient intake, Nutrient digestibility.

Introduction

The vast majority of Nigerians rely on the livestock sector for employment and supply of vital nutrients. Nigeria had a population of 88.2 million goats, 49.1 million sheep, 20.9 million cattle, 9.2 million pigs, and 258.5 million birds (NBS, 2024) which is most likely to be higher today. In Nigeria, the main goal and focus of livestock

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production is to supply the population with good quality animal protein. According to Ben-Salem and Smith (2008), the bulk of the rural population in Nigeria is dependent on livestock and their by-products, and the country's economy is still centred on the production of sheep, goats, and cattle. In addition to producing meat, small ruminants help the leather industry by producing skin, which the FAO estimates to be 7,500 tonnes annually (Mubi *et al.*, 2012). Small ruminants are widely distributed throughout rural, urban, and peri-urban areas and make up approximately 63.7% of all domestic livestock in Nigeria. The northern part of the country is home to 70% of these

Small ruminants. According to importance, the native sheep breeds are Balami (10%), Uda (10%), West African dwarf (20%), and Yankasa (60%) (Ramalan *et al.*, 2022). The short generation interval and high multiple birth rate allowed for the rapid population increase in sheep today (Markos, 2006). The majority of sheep in the Guinea and Sudan Savannah belt of West Africa are Yankasa sheep (Iheukwumere *et al.*, 2008). Yankasa are tall hairy white coloured sheep with black colourations around the muzzles and the eye regions and reaching a height of 50 to 70 cm at the withers, weigh 30 to 50 kg, and have exceptional sexual agility. It is estimated that more than 60% of the 39 million sheep in the nation are of the Yankasa breed, making sheep the second most important livestock species in the nation (FAOSTAT, 2013). The Yankasa sheep breed is the most common and abundant in Nigeria, found throughout the semi-arid and subhumid regions.

The scarcity and high cost of feeds significantly restrict ruminant production vis-a-vis sheep production in many developing countries. According to Jiwuba *et al.* (2022), the lack of feed is especially pronounced during the dry season when natural pastures become poor in crude protein and highly fibrous. Nigeria is producing livestock using non-traditional energy and protein components derived from agriculture and agro-industrial waste (Okonkwo *et al.*, 2008). Cassava (*Manihot esculenta*) is a tropical tuberous food plant that belongs to the *Euphorbiaceae* family. It is grown all throughout the tropical regions for its tuberous roots, are used to make breads, tapioca, cassava flour, laundry starch, alcoholic beverages etc. Ukachukwu (2008) identified cassava as the best option for addressing the persistently high feed costs in livestock industry. Nigeria is currently the world's biggest producer of cassava (Ezenwaka *et al.*, 2018). It has roughly 3.65 Kcal/g ME of energy and about 17- 21% crude protein. The leaves and tender stems make up the foliage, which is a good source of protein, vitamins and dietary ash (Akinfala, 2000). Additionally, the stems contain reasonable dietary fibre. The nutritional value of cassava composite meal, which is a blend of entire leftover stems, and leaves, was documented (Ukachukwu, 2005), who concluded that it might be used as a feed ingredient for livestock and poultry.

Maize (*Zea mays* L.) is the most widely cultivated cereal worldwide. One of the most important grain crops in Africa today is maize, which was brought to the continent from central Mexico before 1500 BC. It quickly expanded to every part of the continent after being introduced. Maize is used to make a variety of industrial products, including biofuels, animal feed, and human consumables. In Africa, maize is an essential component of animal feeding regimens. There is a dearth of information on the utilisation of different combination of cassava and maize composites. This study therefore presents

information on nutrient intake, body weight gain, carcass indices and apparent nutrient digestibility of Yankasa sheep fed dietary levels of cassava and maize composites. It is assumed that different combinations of cassava and maize composites will have a beneficial effect on the nutrient intake, body weight changes, carcass characteristics and apparent nutrient digestibility in Yankasa sheep, due to better nutrient balance. Therefore, the objective of this study was to evaluate the effect of dietary levels of cassava and maize composites on the nutrient intake, body weight gain, carcass characteristics and apparent nutrient digestibility of Yankasa sheep.

Materials and Methods

Experimental location

This experiment was conducted at the small ruminant unit of the teaching and research farm, Michael Okpara University of Agriculture, Umudike, Nigeria. The study area lies between latitude 05° 28' N and longitude 07° 31' E.

Sourcing of the cassava and maize composites

The cassava (TME 419) and maize (ba super) were sourced from the National Root Crop Research Institute, Umudike. Freshly harvested and discarded vegetative parts of the cassava and maize were harvested, chopped to a length of 1-3cm prior to feeding.

Experiment diets

The cassava and maize composites were further prepared into five treatments. Treatment 1: 100% maize composite (MC) and 0% cassava composite (CC), Treatment 2: 75% maize composite and 25% cassava composite, Treatment 3: 50% maize composite and 50% cassava composite, Treatment 4: 25% maize composite and 75% cassava composite and Treatment 5: 0% maize composite and 100% cassava composite. The composites were thoroughly mixed in accordance with the treatment combinations, before being fed fresh to the experimental sheep. The supplemental diet was formulated from palm kernel meal, maize offal, groundnut meal, wheat offal, bone meal, limestone, salt and vitamin premix as shown in Table 1.

Table 1. Composition of the supplemental diet

Palm kernel meal	20.00
Maize offal	40.00
Groundnut meal	8.00
Wheat offal	27.50
Bone meal	2.00
Limestone	1.00
Salt	1.00
Vitamin premix	0.50
Total	100.00

Animal management

In this study, forty Yankasa rams weighing about 10.26 kg and aged 8 to 10 months were sourced from Leggal market, Shongom Local Government Area, Gombe State. The experimental animals were acclimated for 21 days prior to the commencement of the study in accordance with the approval and directives of the Animal Ethics Committee of Michael Okpara University of Agriculture, Abia State, Nigeria. Before the trial, the sheep were administered Ivermectin (1 ml/10 kg body weight (injected subcutaneously) and Albendazole (0.1 mg/kg BW given orally) to treat external and internal parasites. The sheep were vaccinated against *Peste' Petit de' Ruminante'* (PPR) with PPR vaccine at a dosage of 1 ml subcutaneously. For a preliminary period of 21 days, the animals were gradually fed wilted *Panicum maximum* in the morning (8.00 hr) and the supplemental diet in the evening (16.00 hr).

Experimental design, housing and feeding

The sheep were randomly divided into 5 groups each with 8 sheep constituting a replicate. The five experimental diets (100%MC, 75%MC/25%CC, 50% MC/50%CC, 25%MC/75%CC and 100%CC) were allotted to the groups in a completely randomized design. The animals were kept in separate pens with well-ventilated cemented floors having feeders and drinkers. For 82 days, each animal was fed a specific treatment diet in the morning (08:00 hour). Feeding was based on 3.5% body weight per day and to ensure about 10% left over, in addition to 0.5 kg supplemental diet that was fed at 16:00 h. Fresh drinkable water was made available regularly.

Estimation of different parameters

Each animal's voluntary feed intake was calculated daily by subtracting the previous day's feed refusals from the current day's feed supply. The sheep's initial live weights were taken using spring balance at the start of the feeding trial and weekly afterwards in the morning before feeding. At the conclusion of the trial, the sheep were weighed to determine their final live weight. Other parameters were computed using the following equations-

$$\text{Feed intake (kg)} = \text{feed given} - \text{feed left over} \dots\dots\dots(1)$$

$$\text{Average daily feed intake (g/d)} = \frac{\text{total feed intake}}{\text{number of experimental days}} \dots\dots(2)$$

$$\text{Total weight gain (kg)} = \text{final body weight} - \text{initial body weight} \dots(3)$$

$$\text{Average daily weight gain (g/d)} = \frac{\text{total weight gain}}{\text{number of experimental days}} \dots\dots\dots(4)$$

$$\text{Feed Conversion Ratio} = \frac{\text{daily feed intake}}{\text{daily weight gain}} \dots\dots\dots(5)$$

$$\text{Dry matter intake (DMI) (g/day)} = \frac{\text{feed intake} \times \text{dry matter analysed}}{100} \dots\dots\dots(6)$$

$$\text{Dry matter intake as percentage of body weight (\%)} = \frac{\text{dry matter intake}}{\text{body weight of the animal}} \times 100 \dots\dots(7)$$

Other growth performance indexes were computed accordingly.

Digestibility studies

Each treatment group comprising eight Yankasa sheep was transferred to and housed in separate metabolism cages with facilities for collecting faeces and fed the designated diets for 2 days. Thereafter, the other treatment groups were subjected to the same exercise. During each 2 – day feeding period (8 days for the 4 phases), drinking water was provided *ad libitum*. Sample of each diet was collected and used for dry matter (DM) determination and proximate composition analysis.

Faecal samples (not contaminated with urine) were collected and bulked for each animal. A sub sample from each animal was dried in forced draft oven at 100-105⁰C for 48 hours and used for DM determination. Another sample was dried at 60⁰C for 48-72 hours for determination of proximate composition. Apparent coefficient digestibilities for nutrients were determined as given below:

$$\frac{\text{Nutrient in feed} - \text{nutrient in faeces}}{\text{Nutrient in feed}} \times 100$$

Proximate analyses

AOAC (2005) procedures were used to analyse all the feed, and faecal samples for proximate components. Triplicate samples of the composite combinations were analysed for dry matter (DM), crude protein (CP), crude fibre (CF), ash, ether extract (EE), nitrogen-free extract (NFE) and organic matter (OM) according to the methods of AOAC (2005). The neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) fractions were determined using Van Soest *et al.*'s (1991) methods.

The gross energy was calculated using the formula according to Nehring and Haelien (1973); $T = 5.72Z1 + 9.50Z2 + 4.79Z3 + 4.03Z4 + 0.9\%$

where;

T = gross energy;

Z1 = crude protein;

Z2 = crude fat;

Z3 = crude fibre;

Z4 = nitrogen-free extract.

Statistical analyses

The experimental design was a completely randomised design (CRD). Data obtained were analysed using analysis of variance (ANOVA) as described by SAS (2008). Significant means were separated using the Duncan Multiple New Range Test (Duncan 1955) at $P < 0.05$.

Results and Discussion

Proximate compositions

Table 2 shows the proximate compositions of the dietary levels of cassava and maize composites. Crude protein (CP), crude fibre, gross energy and neutral detergent fibre (NDF) showed significant ($p < 0.05$) differences while dry matter (DM), ether extract (EE), ash, nitrogen free extract (NFE) acid detergent fibre (ADF) and acid detergent lignin (ADL) were not significantly ($p > 0.05$) influenced across the groups. Crude protein value of 100% cassava composite (100%CC) was significantly ($p < 0.05$) higher than the other treatments. The CP content was the highest (17.48%) for 100%CC with a corresponding lowest value of 7.73% recorded for 100%MC. Crude fibre was significantly ($p < 0.05$) higher in 100%MC in comparison to 25% MC 75%CC and 100%CC. Neutral detergent fibre showed significant ($p < 0.05$) difference and followed a similar pattern with the CF, with 100%MC and 75% MC/25%CC been higher than 25%MC/75%CC and 100%CC. Gross energy also showed significant difference ($p > 0.05$), with 100%MC, 50% MC/50%CC and 25%MC/75%CC showing higher energy values ($p < 0.05$) than 75%MC/ 25%CC and 100%CC.

Table 2. Chemical compositions of the varying levels of cassava and maize composites

Parameter	Dietary levels				100%CC	SEM
	100%MC	75%MC/ 25% CC	50% MC/ 50%CC	25%MC/75 % CC		
Dry matter	92.76	93.91	92.76	91.56	90.42	12.64
Crude protein	7.73 ^c	10.09 ^{bc}	12.26 ^b	13.97 ^b	17.48 ^a	3.72
Crude fibre	19.28 ^a	17.63 ^a	14.52 ^{ab}	12.37 ^b	10.39 ^b	6.35
Ether extract	2.96	2.84	2.46	2.31	3.75	3.38
Ash	4.24	5.53	5.38	5.18	6.33	2.92
Nitrogen free extract	59.51	57.82	58.14	57.73	52.47	8.41
Gross Energy (Kcal/g)	402.42 ^a	389.71 ^b	402.29 ^a	399.09 ^a	371.71 ^b	29.03
Neutral detergent fibre	54.95 ^a	51.78 ^a	48.93 ^{ab}	43.81 ^b	40.46 ^b	6.84
Acid detergent fibre	32.86	38.17	27.47	23.26	23.09	4.71
Acid detergent lignin	12.97	12.83	10.94	10.06	11.87	2.39

^{a-d} means within the same row with different superscripts are significantly different ($p < 0.05$); MC= Maize composite; CC= cassava composite

Generally, the CP contents of the diets were above 7 and 8% by ARC (1980) and Norton *et al.* (1994) respectively, which are the minimum dietary recommendations for rumen motility and function. The high CF values reported in this study is an indication of the suitability of the composite combinations to supply needed fibre for the animals. Jiwuba (2018) in an earlier study postulated that adequate supply of dietary fibre stimulates rumen motility, equilibrium in rumen ecosystem and chyme chewing. The high NDF values observed in all the diets were in agreement with the findings of Lalman (2012), which stipulated that, ruminant diets should contain at least 20% NDF on a dry matter basis to ensure optimal roughage digestion. The NDF fraction is composed of

hemicellulose, cellulose and lignin, which aggregate to stimulate and aid rumen motility (Jiwuba *et al.*, 2023). The energy values reported in this study is in agreement with earlier reports of ARC (1980) and NRC (1981) on the energy requirements of small ruminants.

Nutrient intake studies

The nutrient intake of Yankasa sheep fed dietary levels of cassava and maize composites are presented in Table 3. All the parameters examined showed significant ($P < 0.05$) differences except TDMI% BW ($\text{g/kgW}^{0.75}$) and Crude fibre intake ($\text{g/kgW}^{0.75}$). Daily feed intake was enhanced in 50% MC/50%CC compared to 100% MC and 100% CC. DM intake for the composites was significantly ($p < 0.05$) higher 50% MC/50%CC. The increased DM intake for 50% MC/50%CC may be attributed to the greater palatability of the diets due to better nutrient balance. DM intake for the supplement was higher ($p < 0.05$) for 25% MC/75%CC in comparison to the other treatments. However, total DM intake represented as g/d and $\text{g/kgW}^{0.75}$ increased significantly ($P < 0.05$) for the Yankasa sheep fed 50% MC/50% CC. Total DM intakes (g/d) obtained herein were in conformity with the findings of Adeleke *et al.* (2022) for Yankasa rams fed roughage and concentrate supplement at different sequences and intervals. Dry matter intake as per metabolic weight (DMI) ($\text{g/kgW}^{0.75}$) obtained in this study (76.66 - 91.85 $\text{g/kgW}^{0.75}$) were well above the voluntary DMI of 58 $\text{g/kgW}^{0.75}$ recommended by Akinsoyinu (1985) and 68 $\text{g/kgW}^{0.75}$ recommended by Kearl (1982) as maintenance requirement for small ruminants in Nigeria and small ruminant breeds found in developing countries respectively. The improved intake obtained in this study can be described by the better supply of both nitrogen and readily available carbohydrates to the rumen microbes which possibly enhanced the rate of degradation of the diets, microbial growth and the fractional outflow of liquid matter from the rumen. In earlier study, Mpairwe *et al.* (2003) observed that providing supplements with adequate CP to ruminants could enhance DMI, rumen degradation and nutrient flow to the small intestine and culminated in higher animal performance. The dry matter intake as percentage body weight (DMI% BW) differed significantly ($P < 0.05$) among the treatment groups, with 25%MC/75%CC and 100%CC showing significantly ($p < 0.05$) higher values. However, the values for all the treatments (3.50-4.43%) compared well with the values of 3%, and 2.8-4.0% recommended daily DM intake (as % BW) requirements for meat type sheep in the tropics by Devendra and McLeroy (1982), and Nuru (1985) respectively. The results generally indicate that animals on the various treatment diets showed positive DM status as evidenced by a general positive performance of the sheep. The CP intakes (g/d and $\text{g/kg W}^{0.75}$) of the sheep fed the 100%MC and 75% MC/25%CC had lower ($p < 0.05$) values and 50% MC/50%CC, 25%MC/75%CC and 100%CC had higher ($p < 0.05$) values. Protein intake is a major determinant of small ruminant performance due to increased availability of fermentable nitrogen and other nutrients required by rumen microbes as well as the greater opportunities for some of the protein to escape rumen fermentation (Jiwuba, 2023). The high CP intake of sheep in the 50%MC/50%CC, 25%MC/75%CC and 100%CC could be due to the higher proportion of CP in the treatments.

Body weight changes

Table 4 shows the body weight gain of Yankasa sheep fed dietary levels of cassava and maize composites. Final body weight, total weight gain and daily body weight showed significant ($p < 0.05$) differences across the groups. Daily weight gains of the sheep showed significant ($p < 0.05$) difference with 50% MC/50%CC showing higher ($p < 0.05$) value in comparison with other treatments. Total feed intake and daily feed intake were significantly ($p < 0.05$) influenced by the composite combinations. The combinations were better ($p < 0.05$) consumed than the sole maize and cassava composites. Feed conversion ratio was significantly ($p < 0.05$) higher in 100%MC and 100%CC in comparison with 50% MC/50%CC. The animals on 50% MC/50%CC gave the highest ($p < 0.05$) daily weight gain (g/day) of 139.63 g/d while those on 100% CC and 100%MC diets yielded significantly lower daily weight gain of 84.02 g/d and 86.71 g/d respectively. The differences in daily weight gain of Yankasa sheep could be attributed to the influence of the combinations in providing protein and energy needed both for effective rumen function and body metabolism by the sheep. Sheep fed 50% MC/50%CC diet yielded the most superior daily weight gain and feed conversion ratio. The improved performance could be attributed to the better nutrient balance of the diet.

Carcass evaluation

The carcass characteristics of Yankasa sheep fed dietary levels of cassava and maize composites is presented in Table 5. Live weight at slaughter and empty weight were significantly ($p < 0.05$) higher in 75% MC/25%CC, 50% MC/50%CC and 25% MC/75% CC in comparison to the 100%MC and 100%CC. Dressed weight was lowest in 100% CC and highest in 75%MC/25%CC and 50% MC/50%CC combinations. Dressing percentage (DP) was higher ($p < 0.05$) in 75% MC/25% CC and 50%MC/50%CC. Leg weights were significantly ($p < 0.05$) influenced with 75% MC/25%CC and 50% MC/50%CC composites showing higher ($p < 0.05$) weights than the other treatment. The DP results were mostly in line with the values reported for tropical breeds by Steele (1996) and Devendra, and Mc Leroy (1982). The findings of the current study also supported the idea that dressing percentage increased with increasing slaughter weight. According to Devendra and Mc Leroy (1982), most tropical sheep and goats dress out between 40 and 50% on balanced diets. However, Anjaneyulu and Joshi (1995), reported 38 to 56 % as baseline for tropical sheep and goats. The higher DP recorded for the sheep on the 75% MC/25%CC and 50% MC/50%CC combinations may be attributed to higher slaughter weights. However, less consideration is given to DP in the tropics than in temperate zones because nearly all the offal is eaten as food, with some parts and organs selling for more money than carcass meat. The significant difference reported for leg indicated that the diets supported the growth and development of the cut parts. The higher leg weights observe in 75% MC/25% CC and 50%MC/50%CC may indicate that the two composite combinations were able to promote the growth and development of the legs.

Table 3. Nutrient intake of Yankasa sheep fed varying levels of cassava and maize composites

Parameters (g/d)	100% MC	75%MC/25% CC	50% MC/50%CC	25%MC/75% CC	100CC	SEM
Daily feed intake (g/d)	470.24 ^b	520.98 ^{ab}	555.98 ^a	511.59 ^{ab}	398.29 ^c	9.63
Dry matter intake (DMI)	436.19 ^c	489.25 ^b	515.73 ^a	468.41 ^b	360.13 ^d	1.40
DMI (g/kgW ^{0.75})	95.45 ^c	104.03 ^{ab}	108.22 ^a	100.69 ^b	82.67 ^d	2.22
Supplement dry matter intake (SDMI)	65.33 ^c	75.38 ^b	78.18 ^b	81.79 ^a	61.39 ^c	3.62
Total DMI	501.52 ^c	564.63 ^b	593.91 ^a	495.61 ^c	421.52 ^d	1.17
Total DMI (g/kgW ^{0.75})	105.98 ^b	115.83 ^a	120.31 ^a	105.04 ^b	93.03 ^c	1.11
Total dry matter intake as percentage of body weight (TDMI%BW) (%)	3.50 ^b	3.82 ^b	3.74 ^b	4.40 ^a	4.43 ^a	4.95
TDMI%BW (g/kgW ^{0.75})	2.26	2.73	2.69	3.03	3.05	0.46
Crude protein intake (CPI)	36.34 ^c	52.57 ^b	68.16 ^a	71.47 ^a	69.62 ^a	3.48
CPI (g/kgW ^{0.75})	14.80 ^c	19.52 ^b	23.72 ^a	24.59 ^a	24.10 ^a	2.67
Crude fibre intake	90.66 ^a	91.85 ^a	80.73 ^b	63.28 ^c	41.36 ^d	5.14
CFI (g/kgW ^{0.75})	29.38	29.67	26.93	22.44	16.31	2.62

^{a-d} means within the same row with different superscripts are significantly different (P<0.05)

Table 4. Body weight gain of Yankasa sheep fed varying levels of cassava and maize composites

Parameters	100% MC	75%MC/25% CC	50% MC/50%CC	25%MC/75% CC	100%CC	SEM
Initial body weight (kg)	10.45	11.21	10.76	12.54	11.78	2.23
Final body weight (kg)	17.56 ^b	21.55 ^a	22.21 ^a	21.82 ^a	18.67 ^b	3.40
Total weight gain (kg)	7.11 ^b	10.34 ^a	11.45 ^a	9.28 ^{ab}	6.89 ^b	2.22
Total feed intake (kg)	38.56 ^b	42.72 ^a	45.59 ^{ab}	41.95 ^a	32.66 ^c	4.47
Daily weight gain (g/d)	86.71 ^c	126.10 ^b	139.63 ^a	113.17 ^b	84.02 ^c	9.62
Daily feed intake (g/d)	470.24 ^b	520.98 ^{ab}	555.98 ^a	511.59 ^{ab}	398.29 ^c	9.63
Feed conversion ratio	5.42 ^a	4.13 ^{ab}	3.98 ^b	4.52 ^{ab}	4.74 ^a	0.69

a-d means within the same row with different superscripts are significantly different (P<0.05)

Table 5. Carcass characteristics of Yankasa sheep fed varying levels of cassava and maize composites

Parameters	100% MC	75%MC/ 25% CC	50% MC/ 50%CC	25%MC/ 75% CC	100%C C	SEM
Live weight at slaughter (kg)	16.77 ^b	20.03 ^a	20.79 ^a	19.73 ^a	16.83 ^b	2.61
Empty weight (kg)	14.43 ^b	17.44 ^a	18.23 ^a	17.57 ^a	14.54 ^b	1.40
Dressed Weight (kg)	8.61 ^b	11.42 ^a	11.49 ^a	9.44 ^{ab}	7.35 ^c	2.22
Dressing Percentage (%)	51.34 ^b	57.01 ^a	55.27 ^a	47.85 ^c	43.67 ^d	3.62
Meat cuts expressed as percentage (%) of dressed weight						
Loin	16.65	18.94	19.44	12.41	11.47	1.17
Set	5.86	5.98	5.98	5.54	5.87	1.11
Shoulder	10.58	9.61	7.58	8.00	11.16	2.47
Leg	30.56 ^b	36.84 ^a	34.76 ^a	27.87 ^c	23.95 ^d	5.82
End	5.15	4.78	4.42	4.51	5.62	1.78

a-d means within the same row with different superscripts are significantly different ($p < 0.05$)

Table 6. Apparent digestibility of Yankasa sheep fed varying levels of cassava and maize composites

Parameter	Dietary levels				100%CC	SEM
	100% MC	75%MC/ 25% CC	50% MC/ 50%CC	25%MC/ 75% CC		
Dry matter digestibility	60.67 ^b	70.65 ^b	75.76 ^a	62.54 ^b	61.78 ^b	5.98
Crude protein digestibility	67.56 ^b	71.55 ^a	72.21 ^a	70.82 ^a	68.67 ^b	4.78
NDF digestibility	56.71	56.10	59.63	53.17	54.02	2.85
ADF digestibility	40.24	40.98	35.98	41.59	38.29	4.56
ADL digestibility	34.85	32.76	34.76	31.63	34.96	1.41

a-d means within the same row with different superscripts are significantly different ($P < 0.05$)

Digestibility studies

The apparent nutrient digestibility of Yankasa sheep fed dietary levels of cassava and maize composites is presented in Table 6. The DM digestibility and CP digestibility and showed significant ($P < 0.05$) difference across the treatments. NDF digestibility, ADF digestibility and ADL digestibility were not significantly ($p > 0.05$) affected by the composite combinations. 50 MC/50%CC produced significantly ($p < 0.05$) high DM digestibility in respect to the other groups. The higher DM digestibility is in disagreement with the report of Bakshi and Wadhwa (2004) who reported that high neutral detergent fibre and acid detergent lignin depress dry matter digestibility. The higher dry matter digestibility recorded for sheep fed 50% MC/50%CC may be attributed the nutritional synergy, optimal carbohydrate-fibre balance and enhanced microbial fermentation; a view corroborated. The study showed that the sheep had a positive crude protein digestibility which ranged from 67.56 -72.21%. The differences observed in crude

protein digestibility could be connected to the source of the protein, CP content in the diet (percentage combination) and solubility in the rumen. The high CP digestibility recorded for the sheep fed 75%MC/25%CC, 50%MC/50%CC and 25%MC/75%CC is an indication that the composite combinations are highly soluble and degradable better than the sole diets.

Conclusion

It could be concluded that 50% MC/50%CC showed significant improvement in dry matter intake, supplement dry matter intake, total dry matter intake, daily weight gain, feed conversion ratio and dry matter digestibility. Dressing percentage and leg weights were better in 75%MC/25%CC and 50%MC/50%CC combination. Dry matter intake ($\text{g/kgW}^{0.75}$), final body weight, total weight gain, live weight at slaughter, empty weight and crude protein digestibility were however better in 75%MC/25%CC, 50%MC/50%CC and 25%MC/75%CC in comparison to 100%MC and 100%CC. Combination of varying levels of maize and cassava composites in sheep diets provided nourishable diets for the sheep. However, treatment 3 (50%MC/50%CC) gave the most enhanced total dry matter intake, body weight gain, feed conversion ratio and DM digestibility, and is hence recommended for enhanced Yankasa sheep production.

Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

Authors' contribution

P.C. J. designed the study, wrote the protocol and wrote the first draft of the manuscript. K.I. performed the chemical, fecal and urine analyses. L.C. J. reviewed the experimental design, performed the statistical analysis and provided the test ingredients (maize and cassava composites). FOA guidance and monitoring of experiment and critical revision on the initial draft and approval of the final manuscript. All the authors read and approved the final manuscript.

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SUITABILITY OF RAPESEED-MUSTARD VARIETIES AS A RELAY WITH T. AMAN RICE

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Abstract

A field experiment on T. Aman-mustard relay cropping was conducted at the Agronomy Research field of Sher-e-Bangla Agricultural University, Dhaka in 2023-2024 to identify the suitable short duration variety for relay with T. Aman. Ten varieties of rapeseed-mustard *viz.*, BINA sharisha4, BINA sharisha9, BINA sharisha10, BINA sharisha11, BARI sharisha14, BARI sharisha15, BARI sharisha16, BARI sharisha17, BARI sharisha18, and BARI sharisha20 were evaluated as relay with T. Aman. The seeds of rapeseed-mustard were broadcasted in a standing T. Aman rice crop after the excess water drained out at 10 days before the rice harvest. The rice was harvested at 15 cm above the ground level. The experiment was conducted in a Randomized Complete Block Design with three replications. Results indicated that growth as well as yield contributing characteristics and seed yield of rapeseed-mustard were significantly varied among the varieties. The variety BARI sharisa16 produced the highest seed yield and followed a trend as BARI sharisa17 > BARI sharisa15 > BARI sharisa14 > BINA sharisha11. These varieties showed higher number of leaf plant⁻¹, leaf area, leaf area index, 1000-seed weight, siliqua plant⁻¹, and seeds siliquae⁻¹.and took minimum days to flower and mature. The seed yields of these varieties were significantly positively correlated with growth duration, and yield contributing attributes. Despite its high yield potential, farmers are not interested to cultivate mustard var. BARI sharisa16 as a relay crop with T. Aman rice due to its long growth duration. On the other hand, mustard var. BARI sharisa14, BARI sharisa15, BARI sharisa17, and BINA sharisha11 matured by 75-80 days, which were suitable as relay crop with T. Aman rice.

Keywords: Duration, Growth, Relay mustard, Variety, Yield.

Introduction

Rapeseed-mustard covering about 80% of the total oilseed area and contributing to more than 60% of the total oilseed production in Bangladesh (Rahman *et al.*, 2022). The estimated total area and production of rapeseed-mustard was 1.04 million hectare

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and 1.35 million tons, respectively in Bangladesh during 2024-2025 (USDA FAS, 2025). The present average rapeseed-mustard seed yield (1.33 t ha^{-1}) is very low as compared to other oilseeds growing countries in the world. Recently many high yielding varieties of T. Aman rice has been released but due to long duration variety of rice, it is difficult to cultivate mustard timely. On the other hand, delay sowing of mustard results in poor growth, ultimately lower yield and difficult to fit in Boro rice season.

Relay cropping under zero tillage conditions is one of the cropping system where growing a crop few days before harvesting of another crop. In Bangladesh, many crops *viz.* lentil, grasspea, chickpea, field pea, maize, etc. are relayed with T. Aman rice (Islam *et al.*, 2017; Roy *et al.*, 2017; Mandal *et al.*, 2015; Ali *et al.*, 2018). This cropping system is generally adopted in areas where T. Aman harvesting delayed and/or land remains moist which takes few to more days to become optimum condition ('Zoe' condition) for land preparation. Under this situation, farmers can grow the crop in optimum time by adopting relay cropping. Moreover, this practice makes the best use of the residual moisture of T. Aman rice field. Relay mustard with T. Aman under zero tillage conditions has already received remarkable attention by the farmers mainly due to time, cost effectiveness and profitability (Rahman *et al.*, 2022). In view of this, the present study was conducted to select the suitable varieties of mustard relay with T. Aman under zero tillage cultivation for increasing the cropping intensity and to increase the production of mustard.

Materials and Methods

The experiment was conducted at the Agronomy farm of Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the 2023-2024. The short duration rice var. BRRI dhan75 was used in this study. Rice seedlings were transplanted in each thirty plots without any treatment variations and fertilized with recommended dose of fertilizers. Rice was transplanted maintaining $25 \times 15 \text{ cm}$ spacing with two seedlings hill⁻¹. Different intercultural operations were performed in each plot for maintaining proper growth and development of rice. Mustard/rapeseed varieties were collected from BARI and BINA and were relayed with T. aman rice under zero tillage conditions. The experiment was randomly arranged using a RCB design with three replicates and the total number of plot was thirty for ten mustard/rapeseed varieties.

Ten varieties of rapeseed-mustard, *viz.* BINA sharisha4, BINA sharisha9, BINA sharisha10, BINA sharisha11, BARI sharisha14, BARI sharisha15, BARI sharisha16, BARI sharisha17, BARI sharisha18 and BARI sharisha20 were included in this study. The varietal characteristics have been given in the Table 1. The seeds of mustard were broadcast in the standing rice crop after the excess water drained out *i.e.*, 10 days before the rice harvest under a sufficient moisture conditions. The rice was harvested at 15 cm above the ground level and transferred from the field within three days. The seed rate of all mustard/rapeseed was used at the rate of 8 kg ha^{-1} . The mustard was fertilized with 120-36-80-20 kg ha^{-1} N-P-K-S as a urea, TSP, MoP and Gypsum, respectively (Ahamed *et al.*, 2018). Half of the urea and the other fertilizers were broadcast in the standing T. Aman crop just three days before relay sowing of seeds. Rest of the urea was applied before flowering stage. Two hand weeding were done at 15 days after sowing (DAS) and 30 DAS manually.

Light irrigation was given at 40 DAS (at flowering stage). The crop was sprayed with Malathion 57 EC at recommended dose to control aphids at siliquae formation.

The growth parameters *viz.*, plant height, number of branches plant⁻¹, number of leaves plant⁻¹, and fresh and dry weight of leaf, leaf area, leaf area index, specific leaf area, specific leaf weight, were measured at 40 and 70 DAS using three plants for every sampling from each plot. Plants were harvested depending on the maturity of variety. At maturity stage i.e. when 80% of the pod turned brown in colour, the crop was harvested from each plot in 4.5 m² area at ground level for seed yield. Prior to harvesting, three plants were randomly uprooted for yield attributes *viz.*, number of siliqua plant⁻¹, number of seeds siliquae⁻¹, and weight of 1000-seeds. Seeds from harvested area collected and sun dried to obtain proper seed moisture content of 12% to get optimum seed weight. The straw was also dried in the sun and weighted. Both seed and straw yields were calculated and expressed as t ha⁻¹. Biological and harvest index were also calculated.

Table 1. Varietal characteristics of different rapeseed-mustard genotypes (Azad *et al.*, 2020)

Name	Types	Duration	Siliqua plant ⁻¹	Seed siliquae ⁻¹	1000-seed weight (g)	Seed yield (t ha ⁻¹)
BINA sharisha4	<i>Brassica napus</i>	85-88	60-85	24.32	3.6-4.0	1.8-2.4
BINA sharisha9	<i>Brassica napus</i>	80-84	75-90	25-28	3.5-4.0	1.7-2.0
BINA sharisha10	<i>Brassica campestris</i>	78-80	110-125	14-16	2.8-2.95	1.5-1.7
BINA sharisha11	<i>Brassica napus</i>	80-83	90-100	28-30	3.5-4.5	1.8-2.1
BARI sharisha14	<i>Brassica campestris</i>	75-80	80-100	22-26	3.5-3.8	1.4-1.6
BARI sharisha15	<i>Brassica campestris</i>	80-85	70-80	20-22	3.25-3.5	1.5-1.6
BARI sharisha16	<i>Brassica juncea</i>	105-115	180-200	9-11	4.7-4.9	2.0-2.5
BARI sharisha17	<i>Brassica rapa</i>	82-86	60-65	28-30	3.0-3.4	1.7-1.8
BARI sharisha18	<i>Brassica napus</i>	95-100	80-130	28-30	3.5-4.0	2.0-2.5
BARI sharisha20	<i>Brassica rapa</i>	80-85	50-55	28-34	3.5-3.8	1.7-2.0

Statistical analysis

All data were analyzed by using SPSS 20.0 for windows (SPSS Inc.). The significant differences among the treatment means were compared by Least Significant Difference (LSD) at 1% levels of probability.

Results and Discussion

Growth characteristics of different rapeseed-mustard

Plant height

The plant height was significantly different among the varieties at all growing stages (Figs. 1a and 1b). At 40 DAS, the maximum plant height was recorded in BARI sharisha14 (86.89 cm) which was at par with BARI sharisha15, BARI sharisha17, BARI sharisha20 and BINA sharisha11, and the lowest in BARI sharisha18 (42.68 cm). After 40 DAS, it increased sharply up to 70 DAS where maximum plant height was recorded in

BARI sharisha16 (164.84 cm) and the lowest in BARI sharisha14 (92.32 cm). The present study revealed that BARI sharisa14 and BARI sharisa15 produced the highest plant height at early stage and BARI sharisa16 at harvesting stage. It could be happened due to the genetic makeup of the variety. BARI sharisa14 and BARI sharisa15 are short duration variety whereas BARI sharisa16 completes its life cycle within 115 DAS. Therefore, BARI sharisa14 and BARI sharisa15 were grown quickly and BARI sharisa16 grown slowly at early stage. Helal *et al.*, 2016; Rahman *et al.*, 2022 was also corroborated the findings.

Number of leaves plant⁻¹

Number of leaves plant⁻¹ at different days after sowing differed significantly at 40 and 70 DAS (Figs. 1c and 1d). Number of leaves plant⁻¹ ranged from 7.66 to 32 at 40 DAS and increased in all varieties at 70 DAS, ranging from 13.44 to 34.67. The maximum number of leaves plant⁻¹ was produced by the var. BARI sharisha15 at 40 and 60 DAS which was statistically similar to BARI sharisha14 and BARI sharisha17 and the minimum by the BINA sharisha9 which was at par with BINA sharisha4, BARI sharisha16 and BARI sharisha18. Rahman *et al.* (2022) reported the similar findings among the tested varieties of rapeseed-mustard and found the highest leaf number at 45 DAS in BARI sharisha14 (19.3 ± 0.8) and BARI sharisha15 (18.0 ± 0.5) and the highest leaf number at 60 DAS were recorded in BARI sharisha14 (27.3 ± 0.8) and BARI sharisha15 (24.6 ± 0.3). It was revealed that a good number of leaves remain upto harvesting may constitute to higher leaf area index and enhanced photosynthetic activity of plants which eventually contribute to higher yield.

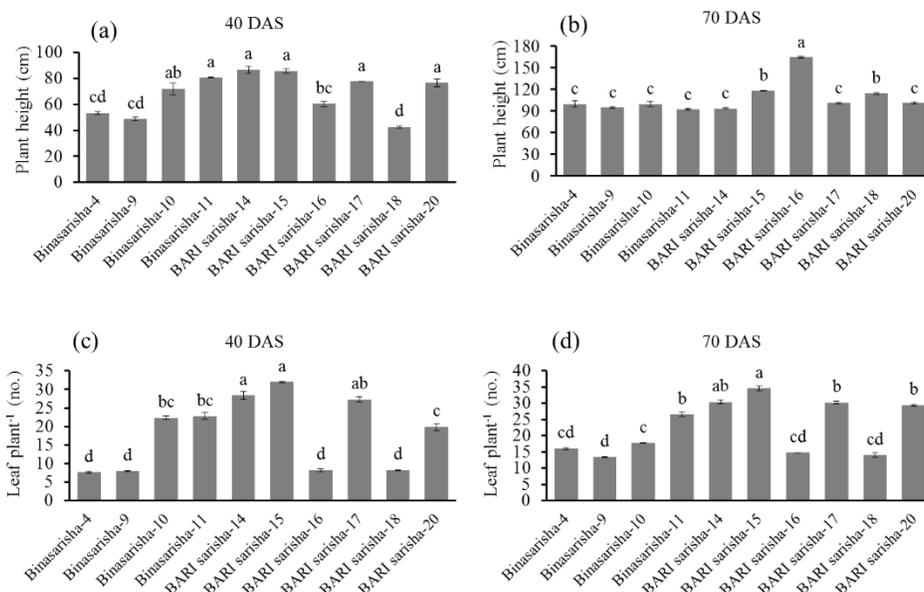


Fig. 1. Plant height and leaf number at different days after sowing (DAS) of different rapeseed-mustard varieties as relay cropping, (a) plant height at 40 DAS and (b) 70 DAS; (c) leaf number at 40 DAS, and (d) 70 DAS. Values labelled with different lower case letters are significantly different at $P < 0.01$.

Leaf area

Significant variation was observed in leaf area at 40 and 70 DAS (Figs. 2a and 2b). Leaf area ranged from 27.13 cm² to 80.01 cm² at 40 DAS and declined in all varieties at 70 DAS, ranging from 6.78 cm² to 65.74 cm². The maximum number of area was observed by the var. BARI sharisha16 which was statistically similar to BARI sharisha20 at 40 DAS and the minimum by the BINA sharisha11 which was at par with BARI sharisha15. At 70 DAS, the highest leaf area was found with BARI sharisha16 whereas the lowest with BARI sharisha14 which was at par with BARI sharisha15. The result revealed that leaf area decreased with increasing crop duration. Higher leaf area at vegetative stage contributes to develop deeper root system and helps to uptake more moisture and nutrient whereas the reduced leaf area at flowering and silique development stage contribute to reduce transpirational water resulting to enhancing tolerance against drought stress under relay cropping conditions (Chauhan *et al.*, 2020). It was stated that leaf area constituted to higher leaf area index and increased photosynthetic activity of plants resulting in higher grain and stover yield. ⁵

Leaf area index

Leaf area index is a dimensionless quantity of plant that determined the plant canopy structure. It is used as a tool to predict the light interception, photosynthesis assimilation, and evapotranspiration and contribute to plant growth. Leaf area index varied significantly at 40 and 70 DAS (Figs. 2c and 2d). Leaf area index ranged from 0.69 to 4.55 at 40 DAS and decreased in all varieties at 70 DAS, ranging from 0.51 to 2.43. The maximum leaf area index was observed by the var. BARI sharisha14 which was statistically similar to BARI sharisha20 at 40 DAS and the minimum by the BINA sharisha4 which was statistically at par with BINA sharisha9, BINA sharisha11, BARI sharisha16 and BARI sharisha18. At 70 DAS, the highest leaf area index was found with BARI sharisha16 whereas the lowest with BARI sharisha14. The probable reason may be attributed to genetic characters of BARI sharisha14 at vegetative growth stage and BARI sharisha16 at harvesting stage which has higher capacity to utilized the photosynthetic more efficiently through maximum leaf area index and ultimately the dry matter production, the similar findings have been reported by Singh *et al.* (2017) and Chauhan *et al.* (2020) stated that higher leaf area index constituted to increase higher photosynthetic activity of plants resulting in higher grain and stover yield.

Specific leaf area

Specific leaf area (SLA) is a measure of the leaf area of the plant to leaf dry weight. Significant variation was observed in SLA at 40 and 70 DAS (Figs. 3a and 3b). SLA ranged from 67 cm² g⁻¹ to 486.05 cm² g⁻¹ at 40 DAS and decreased in all varieties at 70 DAS, ranging from 42.60 cm² g⁻¹ to 118.60 cm² g⁻¹. The maximum SLA was observed by the var. BARI sharisha14 which was statistically similar to BARI sharisha20 at 40 DAS and the minimum by the BARI sharisha16 which was statistically at par with BINA sharisha4, BINA sharisha9, BINA sharisha11 and BARI sharisha18. At 70 DAS, the highest SLA was found with BINA sharisha10 whereas the lowest with BARI sharisha14, which was statistically at par with BINA sharisha11, BARI sharisha15, BARI sharisha16 and BARI sharisha18. The result revealed that SLA decreased with increasing crop duration.

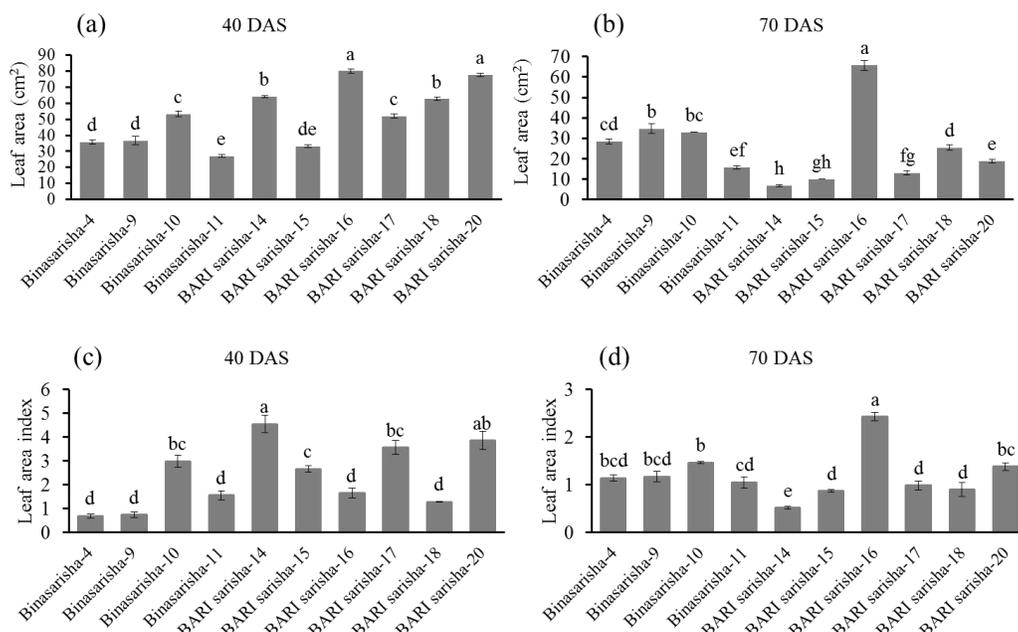


Fig. 2. Leaf area and leaf area index at different days after sowing (DAS) of different rapeseed-mustard varieties as relay cropping, (a) leaf area at 40 DAS and (b) 70 DAS; (c) leaf area index at 40 DAS, and (d) 70 DAS. Values labelled with different lower case letters are significantly different at $P < 0.01$.

Specific leaf weight

Specific leaf weight (SLW) is a measure of the leaf weight per unit leaf area. SLW varied significantly at 40 and 70 DAS (Figs. 3c and 3d). SLW ranged from 0.002 g cm^{-2} to 0.016 g cm^{-2} at 40 DAS and increased in all varieties at 70 DAS, ranging from 0.008 g cm^{-2} to 0.024 g cm^{-2} . The maximum SLW was observed by the variety BARI sarisha16 at 40 DAS and the minimum by the BARI sarisha14 which was statistically similar to BARI sarisha20, BARI sarisha17, BARI sarisha15, BINA sarisha10 and BINA sarisha4. At 70 DAS, the maximum SLW was found with BARI sarisha14 which was statistically at par with BARI sarisha15, BARI sarisha18 and BINA sarisha11 whereas the lowest with BINA sarisha10. The present study stated that SLW increased with increasing crop duration due to the significant reduction in leaf area. Similar result also observed by Akhter *et al.* (2014) and Singh *et al.* (2014) revealed that more SLW per unit leaf area indicated more production of biomass and constituted to increase grain and stover yield.

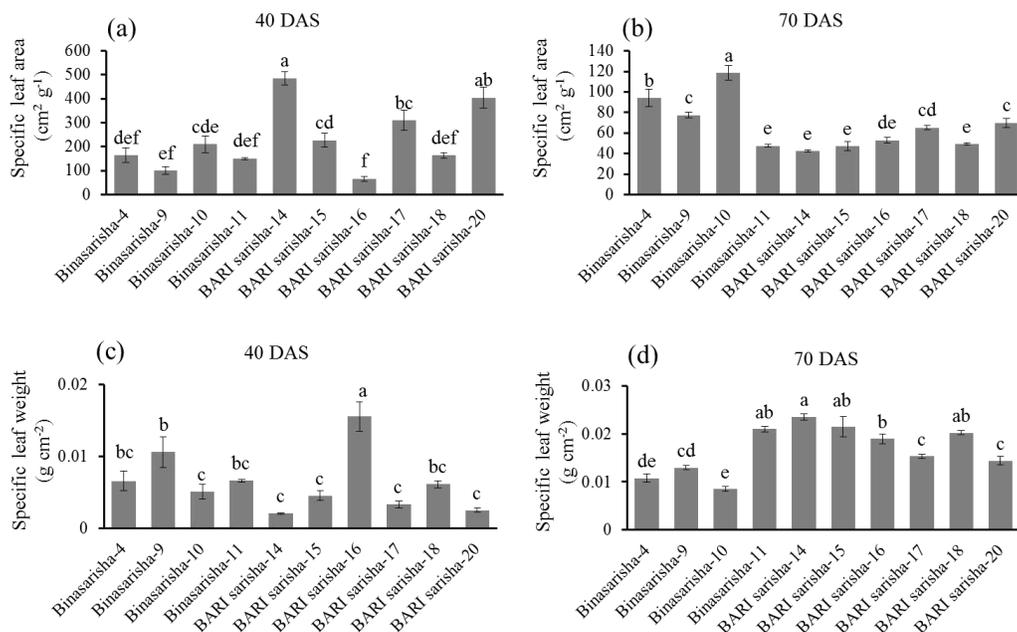


Fig. 3. Specific leaf area and specific leaf weight at different days after sowing (DAS) of different rapeseed-mustard varieties as relay cropping, (a) specific leaf area at 40 DAS and (b) 70 DAS; (c) specific leaf weight at 40 DAS, and (d) 70 DAS. Values labelled with different lower case letters are significantly different at $P < 0.01$.

Leaf fresh weight

Leaf fresh weight (LFW) varied significantly at 40 and 70 DAS (Figs. 4a and 4b). LFW ranged from 0.71 g leaf⁻¹ to 8.58 g leaf⁻¹ at 40 DAS and increased in all varieties at 70 DAS, ranging from 0.94 g leaf⁻¹ to 9.13 g leaf⁻¹. The maximum LFW was observed by the var. BARI sharisha16 at 40 DAS and the minimum by the BARI sharisha14 which was statistically similar to BARI sharisha15, BARI sharisha17, BINA sharisha11, BARI sharisha20, BINA sharisha10 and BINA sharisha4. At 70 DAS, the highest LFW was found with BARI sharisha-16 whereas the lowest with BARI sharisha14.

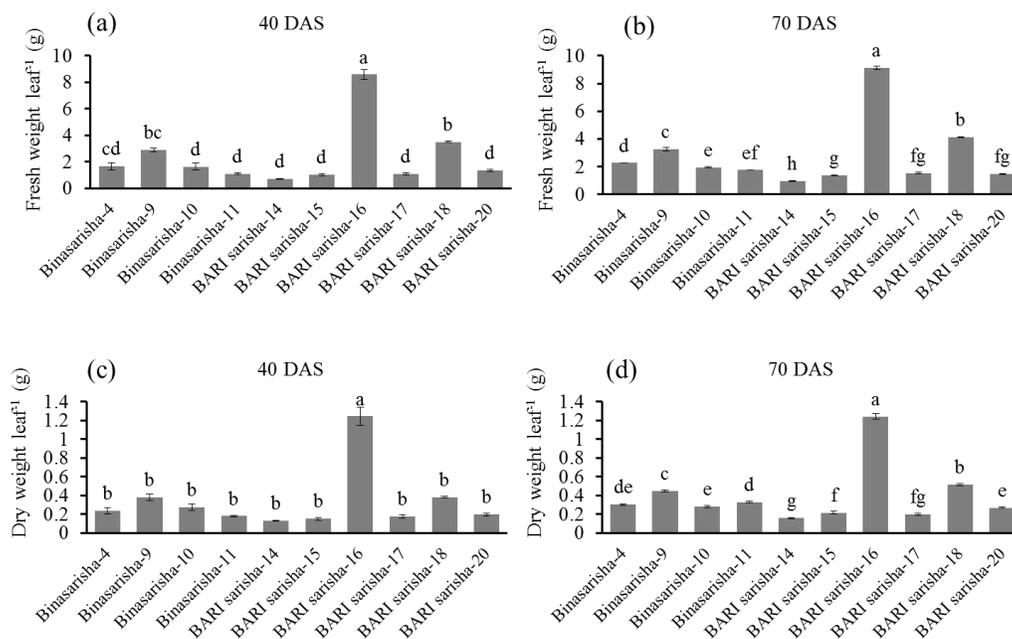


Fig. 4. Fresh weight of leaf area and dry weight of leaf at different days after sowing (DAS) of different rapeseed-mustard varieties as relay cropping, (a) fresh weight of leaf area at 40 DAS and (b) 70 DAS; (c) dry weight of leaf at 40 DAS, and (d) 70 DAS. Values labelled with different lower case letters are significantly different at $P < 0.01$.

Leaf dry weight

Leaf dry weight (LDW) varied significantly at 40 and 70 DAS (Figure 4c and 4d). LDW ranged from 0.13 g leaf⁻¹ to 1.24 g leaf⁻¹ at 40 DAS and increased in all varieties at 70 DAS, ranging from 0.16 to 1.25 g leaf⁻¹. The maximum LDW was observed by var. BARI sarisha16 at 40 DAS and the minimum by the BARI sarisha14 which was statistically similar to all other variety except BARI sarisha16. At 70 DAS, the highest LDW was found with BARI sarisha16 whereas the lowest with BARI sarisha14 which was statistically similar to BARI sarisha17.

Days to flower and growth duration

The days of flower and growth duration of rapeseed-mustard significantly differed among the varieties (Fig. 5). The flowering time ranged between 42-55 DAS and growth duration ranged between 75 DAS to 115 DAS. BARI sarisha14 took minimum days to flowering and mature. The variety BINA sarisha10 also took minimum days to flower and mature. On the other hand BARI sarisha16 and BARI sarisha18 took maximum days to flowering and mature.

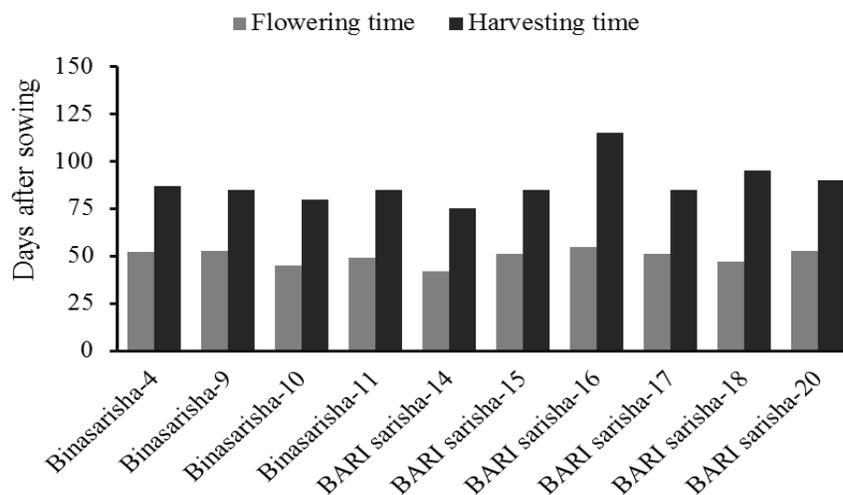


Fig. 5. Days to flower and growth duration of different rapeseed-mustard varieties as relay cropping. Data represent the mean values calculated from three replications of different varieties.

Yield contributing characteristics of rapeseed-mustard

Branch plant⁻¹

Significant variation was observed in number of branches plant⁻¹ at harvesting time (Fig. 6a). The number of branches plant⁻¹ ranged from 7.22 to 14.22. Improved BINA sharisha10 produced the maximum number of branches plant⁻¹ and it was statistically similar to BARI sharisha15, BARI sharisha18, and BARI sharisha20 and BINA sharisha9. On the other hand the lowest branches plant⁻¹ was observed from the BINA sharisha4 which was statistically at par with BINA sharisha11 and BARI sharisha17. The result was in agreement by Mamun *et al.*, 2014 stated that BARI sharisha15 produced 7.45 branches plant⁻¹. It was also found that BINA sharisha10 produced maximum 6.60 branches plant⁻¹ whereas minimum branches plant⁻¹ produced by the variety of BINA sharisha4 (Sohel *et al.*, 2024).

Siliqua plant⁻¹

Significant variation was found in the number of siliqua plant⁻¹ among the varieties (Fig. 6b). The number of siliqua plant⁻¹ ranged from 57.89 to 211.22. The maximum number of siliqua plant⁻¹ was produced by the variety BARI sharisha16 followed by the variety BINA sharisha10 which was statistically similar to BARI sharisha18. On the other hand the lowest siliqua plant⁻¹ was produced by the variety BARI sharisha17 and it was statistically similar to BARI sharisha20 and BARI sharisha15. Similar results were observed by Rahman *et al.* (2022). Laila (2014) also found the highest number of siliqua plant⁻¹ produced by the var. BARI sharisha16 (143.7). Yadav *et al.* (2010) suggested that for ensuring high yields in *B. juncea* (BARI sharisha16), the plant type should have more number of siliqua plant⁻¹ (100-125).

Seeds siliquae⁻¹

Significant variation was observed in terms of number of seeds siliquae⁻¹ among all the varieties (Fig. 6c). The number of seeds siliquae⁻¹ ranged from 14.13 to 34.73. The maximum number of seeds siliquae⁻¹ was produced by the var. BINA sharisha11 (34.73) and it was statistically identical to the var. BINA sharisha4 (34.47) and BARI sharisha12 (30.87). The minimum number of seeds siliquae⁻¹ was produced by the var. BARI sharisha16 (14.13) and it was statistically similar to the var. BINA sharisha10 (16.26).

1000-seed weight

In case of 1000-seed weight, a significant variation was found among all the varieties (Fig. 6d). The 1000-seed weight ranged from 3.58 g to 4.73 g. The maximum 1000-seed weight (4.73 g) was recorded in the var. BARI sharisha14 which was statistically similar to BARI sharisha20 (4.63), BARI sharisha16 (4.50) and BARI sharisha17 (4.47). The minimum 1000-seed weight was observed from the var. BINA sharisha4 (3.58) and it was statistically identical with BINA sharisha11 (3.87). Previous results observed that the maximum 1000-seeds weight was produced in BARI sharisha14 followed by BARI sharisha16, BARI sharisha17 and BARI sharisha20 among the other varieties. The present study is in agreement with previous results by Helal *et al.*, (2016), Soheli *et al.*, (2024) and Rahman *et al.* (2022).

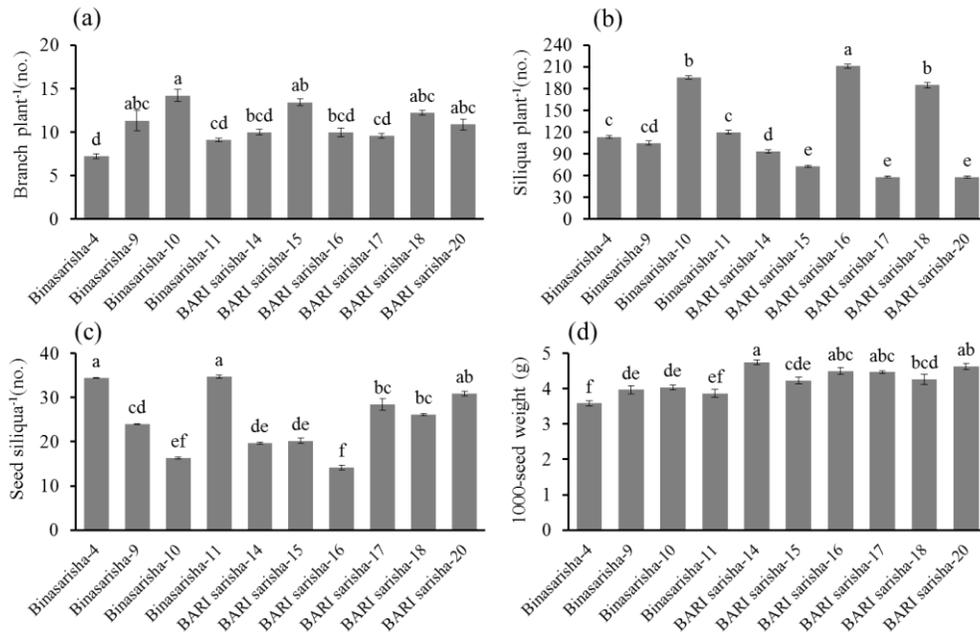


Fig. 6. Yield contributing characteristics of different rapeseed-mustard varieties as relay cropping, (a) number of branch plant⁻¹; (b) number of siliqua plant⁻¹; (c) number of seeds siliqua⁻¹; and (d) 1000-seed weight. Values labelled with different lower case letters are significantly different at P < 0.01.

Yield of rapeseed-mustard

Seed yield

The seed yield of rapeseed-mustard varieties was differed significantly as relay cropping (Fig. 7a). Seed yield was ranged from 0.61 t ha⁻¹ to 1.10 t ha⁻¹. The mustard var. BARI sharisha16 produced the maximum seed yield (1.10 t ha⁻¹) followed by BARI sharisha17 (0.90 t ha⁻¹) and BARI sharisha15 (0.85 t ha⁻¹). The lowest seed yield was observed from the var. BINA sharisha9 (0.61 t ha⁻¹) and it was statistically similar to BINA sharisha4 (0.62 t ha⁻¹) and BARI sharisha18 (0.62 t ha⁻¹).

Stover yield

The stover yield of rapeseed-mustard varieties was differed significantly as relay cropping (Fig. 7b). Stover yield ranged from 3.56 t ha⁻¹ to 5.86 t ha⁻¹. The variety BARI sharisha16 produced the maximum seed yield (5.86 t ha⁻¹) followed by the variety BARI sharisha17 (5.28 t ha⁻¹) whereas lowest stover yield was found from BINA sharisha11 (3.56 t ha⁻¹).

Biological yield

The biological yield of rapeseed-mustard varieties was varied significantly as relay cropping (Fig. 7c). Biological yield ranged from 4.33 to 6.95 t ha⁻¹. The variety BARI sharisha16 produced the maximum seed yield (6.95 t ha⁻¹) followed by var. BARI sharisha17 (5.28 t ha⁻¹). The lowest stover yield was found from BINA sharisha11 (4.32 t ha⁻¹) and it was statistically at par to BINA sharisha10.

Harvest index

The harvest index (HI) of rapeseed-mustard varieties was varied significantly as relay cropping (Fig. 7d). HI ranged from 13.18% to 18.63%. The var. BINA sharisha11 produced the maximum HI (18.63%) and it was statistically similar to BARI sharisha14 (18.15%), BARI sharisha17 (17.63%), BARI sharisha20 (16.54%), BARI sharisha15 (16.33%) and BINA sharisha10 (16.15) followed by var. BARI sharisha17 (5.28 t ha⁻¹). The lowest HI was found from BINA sharisha4 (13.17%) and it was statistically similar to BINA sharisha9 (13.19%).

The present study indicated variation of production of seed and stover yield by different varieties. This might be due to the contribution of cumulative effects of the crop growth and yield contributing characteristics such as leaf number, leaf area index, number of branches plant⁻¹, siliquae plant⁻¹ and seeds siliqua⁻¹, 1000-seed weight, etc. In the study, the variety BARI sharisha16 produced the highest seed yield (1.10 t ha⁻¹) which might be due to the highest leaf area, leaf area index, leaf fresh and dry weight, leaf specific weight, siliqua plant⁻¹, and 1000-seed weight. The highest stover yield produced by BARI sharisha16 also influenced by the highest plant height, leaf area, leaf area index, leaf fresh and dry weight, and leaf specific weight. Similar higher seed and stover yield were reported by Rahman *et al.* (2022) and Sarker *et al.* (2018) in var. BARI sharisha16.

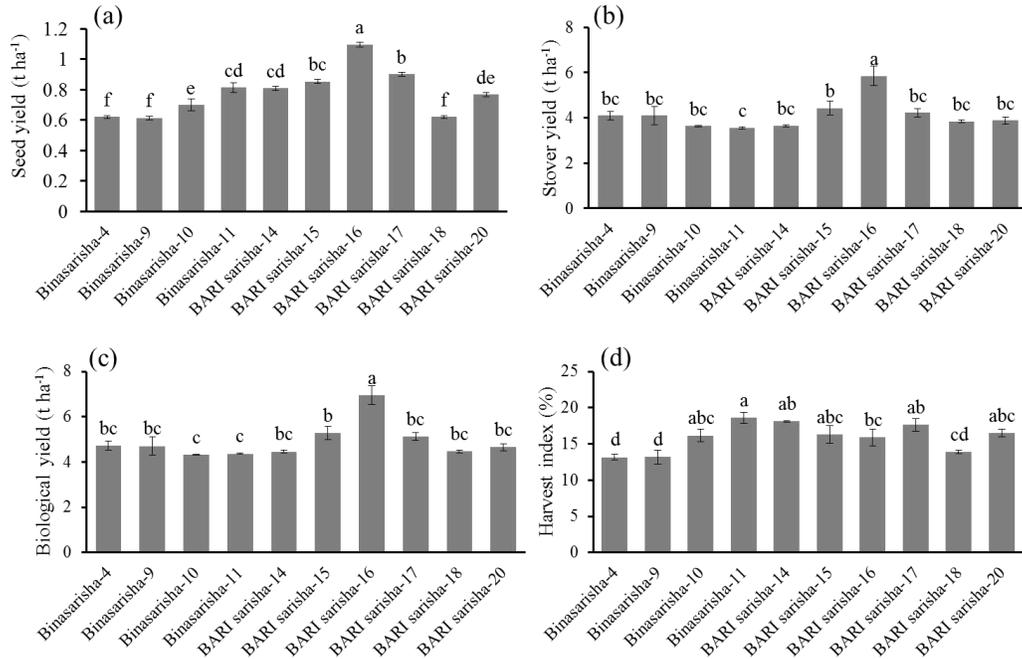


Fig. 7. Yield of different rapeseed-mustard varieties as relay cropping, (a) seed yield (t ha⁻¹); (b) stover yield (t ha⁻¹); (c) biological yield (t ha⁻¹); and (d) harvest index (%). Values labelled with different lower case letters are significantly different at P < 0.01.

Correlation between yield with growth and yield contributing characters

Correlation between seed yield and yield contributing attributes of different rapeseed-mustard varieties are presented in Table 2. It appears that seed yield was significantly and positively correlated with plant height, leaf number, leaf fresh and dry weight, leaf area, leaf area index, days to growth duration, 1000-seed weight and stover yield which indicated that seed yield would increase with the increase growth and yield attributes parameters. Stover yield was also significantly and positively correlated with plant height at 70 DAS, leaf fresh and dry weight, leaf area, leaf area index, specific leaf area, days to flowering and growth duration and seed yield which indicated that stover yield would increase with the increase of these growth and yield attributes. It was reported that seed and stover yield significantly and positively correlated with number of siliques plant⁻¹, 1000-seed weight, stover yield, plant height, biological yield and harvest index as reported by Aytaç and Kınacı (2009), Akter *et al.* (2020) and Helal *et al.* (2022).

Table 2. Pearson's correlations between various growth, yield contributing and yield parameters of different mustard/rapeseed varieties under T. Aman-mustard relay cropping at a significance level less than ≤ 0.05 .

Traits	PH70	LN40	LN70	LDW40	LDW70	LFW40	LFW70	LA40	LA70	LA40	LA70	SLA40	SLA70	SLA40	SLA70	SWI40	SWI70	BN	NS	SS	TSW	FT	HT	SY	SY	BY	HI						
PH40	-0.18	0.89	0.84	-0.35	-0.43	-0.45	-0.49	-0.03	-0.53	0.75	-0.24	0.57	-0.25	-0.46	0.32	0.08	-0.47	-0.09	0.38	-0.29	-0.42	0.44	-0.16	-0.07	0.72								
PH70		-0.30	-0.26	0.86	0.87	0.86	0.87	0.50	0.71	-0.18	0.70	-0.42	-0.29	0.65	0.24	0.10	0.51	-0.52	0.27	0.45	0.88	0.66	0.76	0.79	-0.05								
LN40			0.87	-0.53	-0.60	-0.61	-0.64	-0.14	-0.70	0.78	-0.46	0.62	-0.22	-0.62	0.32	0.19	-0.52	-0.09	0.36	-0.42	-0.57	0.29	-0.27	-0.19	0.64								
LN70				-0.53	-0.56	-0.59	-0.61	-0.09	-0.73	0.69	-0.42	0.67	-0.38	-0.63	0.40	0.02	-0.72	0.12	0.41	-0.18	-0.44	0.34	-0.19	-0.10	0.62								
LDW40					0.98	0.98	0.95	0.48	0.87	-0.32	0.79	-0.56	-0.12	0.88	0.08	-0.06	0.64	-0.49	0.16	0.45	0.87	0.53	0.76	0.76	-0.18								
LDW70						0.98	0.99	0.45	0.90	-0.41	0.82	-0.60	-0.17	0.85	0.11	-0.07	0.68	-0.41	0.11	0.49	0.93	0.51	0.71	0.72	-0.17								
LFW40							0.98	0.49	0.89	-0.39	0.77	-0.60	-0.14	0.87	0.08	-0.03	0.68	-0.46	0.14	0.46	0.91	0.46	0.74	0.74	-0.25								
LFW70								0.46	0.91	-0.44	0.79	-0.60	-0.14	0.82	0.07	-0.07	0.70	-0.43	0.10	0.47	0.92	0.46	0.72	0.72	-0.24								
LA40									0.37	0.44	0.43	0.30	0.13	0.07	0.08	0.05	0.27	-0.40	0.72	0.01	0.49	0.38	0.31	0.34	0.10								
LA70										-0.48	0.90	-0.65	0.25	0.81	-0.30	-0.03	0.71	-0.41	-0.10	0.49	0.80	0.28	0.64	0.61	-0.36								
LA40											-0.25	0.85	-0.14	-0.61	0.20	0.13	-0.41	-0.22	0.70	-0.44	-0.39	0.31	-0.19	-0.11	0.58								
LA70												-0.48	0.25	-0.66	-0.31	-0.04	0.55	-0.34	0.04	0.38	0.79	0.48	0.65	0.66	-0.13								
SLA40													-0.13	-0.80	0.16	-0.06	-0.57	0.04	0.57	-0.47	-0.53	0.02	-0.37	-0.32	0.42								
SLA70														-0.05	-0.95	0.08	0.20	-0.01	-0.44	0.01	-0.21	-0.45	-0.13	-0.20	-0.40								
SWI40																-0.01	-0.05	-0.30	-0.18	0.52	0.71	0.29	0.65	0.62	-0.34								
SWI70																0.00	0.00	-0.09	-0.12	0.44	-0.23	0.10	0.43	0.04	0.11	0.48							
BN																	0.21																
NS																																	
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Red indicates negative correlation, and blue indicates positive correlation. Plant height (PH); Leaf number (LN); Leaf fresh weight (LFW); Leaf dry weight (LDW); Leaf area (LA); Chl (Chlorophyll) SPAD value); Specific leaf area (SLA); Specific leaf weight (SLW); Branch number (BN); Number of siliqua (NS); Seed per siliqua (SS); Thousand seed weight (TSW); Flowering time (FT); Harvesting time (HT); Seed yield (SY); Straw yield (SY); Biological yield (BY) and Harvest index (HI).

Conclusion

The yield contributing characteristics and yield indicated that the mustard var. BARI sharisa16 performed the highest yield and followed a trend as var. BARI sharisha17>BARI sharisa15>BARI sharisa14>BINA sharisha11. These varieties showed higher number of leaf plant⁻¹, leaf area, leaf area index, 1000-seed weight, siliqua plant⁻¹, and seeds siliquae⁻¹. However, crop duration is an inevitable part of *Brassica* oilseed crop in Bangladesh. Generally short duration varieties are preferable to the farmers of Bangladesh as these can be fitted in rice-based cropping pattern. Although BARI sharisha16 has a high yield potential, farmers are hesitant to adopt it as a relay crop with T. Aman rice due to its long growth duration. In contrast, BARI sharisha14, BARI sharisha15, BARI sharisha17, and BINA sharisha11 mature within 75-80 days and could be potentially well-suited as relay cropping with the T. Aman. Considering overall yield and crop duration, the mustard varieties BARI sharisa14, BARI sharisha15, BARI sharisha17 and BINA sharisha11 are suited as relay cropping with T. Aman rice.

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Conflicts of interest

The authors declare no conflicts of interest regarding publication of this manuscript.

Authors' contribution

Conceptualization, Supervision, Writing-original draft: AAFB and MH, Data curation: MNS and FI; Formal analysis: MNS and MH; Funding acquisition: MH; Investigation: FA and MM; Methodology: MAB and SMM; Resources: FA, MAB and MMB; Validation: FI and SMM; Visualization: FI, MH; Review and editing: SMM, MAB, MH.

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ROLE OF ASCORBIC ACID AS A SEED PRIMING AGENT IN ALLEVIATING SALT INDUCED DAMAGES IN GERMINATION AND EARLY SEEDLING GROWTH OF RICE (*Oryza sativa* L.)

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Abstract

Salinity is one of the major brutal abiotic stresses that affect crop productivity worldwide. Seed priming with different bio-regulators has emerged as an effective and practical approach to inducing the plant tolerance against different abiotic stress including salinity. Therefore, a study was conducted at the Agroforestry Field Laboratory, Sher-e-Bangla Agricultural University, Dhaka during July 2022 to September 2022 to find out potential of seed priming with ascorbic acid in alleviation of germination and growth inhibition of rice (*Oryza sativa* L.) seedlings under salt stress. The study included four levels ascorbic acid viz. i) 0 mM (A₀), ii) 0.125 mM (A₁) iii) 0.250 mM (A₂) iv) 0.5 mM (A₃) for seed priming and four levels of salinity: i) 0 dS m⁻¹ (S₀), ii) 5 dS m⁻¹ (S₁), iii) 10 dS m⁻¹ (S₂), iv) 15 dS m⁻¹ (S₃) NaCl set up in petridishes and pots. Salinity levels significantly affected germination and growth attributes like germination percentage, germination speed, germination energy, radical length, plumule length, plant height, plant fresh weight, plant dry weight, SPAD value and leaf relative water content. However, ascorbic acid primed seeds provided higher germination percentage, germination speed, germination energy, radical length, plumule length, plant height, plant fresh weight, plant dry weight, SPAD value and leaf relative water content in contrast to respective salt stress. Among the doses of ascorbic acids 0.250 mM and 0.5 mM performed better than the 0.125 mM. Thus, this study suggests that use of ascorbic acid as a seed priming agent with appropriate dose can enhance the tolerance of rice seedlings against salt stress.

Keywords: Ascorbic acid, Germination and growth, Salinity stress, Seed priming.

Introduction

Crop production is vulnerable to climate variability, and climate change associated with increases in different abiotic stresses which may lead to a considerable decline in crop yield (Mall *et al.* 2017). Abiotic stresses such as salinity, drought, flooding, heat, cold, freezing, excess light, UV radiation, and heavy metal toxicity have a significant impact on seed which reduce germination rate, seedling growth and yield with

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significant variations from crop to crop worldwide (Zhao *et al.*, 2007). Among them salinity is one of the major abiotic stresses that affect crop production in arid and semiarid areas (Ibrahim, 2016) including southern part of Bangladesh. Salt stress adversely affects physiology and biochemistry of plants primarily by creating osmotic stress, ionic imbalance, and toxicity (Hajlaoui *et al.*, 2009). As Reactive oxygen species (ROS) are responsible for damaging plant cells under salt stress, elimination of these toxic compounds is considered a strategy for developing salt stress tolerance. Seed priming has emerged as an effective and practical approach to induce the plant tolerance against different stress factors including salinity. Priming of seed enables the faster and better germination in plants under stressful conditions as they have potential to upregulate the antioxidant defense system.

Different cellular and metabolic events are involved in induction of salinity tolerance after seed priming. Primed seeds can activate the signal pathways during the early growth stage and triggered the faster stress response. Faster emergence and uniform stand establishment in primed seeds ultimately increases the crop productivity under salinity conditions (Hussain *et al.*, 2022). Several priming strategies have been tested in rice under salinity stress. For example, bio-priming with *Trichoderma harzianum* alleviates salinity stress by improving physiological and biochemical traits (Rawat *et al.*, 2012). Halo-priming or osmo-priming with salts such as potassium nitrate (KNO_3) or calcium chloride (CaCl_2) enhances germination and seedling establishment in saline environments (Ahmandvand *et al.*, 2012; Farooq *et al.*, 2019). Even low-cost hydro-priming (soaking seeds in water followed by drying) has proven effective in improving germination and vigor under stress (Casenave and Toselli, 2007; Afzal *et al.*, 2005). More recently, nano-priming approaches using chitosan nanoparticles (CNPs) have shown superior enhancement of germination and seedling vigor in rice under salinity stress (Abdel-Aziz *et al.*, 2019).

Despite the availability of these techniques, ascorbic acid (AsA) remains particularly attractive because of its dual role as a potent antioxidant and signaling molecule. AsA regulates enzymatic and non-enzymatic antioxidant activities, modulates gene expression, and improves stress adaptation (Roy *et al.*, 2016). Furthermore, experimental studies on different plants have showed that exogenous application of AsA may reduce salt-induced adverse effects and significant increment of growth and yield (Athar *et al.*, 2009; Salama, 2009; Khan *et al.* 2010). Although there have been few studies regarding the impact of ascorbic acid as seed priming agent on alleviating salt stress in a variety of plants, but no investigation of the roles of ascorbic acid priming agent in seed germination, growth, physiology and yield of aman rice variety under salt stress has been reported. Therefore, this study was designed to investigate the roles of ascorbic acid as priming agents at different concentrations in seed germination, seedling growth and physiological performance of rice (*Oryza sativa* L.) of *T. aman* variety) under different salinity conditions.

Materials and Methods

Experimental site

The study was conducted from July to September 2022 at the Field Laboratory, Department of Agroforestry and Environmental Science, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. It included both laboratory (petri-dish) and pot experiments. The site, situated at 23°74'N and 90°35'E, 8 m above sea level, lies in the “Madhupur Tract” agro-ecological zone (AEZ-28).

Climate and soil

The Field Laboratory experiences a subtropical climate, marked by hot, humid, and rainy summers with gusty monsoon winds, and cooler, drier winters with scattered rainfall.

Planting materials

Rice var. BRRI dhan78 (slightly salinity tolerant) seed was collected from BRRI, Gazipur on June, 2022.

Treatments of the experiment

The following treatments were maintained in this study for each studies. Priming treatments: i) 0 mM (A0), ii) 0.125 mM ((A1)) iii) 0.250 mM (A2) iv) 0.5 mM (A3) ascorbic acid. Before sowing, seeds were sterilized with 70% ethanol, then primed with ascorbic acid for 12 hours. Control seeds were soaked in distilled water for the same duration. After treatment, all seeds were rinsed three times, dried on filter paper, and air-dried for 48 hours at room temperature. Salinity treatments: i) 0 dS m⁻¹ (S0), ii) 5 dS m⁻¹ (S1), iii) 10 dS m⁻¹ (S2), iv) 15 dS m⁻¹ (S3) NaCl were maintained in growing media of both experiments. So, the total no. of treatments was 16. The treatments were: i. A0S0, ii. A0S1, iii. A0S2, iv. A0S3, v. A1S0, vi. A1S1, vii. A1S2, viii. A1S3, ix. A2S0, x. A2S1, xi. A2S2, xii. A2S3, xiii. A3S0, xiv. A3S1, xv. A3S2, xvi. A3S3

Design and layout of the experiment

July to September 2022, two experiments were conducted to assess ascorbic acid seed priming effects on rice (*Oryza sativa* L.) under salinity. Both experiments were laid out in Completely Randomized Design (CRD) with 16 treatment combinations based on four ascorbic acid levels and four salinity levels, each with three replications (48 pots) Germination was tested in the lab (petri-dish), and morpho-physiology and early seedling growth were evaluated in the pot experiment.

Petri-dish and pot preparation

The experiment was conducted in a Completely Randomized Design (CRD) with three replications. In the petri-dish experiment, 9 cm dishes with six layers of blotting paper were used, and 20 seeds per dish were considered an experimental unit. Germination parameters were recorded for all seeds within each dish. In the pot experiment, pots (35 cm

height \times 30 cm top diameter \times 20 cm bottom diameter) were filled with sun-dried soil mixed with recommended organic manures, fertilizers, and Furadan 5G. Ten seedlings were sown per pot, later thinned for uniform growth, and each pot was considered an experimental unit. Growth and physiological parameters, including plant height, biomass, SPAD, and leaf RWC, were recorded on the plants within each pot.

Manure and fertilizer application

In the petri-dish experiment, a nutrient solution of Hyponex (Japan) was used; its composition included N, P₂O₅, and K₂O at 6%, 10%, and 5%, respectively, along with essential micronutrients such as calcium and trace elements. For the pot experiment, soil was mixed with well-decomposed cow dung and supplemented with additional nutrients, with fertilizer doses calculated based on field rates per bigha according to the fertilizer recommendation by BRRI for BRRI dhan 78. Each pot received the recommended doses of urea (3.0 g), TSP (2.0 g), MoP (1.25 g), gypsum (1.2 g), and zinc (0.15 g) before seedling transplantation.

Application of salt treatment

Rice plant is evaluated in different level of salt treatment. S₀, S₁, S₂ and S₃ indicate 0, 5, 10 and 15 dSm⁻¹ NaCl, respectively.

Intercultural operations

Irrigation

After transplanting, seedlings were given light watering immediately to prevent water stress, followed by regular watering every two days.

Weeding

Weeding was carried out to maintain clean plots and ensure proper soil aeration, promoting better growth. Newly emerged weeds were carefully removed, and mulching was applied as needed to break soil crust.

Data recording

Data were recorded from each pot based on growth and yield parameters. Data were recorded in respect of the following parameters:

Petri-dish experiment

Germination parameters

Germination percentage, speed of germination, germination energy, radical and plumule length were measured (for first experiment). Final germination percent (FGP), speed of germination (SG) and germination energy percentage (GE %) were calculated by the following formulae (Ellis and Robert, 1981; Ruan *et al.*, 2002).

$$SG = \frac{\text{Number of germinated seeds}}{\text{Days of first count}} + \dots + \frac{\text{Number of germinated seeds}}{\text{Days of final count}}$$

$$\text{GE (\%)} = \frac{\text{Number of germinated seeds at 4 DAS}}{\text{Total number of seed tested}} \times 100$$

$$\text{FGP} = \frac{\text{Number final germinated seeds}}{\text{Total number of seed tested}} \times 100$$

Plumule and radicle length: Plumule and radicle length were measured in cm basis.

Pot experiment

Plant height

Plant height (cm) was measured at 15 and 30 DAS from each replication were averaged to obtain mean plant height.

Plant fresh weight

Fresh weight (mg) was measured after uprooting plants at 15 and 30 DAS using an electronic balance.

Plant dry weight

Dry weight (mg) was recorded after drying plants in an oven at 70°C for 48 hours at 15 and 30 DAS.

SPAD value

SPAD value was estimated using a portable SPAD 502 Plus meter (Konica-Minolta, Tokyo, Japan) at 15 and 30 DAS. Each leaf was measured five times from tip to base, and the average SPAD value was used.

Leaf relative water content (RWC)

RWC (%) was determined following Barrs and Weatherly (1962) at 15 and 30 DAS. Leaf laminae were weighed for fresh weight (FW), floated on distilled water for 8 h to get turgid weight (TW), and then dried at 80°C for 48 h for dry weight (DW). RWC was calculated as: $\text{RWC (\%)} = [(\text{FW}-\text{DW}) / (\text{TW}-\text{DW})] \times 100$

Statistical analysis

Data were analyzed using Statistix 10. Data for all parameters were subjected to analysis of variance (ANOVA) to determine the effects of ascorbic acid priming (AsA) and salinity level (NaCl) alone and in combination, using the statistical software Statistix 10. Where the ANOVA indicated significant F-values ($p \leq 0.05$), treatment means were separated using Tukey's Honest Significant Difference (HSD) test.

Results and Discussion

Final germination percentage (FGP)

Germination of rice seeds declined with increasing salt stress, with the lowest value in S₃. In non-primed seeds, germination was 96.3, 92.0, 81.3 and 51.3% under S₀,

S₁, S₂ and S₃, respectively representing 4.5, 12.5 and 46.7% reductions compared to control. Ascorbic acid priming significantly improved germination under all stress levels (Fig. 1), with the greatest gains from A₂ and A₃. Under S₃, germination increased by 43.7% with A₂ and 44.8% with A₃ compared to the respective control.

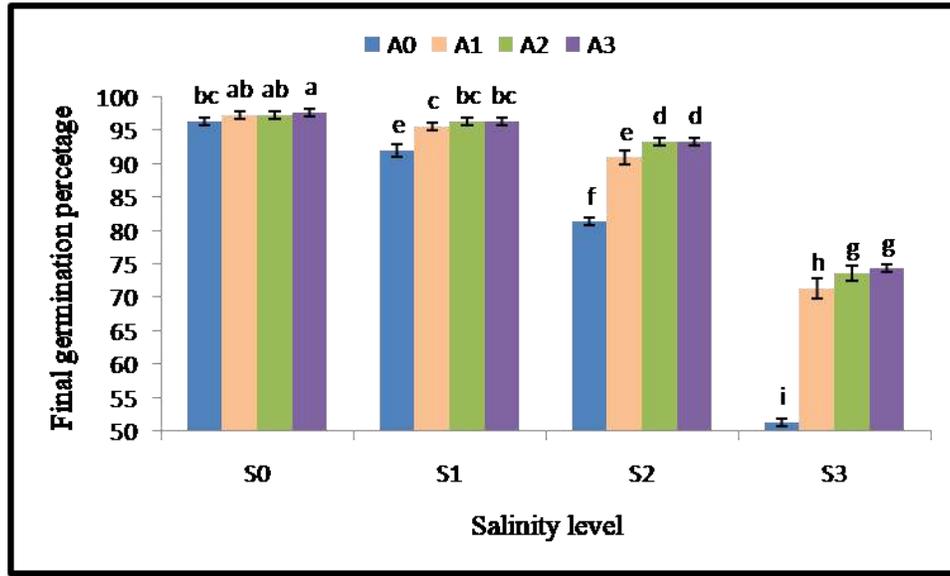


Fig. 1. Effect of ascorbic acid as seed priming agent on final germination percentage of rice under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Speed of germination (SG)

Salinity delayed rice seed germination, reducing germination speed in a dose-dependent manner. In non-primed seeds, germination speed was 20.2, 18.2, 12.1 and 3.0 for S₀, S₁, S₂ and S₃, respectively, representing reductions of 9.9, 40.1 and 85.1% compared to control. Ascorbic acid priming accelerated germination under all stress levels (Fig. 2). Under S₁ and S₂, A₂ and A₃ performed similarly, while under S₃, A₃ showed the highest improvement, increasing germination speed by 336.7% compared to the respective control followed by A₂ with 303.3%.

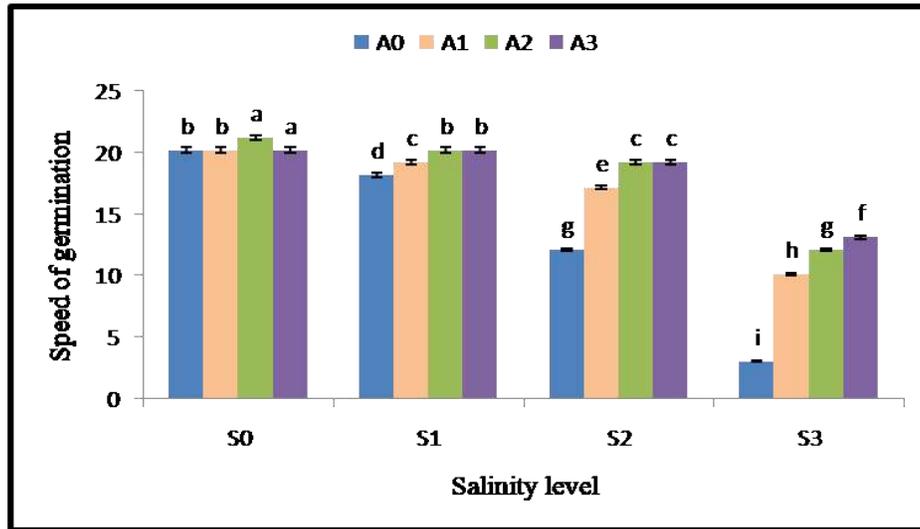


Fig. 2. Effect of ascorbic acid as seed priming agent on speed of germination of rice under different levels of salt stress. Here, A_0 , A_1 , A_2 , A_3 indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S_0 , S_1 , S_2 , S_3 indicate 0 dS m^{-1} , 5 dS m^{-1} , 10 dS m^{-1} , 15 dS m^{-1} NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Germination energy percentage (GE %)

Germination energy (GE%) measured on the 4th day after soaking declined significantly with increasing salinity, reaching 0% in S_3 under non-primed conditions. Ascorbic acid priming improved GE% under all stress levels (Fig.3), including S_3 , where A_1 , A_2 , and A_3 achieved 24.0, 33.3, and 35.0%, respectively. The maximum GE (77.3%) was observed in A_3S_0 , followed by A_2S_0 .

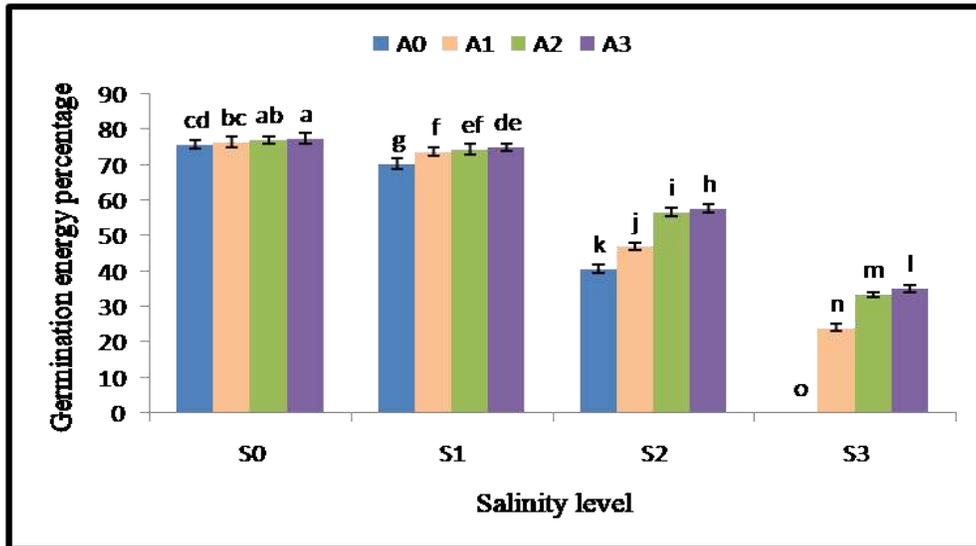


Fig. 3. Effect of ascorbic acid as seed priming agent on germination energy percentage of rice under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Plumule length

Plumule length of rice declined under all salt treatments, with greater reductions at higher salinity. In non-primed seeds, plumule length was 5.6, 4.5, 3.1 and 2.0 cm for S₀, S₁, S₂ and S₃, representing reductions of 19.6, 29.0 and 64.3% compared to control. Ascorbic acid priming improved plumule length under all stress levels (Fig. 4). Under S₁, S₂ and S₃, A₁ increased plumule length by 6.7–35.0%, A₂ by 13.5–70.0%, and A₃ by 17.8–80.0% relative to respective stress treatments.

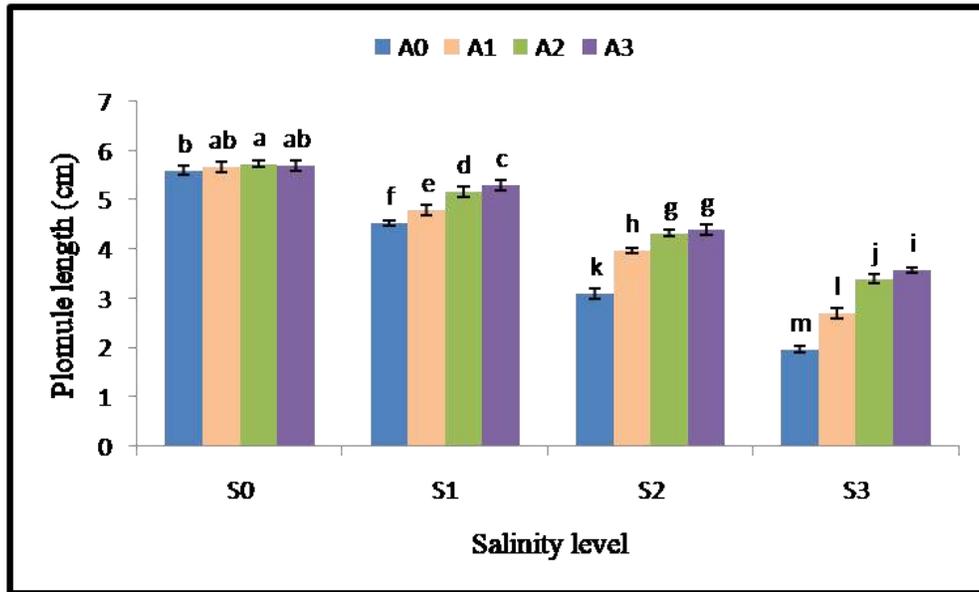


Fig. 4. Effect of ascorbic acid as seed priming agent on plumule length of rice under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Radicle length

Similar to plumule length, radicle length decreased with increasing salinity, showing greater suppression than plumule at each salt level. In non-primed seeds, radicle length was 5.7, 3.2, 1.8, and 0.9 cm for S₀, S₁, S₂, and S₃, representing reductions of 19.6, 46.6 and 64.3% compared to control. Ascorbic acid priming improved radicle length under all stress levels (Fig. 5). Under S₁, S₂, and S₃, A₁ increased radicle length by 25.0, 33.3 and 33.3%, A₂ by 40.6, 77.8 and 111.1%, and A₃ by 43.8, 77.8 and 111.1% relative to the respective stress treatments.

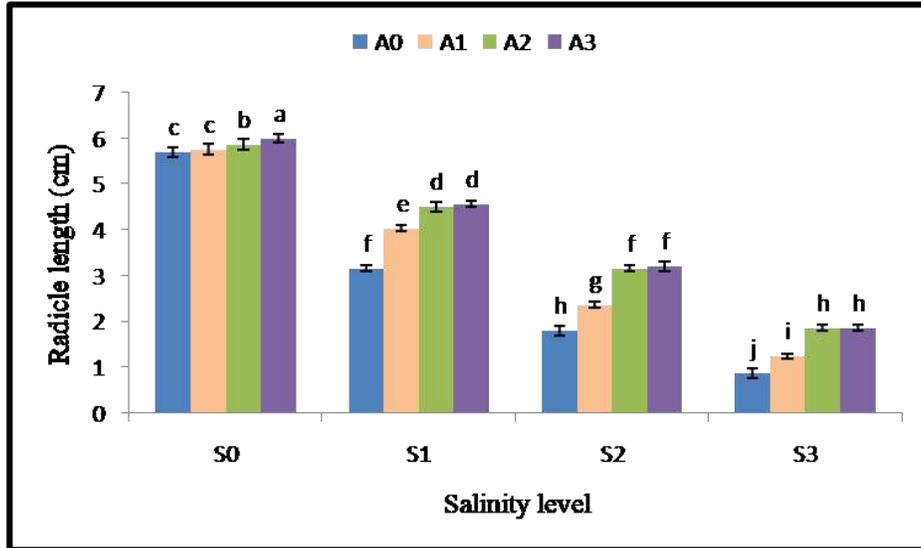


Fig. 5. Effect of ascorbic acid as seed priming agent on radicle length of rice under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Plant height

Plant height declined under all salt stress levels in a dose-dependent manner at both 15 and 30 DAS (Fig. 6), with the greatest reduction in S₃. In non-primed plants, height was 22.2, 21.3, 19.1 and 17.4 cm at 15 DAS, and 41.1, 35.1, 32.1 and 28.1 cm at 30 DAS for S₀, S₁, S₂ and S₃, respectively, representing 4.1, 13.9 and 21.6% and 14.6, 21.9 and 31.6% reductions compared to control. Ascorbic acid priming improved plant height under stress, with A₂ and A₃ performing better than A₁ at 15 DAS, and A₃ showing the greatest improvement at 30 DAS, increasing height by 14.2, 21.8 and 21.4% under S₁, S₂ and S₃ stress.

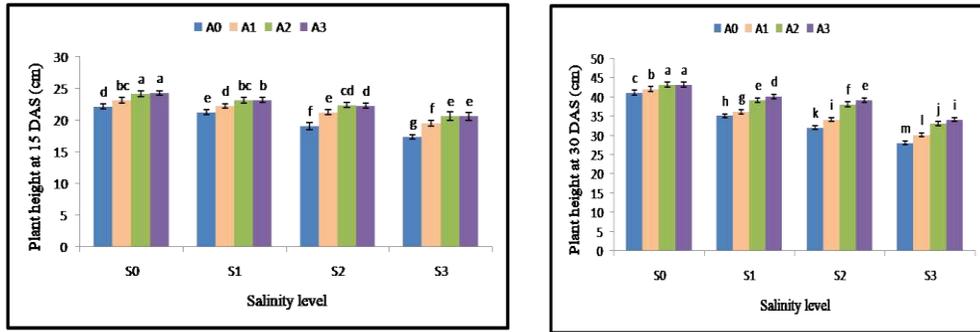


Fig. 6. Effect of ascorbic acid as seed priming agent on plant height of rice at 15 and 30 DAS (days after sowing) under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Fresh weight of plant

Plant fresh weight declined under all salt treatments in a dose-dependent manner at both 15 and 30 DAS, with the highest reduction in S₃ (Fig. 7). In non-primed plants, fresh weight was 152.3, 142.3, 123.2 and 103.0 mg at 15 DAS, and 2067.3, 1851.3, 1553.3 and 1302.0 mg at 30 DAS for S₀, S₁, S₂ and S₃, respectively, showing reductions of 6.6, 19.1 and 32.4% and 10.4, 24.9 and 37.0% compared to control. Ascorbic acid priming increased fresh weight under all stress levels. At 15 DAS, A₁, A₂ and A₃ increased fresh weight by 2.8, 6.5 and 6.9%, 5.6, 10.6 and 19.6% and 5.9, 11.4 and 22.5%, respectively, under S₁, S₂ and S₃ stress, with a similar trend at 30 DAS.

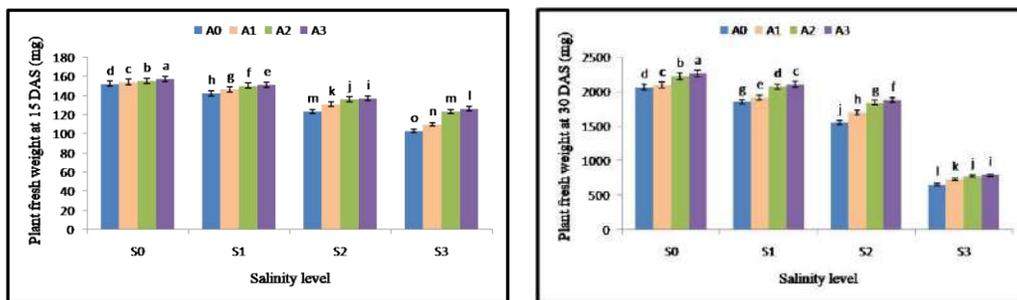


Fig. 7. Effect of ascorbic acid as seed priming agent on plant fresh weight of rice at 15 and 30 DAS (days after sowing) under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Dry weight of plant

Like fresh weight, plant dry weight also declined under salinity in a dose-dependent manner at both 15 and 30 DAS (Fig. 8), with the greatest reduction in S_3 . In non-primed plants, dry weight was 19.3, 18.4, 16.0 and 13.4 mg at 15 DAS, and 288.2, 267.7, 224.4 and 189.2 mg at 30 DAS for S_0 , S_1 , S_2 and S_3 , respectively, representing 4.7, 17.1 and 30.6% and 7.1, 22.1 and 34.4% reductions compared to control. Ascorbic acid priming improved dry weight under all stress levels. At 15 DAS, A_1 , A_2 , and A_3 increased dry weight by 3.3, 6.3 and 6.7%, 6.0, 10.6 and 19.4%, and 7.1, 11.3 and 21.6%, respectively, under S_1 , S_2 and S_3 stress, with a similar trend at 30 DAS.

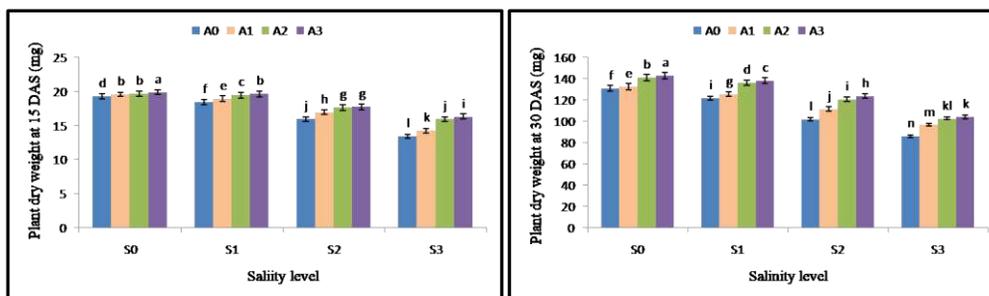


Fig. 8. Effect of ascorbic acid as seed priming agent on plant dry weight of rice at 15 and 30 DAS (days after sowing) under different levels of salt stress. Here, A_0 , A_1 , A_2 , A_3 indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S_0 , S_1 , S_2 , S_3 indicate 0 dS m^{-1} , 5 dS m^{-1} , 10 dS m^{-1} , 15 dS m^{-1} NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Leaf SPAD value

SPAD value declined under salt stress in a dose-dependent manner, with the greatest reduction in S_3 at both 15 and 30 DAS (Fig. 9). In non-primed plants, SPAD values were 41.0, 39.7, 35.0 and 31.0 at 15 DAS, and 45.3, 44.0, 38.7 and 34.0 at 30 DAS for S_0 , S_1 , S_2 and S_3 , respectively, showing reductions of 3.2, 14.6 and 24.4% compared to control. Ascorbic acid priming improved SPAD under stress. At 15 DAS, A_1 , A_2 , and A_3 increased SPAD by 3.3, 4.9 and 7.4%, 5.8, 14.3 and 17.1%, and 6.5, 16.3 and 19.4%, respectively; at 30 DAS, the increases were 3.0, 4.1 and 7.9%, 5.2, 14.5 and 17.6%, and 6.1, 16.3 and 20.6%, respectively, under S_1 , S_2 and S_3 stress.

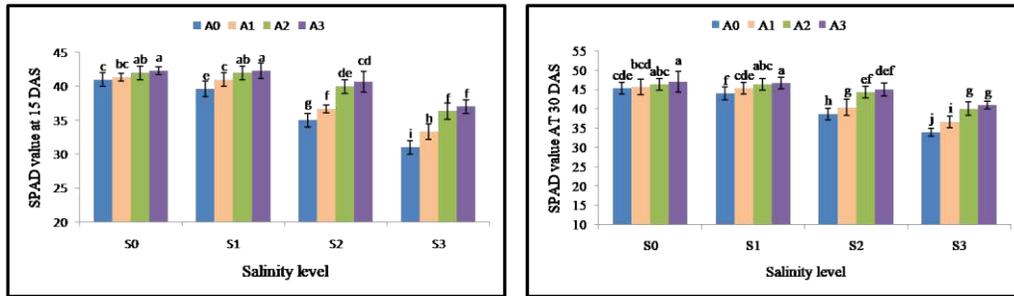


Fig. 9. Effect of ascorbic acid as seed priming agent on SPAD value of rice at 15 and 30 DAS (days after sowing) under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Leaf relative water content (RWC) (%)

Leaf relative water content (RWC), an indicator of plant water status, declined significantly under salt stress in a dose-dependent manner at both 15 and 30 DAS, with the greatest reduction in S₃ (Figure 10). In non-primed plants, RWC was 97.5, 93.5, 87.5 and 82.4% at 15 DAS, and 94.9, 91.0, 85.1 and 80.3% at 30 DAS for S₀, S₁, S₂ and S₃, respectively, representing reductions of 4.1, 10.3 and 15.5% compared to the control. Ascorbic acid priming improved RWC under all stress levels. At 15 DAS, A₁ increased RWC by 1.9, 3.4 and 2.4%, A₂ by 4.0, 6.9 and 7.4%, and A₃ by 4.4, 7.1 and 8.6% under S₁, S₂ and S₃ stress, with similar trends at 30 DAS.

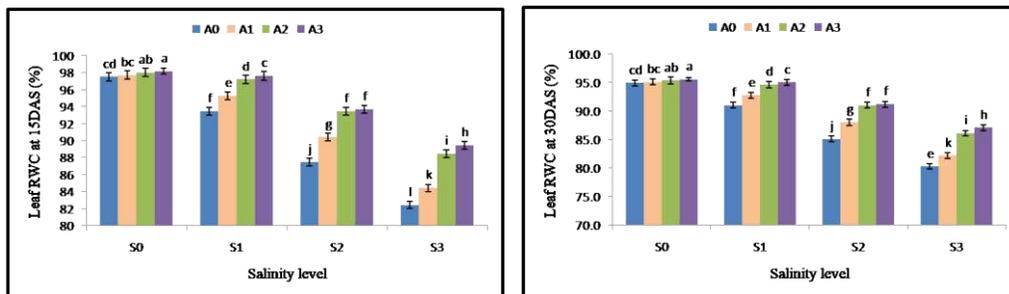


Fig. 10. Effect of ascorbic acid as seed priming agent on leaf relative water content of rice at 15 and 30 DAS (days after sowing) under different levels of salt stress. Here, A₀, A₁, A₂, A₃ indicate 0 mM, 0.125 mM, 0.250 mM, 0.5 mM ascorbic acid, respectively, and S₀, S₁, S₂, S₃ indicate 0 dS m⁻¹, 5 dS m⁻¹, 10 dS m⁻¹, 15 dS m⁻¹ NaCl stress, respectively. Bars sharing the same letter within a salinity level are not significantly different according to Tukey's HSD test ($p \leq 0.05$). Bars with different letters indicate significant differences at $p \leq 0.05$ according to Tukey HSD test. The interaction effect (AsA x NaCl) was significant ($p \leq 0.05$)

Discussion

Seed germination, speed of germination, and germination energy are fundamental processes for successful crop establishment, ultimately determining yield potential (Almansouri *et al.*, 2001; Murungu *et al.*, 2003). These processes are often severely hampered under abiotic stress conditions in most crops (Omid *et al.*, 2012). Among all developmental stages, seed germination is considered the most sensitive to environmental stresses, including salinity (Omid *et al.*, 2012; Redmann, 1974).

In the present study, rice seeds were subjected to different levels of salt stress, and the mitigating role of ascorbic acid (AsA) priming was evaluated. Our results (Figures 1–3) show that the tested rice variety was sensitive to salinity, exhibiting marked reductions in final germination percentage, germination speed, and germination energy with increasing NaCl concentration. However, seed priming with AsA (0.125, 0.250, and 0.5 mM) significantly improved germination traits under all stress levels. The observed improvement is consistent with the known role of AsA as a non-enzymatic antioxidant that scavenges reactive oxygen species (ROS) and protects cellular components during germination (Baig *et al.*, 2021). Specifically, the significant enhancement of radicle length under AsA priming (Figure 5) indicates that AsA protects the root-tip meristem from oxidative damage, which is essential for early root elongation (Afzal *et al.*, 2005). Similarly, plumule and radicle lengths were substantially reduced under higher salinity, resulting in shorter seedlings. AsA priming partially restored these growth parameters (Figures 4 and 5), likely due to its role in maintaining osmotic balance and promoting antioxidant defense, which supports cell division and elongation in young tissues. This aligns with previous findings that AsA can stabilize cell membranes and maintain turgor under stress, leading to improved shoot and root growth (Saboora and Kiarostami, 2006; Gupta and Srivastava, 1989).

Plant height, fresh weight, and dry weight were also adversely affected by salinity (Fig. 6-8). The partial recovery of these growth parameters in AsA-primed plants can be explained by enhanced metabolic activity and improved biomass accumulation, as primed seeds exhibit faster germination and uniform seedling establishment. These findings are consistent with reports that priming accelerates seedling vigor and increases shoot and root biomass under stress (Ghoulam and Fares, 2001; Salim, 1991). In addition to growth, physiological traits such as SPAD value and leaf relative water content (RWC) were significantly reduced by salinity (Figures 9 and 10). The maintenance of chlorophyll in AsA-primed plants can be attributed to the antioxidant role of AsA, which prevents pigment degradation and protects pigment–protein complexes. Likewise, the improved RWC in primed plants suggests better osmotic regulation and water retention, helping plants maintain turgor and cellular hydration under salt stress. These physiological improvements clearly correlate with the enhanced growth and biomass observed in AsA-primed seedlings. These results demonstrate that salinity negatively impacts seed germination, seedling growth, and key physiological processes in rice. Exogenous application of AsA through seed priming mitigates these effects by enhancing antioxidant defense, protecting meristematic tissues, maintaining osmotic balance, and supporting chlorophyll and water status. The significant improvements observed in germination traits, radicle and plumule lengths, plant height, biomass, SPAD values, and RWC

directly reflect the underlying physiological mechanisms, confirming that AsA priming is an effective strategy to improve salinity tolerance in rice at germination and early seedling stages.

Conclusion

Soil salinity is one of the most pressing challenges for agriculture worldwide, and in Bangladesh, it is a major constraint, especially in coastal areas where over half of the land is affected. This study revealed that priming rice seeds with ascorbic acid (AsA) improved germination, growth, and physiological traits under different salinity levels, with 0.25 mM and 0.5 mM proving more effective than 0.125 mM. These findings indicate that AsA seed priming can enhance rice tolerance to salinity, but further field-level research is needed to confirm its effects on overall growth, development, and yield.

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Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

Authors' contribution

Conceptualization, Supervision, Writing-original draft: JAM, MA and HA; Data curation: MA, HA and FA; Formal analysis: JAM; Funding acquisition: JAM; Investigation: HA, MA, FA and MGJH; Methodology: HA and JA; Project administration: JAM and MGJH; Validation: JAM and HA; Review and editing: JAM, MA and MGJH.

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A COMPARATIVE STUDY ON THE CARBON STORAGE AND OXYGEN RELEASE CAPACITY OF *Swietenia macrophylla* king. and *Eucalyptus camaldulensis* Dehn. IN NORTHWEST BANGLADESH

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Abstract

Estimating the carbon sequestration capacity of forest tree species is essential for implementing a massive plantation program in developing countries such as Bangladesh. The present study was conducted on the estimation of carbon storage and oxygen release capacity of *Swietenia macrophylla* and *Eucalyptus camaldulensis*, which were planted forest tree species in the same ecological condition. Allometric equations were applied to estimate organic carbon in two species of trees. The diameter increased with increasing height and positive correlations were found in *S. macrophylla* and *E. camaldulensis*, respectively ($p < 0.05$). The maximum carbon storage of *S. macrophylla* and *E. camaldulensis* were 17.24 kg tree⁻¹ year⁻¹ and 21.73 kg tree⁻¹ year⁻¹ at twenty-year-old trees, respectively. The lowest carbon storage of *S. macrophylla* and *E. camaldulensis* were 5.03 and 9.24 kg tree⁻¹ year⁻¹ at five years old, respectively. There was no significant difference (df=11; p=0.658) found between the DBH of the two species, while their DBH were significantly different among their ages (df=11; p=0.000). Besides, the height of these two species was significantly different (df=11; p=0.002) but not significant in their ages (df=11; p=0.694). The height and DBH growth became slower with the increase in the age of the plantations. The biomass, carbon stock, carbon dioxide storage, and O₂ releasing potentiality were related to each other and significantly differed with their ages (p-value varied from 0.001 to 0.023). Comparatively higher growth performances were observed in *E. camaldulensis* than *S. macrophylla* in the same environmental conditions, management and equal ages. The findings indicated that *S. macrophylla* and *E. camaldulensis* can both be selected in the massive plantation programs in this area, which will contribute to large carbon storage and play a vital role in mitigating climate change.

Keywords: Biomass, Carbon, Global warming, Non-destructive method, Plantation.

Introduction

Decline of biodiversity and increased CO₂ have been recognized as two major concerns nowadays (Kumar, 2011). One is the result, and the other is the cause of global warming and climate change; meanwhile, plantations are a crucial tool for mitigating

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their effects. We know only plants can capture atmospheric CO₂ through photosynthesis, store it as biomass, and produce a massive quantity of oxygen (Lukito and Rohmatiah, 2013; Pitol and Mian, 2023). Plantation may lead to the enhancement of forestation, although it reduces diversity (Rahman *et al.*, 2021). There are two types of plantations (such as artificial and natural plantations) (Menne, 2015), while the number of artificial plantations is increasing more rapidly than natural plantations in the tropical regions of the world. Artificial forests contribute to the declining pressure on timber extraction from natural forests and play a vital role in the conservation of forest resources (Kaul *et al.*, 2010). It is not possible to increase the forest and agriculture lands, but the production will be maximized by converting the traditional lands into sustainable uses like agroforestry home gardens, tea plantations and woodlot plantations (Nair and Kumar, 2006; Pitol *et al.*, 2019). Plantation forests give us hope for the sustainable use of forest resources. Approximately, the world has 264.084 million ha of plantation forests (6.6% % of total forest area) with a new planting rate of 4.925 million ha per year (FAO, 2010). Planted forests supply 35% of total wood demand with a projected increase to 44 % by 2020 (FAO, 2010, ABARE and Jaakko Pöyry, 1999).

Homestead forests have enormously increased in different parts of Bangladesh to fulfill the wood and fuel wood demand. They are increased based on special types of timber species that are fast-growing and of high timber quality. The selection of plant species plays a vital role in mitigating global warming. In Bangladesh, the plantation forests increased from 238.81 (000 ha) to 278.11(000 ha) from 1990 to 2005 (FAO, 2010), while Jashimuddin and Inoue (2012) recorded that 48,420 ha of roadside plantations, 30,666 ha of woodlots and 8778 ha of agroforestry plantations were established during the last 30 years. However, the plantation activities are continuing without assessment of the carbon storage capacity of tree species in many regions of the world, as well as in Bangladesh. There is an urgent need to estimate biomass, carbon storage and released oxygen in different species for implementing massive plantation programs. Biomass is an important parameter to assess the assimilation of carbon by plants. Biomass and carbon storage play an important role in the global carbon cycle (Cairns *et al.*, 2003; Li *et al.*, 2011; Zhao *et al.*, 2014) and are now considered for creating any woodlot (Ekholm, 2016; Gren and Zeleke, 2016; Riutta *et al.*, 2018; Nonini and Fiala, 2019; Rinnamang *et al.*, 2020).

Normally, homestead forests are established with a single tree species, which is known as monoplantation. Monoplantations are increasing a geometric rate in the northern parts of Bangladesh to fulfill the local wood-related demands. Numerous experts recommended that the homestead flora of Bangladesh provides about 70% of all wood consumed and 90% of all fuel wood and bamboo (Alam *et al.*, 1990). Many kinds of exotic and indigenous forest tree species are planted in the homestead forests of Bangladesh, while *Swietenia macrophylla* and *Eucalyptus camaldulensis* are the best choice for their fast-growing and well adaptable potential. Private landowners plant fast-growing tree species for local consumption, such as fuel wood, poles, posts, and small wood and cottage industries (BBS, 2014). Moreover, the adaptation ability, growth performances and carbon storage capacity of planted tree species in most of the areas in

Bangladesh have been estimated, though it is too scanty. It is essential to know the role of plantation forests in carbon trade and ecosystem services (Nair, 2012). It improves the country's negotiations for REDD+ and carbon trade mechanisms (Nair, 2012; Jashimuddin and Inoue, 2012). Direct and indirect methods are mostly used for biomass calculation, while indirect methods are based on allometric equations using measurable parameters (Salazar-Iglesias *et al.*, 2010). This method is easy and suitable for the estimation of carbon storage in tropical forests (Razakamanarivo *et al.*, 2012; Rahman, *et al.*, 2019). Therefore, keeping this point in mind, an attempt was made to estimate a comparative study of the biomass, carbon storage and oxygen release between *Swietenia macrophylla* and *Eucalyptus camaldulensis* in the northern district of Bangladesh. The findings of the study will provide essential data on biomass, carbon storage and oxygen release, which will be used for carbon monitoring at the national and international levels.

Materials and Methods

The study area

The study was conducted on homestead forest areas at Natore Sadar Upazila of Natore district in Bangladesh. Geographically, the study area is situated between 24° 07' to 24° 43' north latitudes and between 88° 17' to 88° 58' east longitudes (Fig.1). This area falls under the tropical region, also known as Bangladesh's hottest district. The climatic condition is a hot-humid summer with moderate rainfall and a mild winter with foggy conditions sometimes. The summer season is considered from April to the last of June. The rainy season starts at the end of June and lasts up to September. The winter season comes from the middle of November and lasts up to the end of February. The temperature variation appears that the average annual temperature is about 26 °C to 36 °C. The minimum and maximum average temperature during winter varies from 9 °C to 14 °C. The minimum and maximum average temperatures vary from 25.50 °C to 40.70 °C during summer. The hottest month was June and the coldest month was January. The average rainfall was 1613.4 mm. The soil of the study area is rich in alluvium and clay texture with a pH of 7.22 on average. This soil is perfect for agriculture and horticulture (BBS, 2022). The study area was covered by various planted timber tree species. The following planted species were dominant, such as *Mangifera indica*, *Azadirachta indica*, *Swietenia macrophylla*, *Albizia richardiana*, *Eucalyptus camaldulensis*, *Samanea saman*, *Artocarpus heterophyllus*, *Delonix regia*, *Caesalpinia pulcherrima* and *Citrus maxima*, etc. Homestead forests are accelerating at a geometrical rate to fulfill the demand for fuel wood and timber. Massive plantations have been started in the study area with the help of some selected forest tree species. Before plantation, the area was included in cultivation land and different types of agro-cultural and horticultural crops were grown such as *Oryza sativa*, *Corchorus capsularis*, *Saccharum officinarum*, *Litchi chinensis*, *Manilkara zapota*, *Ziziphus mauritiana*, *Averrhoa carambola*, *Psidium guajava* and *Musa sapientum*, etc.



Fig. 1. Natore Sadar Upazila map, the yellow line below shows the scale, the yellow circle upper right side shows the north sign, the red circle and red shape on the left side show the study area.

Sampling and measurements

The study was carried out from January 2023 to December 2023. A multistage random sampling technique was used for the selection of plots. Firstly, a reconnaissance survey was conducted to select the potential landowners who have *Eucalyptus camaldulensis* and *Swietenia macrophylla* orchards. Landowners were interviewed to know about the age and management procedures of the orchards, while 20 hectares of area for each species were surveyed to collect data for biomass, carbon stock and oxygen release potential calculation. Most of them used mono species and bought seedlings from nearby nurseries. Thinning and pruning were done frequently at the early stage of plantations. The geographical location of each plot was recorded using a global positioning system (GPS) and the size of each plot was 10 m×10 m. Brown's model (Brown *et al.*, 1989) was used to estimate the aboveground biomass of each tree of each experiment plot. Several scientists suggested that allometric equations are one of the most suitable methods for biomass estimation in tropical forests (Alves *et al.*, 1997; Schroeder *et al.*, 1997). Trees height and diameter at breast height (DBH > 5cm) from ground level (1.30 m) of all trees were measured using a clinometer and DBH tape, respectively. Trees on the border were included in a plot if 50% of their basal area fell within the plot and excluded if 50% of their basal area fell outside the plot. Trees overhanging the plots were excluded, but with their trunk inside the sampling plots, and branches out were included. Care was taken to ensure the diameter tape was put on the stem exactly at the measurement point.

Biomass, carbon stock, CO₂, and release O₂ estimation

The study was conducted in planted forest areas and all trees were measured with the help of a tape and a clinometer. It was impossible to cut all the trees to estimate the biomass and carbon of the trees. Some models were developed by Brown (1997), Luckman *et al.* (1997), Negi *et al.* (1988) and Brown *et al.* (1989). Brown's models (Brown *et al.*, 1989) were used to determine above-ground biomass because this method is the most suitable for tropical forests (Alves *et al.*, 1997; Brown, 1997; Schroeder *et al.*, 1997; Miah *et al.*, 2011; Ullah and Al-Amin, 2012). This is the simplest method of estimating forest tree biomass in the tropics as it requires only tree diameter at breast height, total height and wood-specific gravity. While other models or regression equations require sectional diameter, this simply deals with diameter at breast height. The model is as follows:

$$Y = \exp. \{-2.4090 + 0.9522 \ln (D^2HS)\}$$

Where, Y=Aboveground biomass in kg, H=Height of the trees in meters, D=Diameter at breast height (1.30 m) in cm, and S=Wood density in units of tons m⁻³ for a specific species (Brown 1997; Sattar *et al.*, 1999).

Using this model, the aboveground biomass of each tree was estimated. From aboveground biomass of each individual's tree was calculated and the biomass was converted to tons ha⁻¹ and added to get the total aboveground biomass. Belowground biomass was calculated considering 15% of the aboveground biomass (MacDicken, 1997; IPCC, 2003; Miah *et al.*, 2011). Belowground biomass was calculated for each tree. Aboveground and belowground biomass of trees was added to get the total biomass of trees.

$$BGB = AGB \times (20/100).$$

The total carbon (TC) of the tree was determined by using the following formula.

$$TC = (AGB + BGB) \times 0.50$$

Where, 0.50 is the conversion factor (Schroeder, 1997).

Besides, the carbon dioxide capturing (CO₂) was calculated by multiplying the total carbon stock by 3.67 (Kauffman and Donato, 2012) and then the released oxygen was calculated by multiplying the total carbon dioxide capturing by 0.727 (Pitol and Mian, 2023; Pitol *et al.*, 2025).

Data analysis

All calculations were done using Microsoft Excel software, and figures were also produced using Microsoft Excel software. Analysis of variance (ANOVA) was performed to check the significant difference between the two species (Appendix 1) and among their ages (Appendix 2) by using the Statistical Package for the Social Sciences (SPSS-20).

Results

Diameter and height of different age plantations

Diameter, height and wood density are the most important indicators and are frequently used for estimating biomass and carbon of trees (Chave et al., 2005, 2014; Komiyama et al., 2008; Pitol et al., 2019, 2025). Biomass and carbon were calculated based on the diameter, height and wood density of planted forest tree species in the study area. The study revealed that the diameter and height were 27.78 cm and 29.65cm; and 17.44m and 9.55m were found in *Eucalyptus camaldulensis* and *Swietenia macrophylla* at 20 years old, respectively (Figure 2). There was no significant difference ($df=11$; $p=0.658$) found between the DBH of the two species (Appendix 1), while their DBH were significantly different among their ages ($df=11$; $p=0.000$) (Appendix 2). Moreover, the height of these two species was significantly different ($df=11$; $p=0.002$) but not significant in their ages ($df=11$; $p=0.694$) (Appendix 1 and Appendix 2). Comparatively higher growth performances were observed in *E. camaldulensis* than *S. macrophylla* in the same environmental conditions, management and equal ages (Fig. 1).

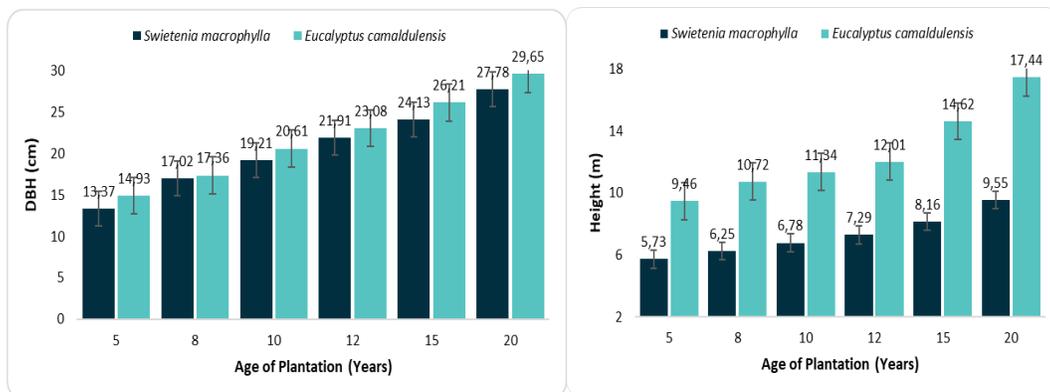


Fig. 2. Diameter at breast height and height of *Swietenia macrophylla* and *Eucalyptus camaldulensis* in different ages.

Mean Annual increment of diameter, height, biomass, carbon stock, CO₂ capturing and O₂ releasing potentiality of different ages of plantations

The mean annual increment of DBH was insignificant ($df=11$; $p=0.629$) between these two species when they significantly varied among the ages ($df=11$; $p=0.000$). Besides, the mean annual height increment was significantly varied ($df=11$; $p=0.034$) between these two species when they were not considerably diverse among the ages ($df=11$; $p=0.321$). It was found that the mean annual diameter increments and mean annual height increments were 1.93cm and 2.06 cm; and 0.78m and 1.24 m for *S. macrophylla* and *E. camaldulensis*, respectively (Figure 3). The present study revealed that the value of the mean annual diameter increments and mean yearly height increment of *E. camaldulensis* was comparatively higher than *S. macrophylla*. The height and DBH growth became slower with the increase in the age of the plantation.

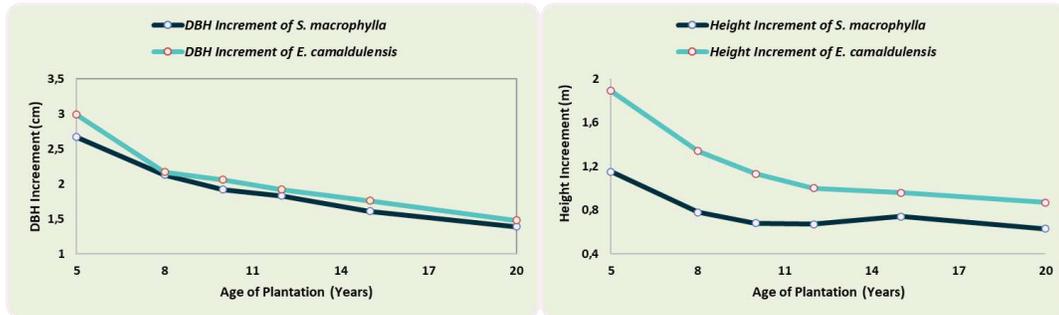


Fig. 3. Mean annual diameter increment rate and mean annual height increment rate of *Swietenia macrophylla* and *Eucalyptus camaldulensis*

The aboveground biomass, belowground biomass, total biomass, aboveground carbon, belowground carbon, total carbon, carbon dioxide storage and O_2 releasing potentiality were related to each other and significantly differed with their ages (p -value varied from 0.001 to 0.023). The value was maximum for both species in 20-year-old plantations and minimum for 5-year-old plantations (Table 1). The highest aboveground biomass, belowground biomass and total biomass were $574.55 \text{ kg tree}^{-1}$, $114.91 \text{ kg tree}^{-1}$, $689.46 \text{ kg tree}^{-1}$ and $724.38 \text{ kg tree}^{-1}$, $144.88 \text{ kg tree}^{-1}$, $869.26 \text{ kg tree}^{-1}$ in *S. macrophylla* and *E. camaldulensis* at twenty years old, respectively (Table 1). The lowest aboveground biomass, belowground biomass and total biomass were $41.94 \text{ kg tree}^{-1}$, $8.39 \text{ kg tree}^{-1}$, $50.33 \text{ kg tree}^{-1}$ and $76.99 \text{ kg tree}^{-1}$, $15.40 \text{ kg tree}^{-1}$, $92.39 \text{ kg tree}^{-1}$ in *S. macrophylla* and *E. camaldulensis* at five years old, respectively (Table 1). Moreover, the maximum aboveground carbon, belowground carbon and total carbon were $287.28 \text{ kg tree}^{-1}$, $57.46 \text{ kg tree}^{-1}$, $344.73 \text{ kg tree}^{-1}$ and $362.19 \text{ kg tree}^{-1}$, $72.44 \text{ kg tree}^{-1}$, $434.63 \text{ kg tree}^{-1}$ in *S. macrophylla* and *E. camaldulensis* at twenty years old. The lowest aboveground carbon, belowground carbon and total carbon were $20.97 \text{ kg tree}^{-1}$, $4.19 \text{ kg tree}^{-1}$, $25.16 \text{ kg tree}^{-1}$ and $38.50 \text{ kg tree}^{-1}$, $7.70 \text{ kg tree}^{-1}$, $46.20 \text{ kg tree}^{-1}$ in *S. macrophylla* and *E. camaldulensis* at five years old (Table 1). However, the carbon storage varied from 5.03 to $17.24 \text{ kg tree}^{-1} \text{ year}^{-1}$ while capturing CO_2 varied from 18.46 to $63.26 \text{ kg tree}^{-1} \text{ year}^{-1}$ and releasing O_2 varied from 13.42 to $45.99 \text{ kg tree}^{-1} \text{ year}^{-1}$ for *S. macrophylla*. In addition, the carbon storage varied from 9.24 to $21.73 \text{ kg tree}^{-1} \text{ year}^{-1}$, while capturing CO_2 varied from 33.91 to $79.75 \text{ kg tree}^{-1} \text{ year}^{-1}$ and releasing O_2 varied from 24.65 to $57.98 \text{ kg tree}^{-1} \text{ year}^{-1}$ for *E. camaldulensis* (Table 1).

Table 1. Aboveground biomass (AGB), belowground biomass (BGB), total biomass (TB), aboveground carbon (AGC), belowground carbon (BGC), total carbon (TC), carbon storage, CO₂ capturing and O₂ releasing potential of *Swietenia macrophylla* and *Eucalyptus camaldulensis* in different ages

Species Name	Age of Plantation (years)	AGB per tree (kg)	BGB per tree (kg)	TB per tree (kg)	AGC per tree (kg)	BGC per tree (kg)	TC per tree (kg)	Carbon storage kg tree ⁻¹ year ⁻¹	Capturing CO ₂ kg tree ⁻¹ year ⁻¹	Releasing O ₂ kg tree ⁻¹ year ⁻¹
<i>Swietenia macrophylla</i>	5	41.94	8.39	50.33	20.97	4.19	25.16	5.03	18,46	13.42
	8	72.14	14.43	86.57	36.07	7.21	43.28	5.41	19,85	14.43
	10	98.16	19.63	117.79	49.08	9.82	58.90	5.89	21,62	15.72
	12	174.13	34.83	208.96	87.06	17.41	104.48	8.71	31,95	23.23
	15	326.20	65.24	391.44	163.1	32.62	195.72	13.05	47,89	34.82
	20	574.55	114.91	689.46	287.28	57.46	344.73	17.24	63,26	45.99
<i>Eucalyptus camaldulensis</i>	5	76.99	15.40	92.39	38.50	7.70	46.20	9.24	33,91	24.65
	8	115.58	23.12	138.70	57.79	11.56	69.35	8.67	31,81	23.13
	10	169.07	33.81	202.88	84.53	16.91	101.44	10.14	37,23	27.07
	12	259.51	51.90	311.41	129.75	25.95	155.70	12.96	47,62	34.62
	15	418.36	83.67	502.03	209.18	41.84	251.01	16.73	61,41	44.65
	20	724.38	144.88	869.26	362.19	72.44	434.63	21.73	79,75	57.98

Discussion

The two basic functions of trees are capturing carbon dioxide and producing oxygen for curbing climate change and the survival of life on this earth, respectively. Nowadays, we are concerned about the carbon and carbon dioxide storage capacity of trees. In this study, we also observed the oxygen release potential of two widely used fast-growing species in Bangladesh. Comparatively higher growth performances were observed in *E. camaldulensis* than *S. macrophylla* in the same environmental conditions, management and equal ages. It revealed that the diameter and height were 27.78 cm and 29.65cm; and 17.44m and 9.55m in *Eucalyptus camaldulensis* and *Swietenia macrophylla* at 20-year-old plantations, respectively. The height of *S. macrophylla* increased very slowly and *E. camaldulensis* increased very fast, while both showed similar dbh growth (Fig. 2). Normally, growth parameters are mainly influenced by genetic criteria, which is known as genotype. In this regard, the following equation may be regarded as phenotype = genotype + environment. The present findings indicated that growth performances varied between the two species due to the genotypic criteria. The phenotype depends on genotype and environmental factors. Several scientists worked on the estimation of the diameter and height of forest tree species in Bangladesh. Rahman (2022a) found that the dbh and height of *Casuarina equisetifolia* at Inani and Teknaf Forest Ranges 14.10 cm and 12.70 m; 17.10 cm and 17.10 m; and 23.54 cm and 20.33 m for 5-year, 10-year and 20-year-old plantations separately. (Rahman, 2022b). Besides, the dbh and height of *Acacia auriculiformis* were 5.03 cm and 4.27 m; and 10.35 cm and 8.28 m for 5-year and 10-year plantations at Pomra, Hosnabad, Rajanagar and Parua Forest Ranges under the Chattogram North Forest Division in Bangladesh, respectively (Rahman, 2022b). Dey et

al. (2022) found the dbh and height of *Eucalyptus camaldulensis* were 10.6 m and 11.9 cm for a 5-year plantation, and 30.9 m and 42.7 cm for a 21-year plantation, while Azad et al. (2021) found the dbh for 10.14 cm, 26.47 cm and 29.21cm for 5-year, 15-year, and 20-year plantations individually. It seemed that the height and dbh growth of *E. camaldulensis* was higher at every year of plantations than the *C. equisetifolia*, *A. auriculiformis* and *S. macrophylla* and very close to *Hevea brasiliensis* plantations.

In our study, the mean annual diameter increments and mean annual height increments were 1.93cm and 2.06 cm; and 0.78m and 1.24 m for *S. macrophylla* and *E. camaldulensis* respectively (Figure 3). The present study revealed that the value of the mean annual diameter increments and mean yearly height increment of *E. camaldulensis* was comparatively higher than *S. macrophylla*. Moreover, the height and DBH growth became slower with the increase of the age of the plantation. It exhibited that the tree grows faster at an early age. However, the mean annual diameter increment rate and mean annual height increment rate also varied from species to species and age to age. The mean annual diameter increment rates were 3.08 cm, 1.71 cm and 1.17 cm, while the mean annual height increment rates were 2.54 m, 1.71 m and 1.02 m found in *Casuarina equisetifolia* at 5, 10 and 20-year trees (Rahman, 2022b). In addition, the mean annual diameter increment rates were 1.01 cm and 1.04 cm found in *Acacia auriculiformis* while the mean annual height increment rates were 0.94 m and 0.91 m found in *Acacia auriculiformis* at 5 and 10-year trees. There was a positive correlation between diameter and height, but the diameter and height rates varied from species to species.

The biomass, carbon, carbon-dioxide storage and O₂-releasing potentiality were related to each other and significantly differed with ages (p-value varied from 0.001 to 0.023). There was a positive relation between age and biomass, carbon, carbon dioxide storage, and O₂-releasing potential of trees. The present study was conducted in the northern parts of Bangladesh which is situated in the hottest tropical regions of Bangladesh. Normally, biomass and carbon storage vary in different regions of the world. Scientists observed that carbon storage capacity varied from species to species due to ecological and management conditions (Rahman et al., 2019, 2020). A study was conducted in the tropical forests of Badamalai hills in India and reported that the average carbon stock of single tree species was 0.04tC/tree. It was also reported that the maximum value was 0.68 t C/tree found in *Ficus benghalensis*, followed by *Tamarindus indica*, *Spondias pinnata*, *Diospyros ebenum* and *Ficus beddomei* 0.51 t C/tree, 0.46 t C/tree, 0.30 t C/tree, and 0.22 t C/tree respectively (Pragasam et al., 2015). In this case, their findings were higher than the findings of the present study. However, wide variations in the biomass potential of a tree may occur due to differences in provenances, stand density, tree age, site characteristics, management, etc. Several scientists (observed that the total aboveground biomass in the range of 9.80 to 306.01 kg tree⁻¹ for *Gmelina arborea* and 7.25 to 314.61 kg tree⁻¹ for *Swietenia Macrophylla* (Kawahara et al., 1981; Pitol et al. 2019; Pitol and Mian, 2023). On the other hand, Buante (1997) observed the total aboveground biomass of *Acacia auriculiformis* and *Gmelina arborea* in the ranges of only 15.71 to 49.08 kg tree⁻¹ and 9.18 to 68.58 kg tree⁻¹. The following tree species were included such as *Eucalyptus deglupta*, *paraserianthes falcataria*, *Swietenia macrophylla*, *Acacia auriculiformis* and *Gmelina arborea* and their values were 365.70

kg tree⁻¹, 90.70 kg tree⁻¹, 156.30 kg tree⁻¹, 248.20 kg tree⁻¹ and 114.80 kg tree⁻¹ respectively (Dey *et al.* 2022; Kawahara *et al.*, 1981; Pitol *et al.* 2019; Pitol and Mian, 2023). Generally, the total biomass and carbon were estimated based on aboveground and belowground biomass all over the world. Several scientists reported that total biomass and carbon varied from species to species and different ages such as 776.90 kg tree⁻¹ to 1574 kg tree⁻¹ biomass was found in *Mangifera indica* at 25 years old (Ganeshamurthy *et al.*, 2016).

Carbon dioxide is the most effective greenhouse gas which traps heat and increases temperature in different levels of the atmosphere. The elevated temperature adversely affects biotic and abiotic components of all types of ecosystems which is the main obstacle to the sustainable development of the environment. In this case, plantations sequester carbon dioxide and produce oxygen from the atmosphere through photosynthesis and act as sinks which help to reduce global warming. Carbon storage capacity is the most important for the development of plantations based on species. The same species contained different amounts of carbon when grown in different regions. Scientists observed variations in carbon storage with the age of the forest, stand condition, species composition, climate condition, physiographical position and degree of disturbance (Kanime *et al.*, 2013 and Kumar *et al.*, 2016). Biomass, carbon storage, CO₂ and oxygen release assimilation vary with species. Scientists reported that higher values were found in *Eucalyptus spp.* while it was the lowest value in *S. javanica* (Ganeshamurthy *et al.*, 2019). Some species such as *C. camphora*, *S. babylonica*, *P. roxburghii* *G. robusta* and *Diospyros* sp. also have high values of carbon storage, and carbon assimilation. Some species particularly, *M. koenigii*, *Mimosasp.*, *F. auriculata*, *F. lacor* and *Dalbergia* sp. have low values. Myrtaceae was the family with the highest carbon storage, carbon assimilation and followed by Lauraceae Salicaceae and Pinaceae (Kaul *et al.*, 2010). Maximum scientists (Chave *et al.*, 2014) opined that carbon sequestration depends on single or multiple factors such as age, size, density and climatic conditions, etc. However, our study was conducted in a narrow zone of the country. A massive survey is required to assess the feasibility and potentiality of plantation forests. It is also a prerequisite for our fair share in the global carbon trade mechanism.

Conclusion

Plantation sequesters carbon dioxide and acts as a carbon sink and oxygen source in the atmosphere. Elevated carbon dioxide in the atmosphere is harmful to all living organisms of the terrestrial environment. So, plantations should be increased to continue the equilibrium balance of the environment. The present findings of the study indicated that planted forests with fast-growing tree species play a vital role in sequestering carbon and generating oxygen and their utilization demands are also high for the quality of timber and fuel wood. It is also remarkable that the planted forest tree species are well adapted to the selected study areas. The socio-economic conditions can be easily developed through applying silviculture methods in the social plantation programs. Therefore, policymakers, administrators and planters can choose *Swietenia macrophylla* and *Eucalyptus camaldulensis* for the massive plantations based on environmental conditions.

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Conflict of interest

The authors declare that there are no competing interests.

Ethics and biosecurity

We did not use any human or animal biological data in this manuscript.

Data availability statement

Data will be made accessible on request.

Funding statement

The authors' self-funding was used for data collection.

Authors' contribution

M M Rahman: Conceptualization, Formal analysis, and Writing Original draft. M Rahman: Conceptualization, Data Collection and Review. M N S Pitol: Formal Analysis, writing draft, Review, Editing and Supervision

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**APPENDIX 1 (Compare between the plantations of *Swietenia macrophylla* and
Eucalyptus camaldulensis)**

		Sum of Squares	df	Mean Square	F	Sig.
DBH	Between Groups	5.908	1	5.908	.208	.658 ^{ns}
	Within Groups	283.601	10	28.360		
	Total	289.509	11			
Height	Between Groups	84.429	1	84.429	16.089	.002 ^{**}
	Within Groups	52.475	10	5.248		
	Total	136.904	11			
DBH Increment	Between Groups	.057	1	.057	.248	.629 ^{ns}
	Within Groups	2.314	10	.231		
	Total	2.372	11			
Height Increment	Between Groups	.538	1	.538	6.041	.034 [*]
	Within Groups	.890	10	.089		
	Total	1.428	11			
Above-Ground Biomass	Between Groups	18942.469	1	18942.469	.376	.553 ^{ns}
	Within Groups	503737.399	10	50373.740		
	Total	522679.869	11			
Below-Ground Biomass	Between Groups	757.635	1	757.635	.376	.553 ^{ns}
	Within Groups	20149.630	10	2014.963		
	Total	20907.265	11			
Total Biomass	Between Groups	27276.775	1	27276.775	.376	.553 ^{ns}
	Within Groups	725382.659	10	72538.266		
	Total	752659.434	11			
Above-Ground Carbon	Between Groups	4735.419	1	4735.419	.376	.553 ^{ns}
	Within Groups	125936.064	10	12593.606		
	Total	130671.483	11			
Below-Ground Carbon	Between Groups	189.528	1	189.528	.376	.553 ^{ns}
	Within Groups	5038.006	10	503.801		
	Total	5227.534	11			
Total Carbon	Between Groups	6819.194	1	6819.194	.376	.553 ^{ns}
	Within Groups	181345.015	10	18134.502		
	Total	188164.209	11			
Carbon Storage Potentiality	Between Groups	48.562	1	48.562	1.918	.196 ^{ns}
	Within Groups	253.244	10	25.324		
	Total	301.805	11			
CO ₂ Capturing Potentiality	Between Groups	655.641	1	655.641	1.922	.196 ^{ns}
	Within Groups	3410.457	10	341.046		
	Total	4066.098	11			

**APPENDIX 2 (Compare among the age classes of *Swietenia macrophylla* and
Eucalyptus camaldulensis plantations)**

		Sum of Squares	df	Mean Square	F	Sig.
DBH	Between Groups	282.658	5	56.532	49.512	.000 ^{***}
	Within Groups	6.851	6	1.142		
	Total	289.509	11			
Height	Between Groups	46.430	5	9.286	.616	.694 ^{ns}
	Within Groups	90.475	6	15.079		
	Total	136.904	11			
DBH Increment	Between Groups	2.291	5	.458	33.874	.000 ^{***}
	Within Groups	.081	6	.014		
	Total	2.372	11			
Height Increment	Between Groups	.788	5	.158	1.480	.321 ^{ns}
	Within Groups	.639	6	.107		
	Total	1.428	11			
Above-Ground Biomass	Between Groups	499491.867	5	99898.373	25.849	.001 ^{***}
	Within Groups	23188.002	6	3864.667		
	Total	522679.869	11			
Below-Ground Biomass	Between Groups	19979.776	5	3995.955	25.850	.001 ^{***}
	Within Groups	927.490	6	154.582		
	Total	20907.265	11			
Total Biomass	Between Groups	719268.894	5	143853.779	25.849	.001 ^{***}
	Within Groups	33390.540	6	5565.090		
	Total	752659.434	11			
Above-Ground Carbon	Between Groups	124874.947	5	24974.989	25.852	.001 ^{***}
	Within Groups	5796.536	6	966.089		
	Total	130671.483	11			
Below-Ground Carbon	Between Groups	4995.609	5	999.122	25.848	.001 ^{***}
	Within Groups	231.926	6	38.654		
	Total	5227.534	11			
Total Carbon	Between Groups	179816.979	5	35963.396	25.851	.001 ^{***}
	Within Groups	8347.230	6	1391.205		
	Total	188164.209	11			
Carbon Storage Potentiality	Between Groups	252.716	5	50.543	6.178	.023 ^{**}
	Within Groups	49.090	6	8.182		
	Total	301.805	11			
CO ₂ Capturing Potentiality	Between Groups	3403.260	5	680.652	6.161	.023 ^{**}
	Within Groups	662.838	6	110.473		
	Total	4066.098	11			

RESPONSE OF BORO RICE (*Oryza sativa* L.) GENOTYPES TO GENETIC DIVERSITY AND CHARACTER ASSOCIATION FOR YIELD ASSOCIATED TRAITS

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Abstract

An experiment was conducted at the research field of Sher-e-Bangla Agricultural University, Dhaka-1207 during the Boro season (December 2020 to May 2021) using twenty-three Boro rice genotypes to evaluate genetic variability, heritability, genetic advance, correlation, path analysis and genetic diversity for yield-related traits. The experiment followed a randomized complete block design (RCBD) with three replications. Significant variation among genotypes were observed for all fourteen studied traits. The highest phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were observed (48.90% and 47.72%, respectively) for the number of unfilled grain per panicle. High heritability along with high genetic advance in percentage of mean was recorded for leaf sheath length, number of unfilled grain per tiller, number of primary branches per panicle, panicle length and thousand grains weight, suggesting these traits are governed by additive gene action. Yield per hill was positively and significantly correlated with the number of filled grains per tiller, unfilled grains per tiller and thousand grain weight. Traits such as leaf blade length, stem length, effective tillers, panicle length and branching showed positive direct effects on yield. The genotypes were grouped into four clusters. Based on cluster means and genetic parameters, G20 (BRRI dhan96), G1 (BR 1), G3 (BR 5) and G5 (BR 14) were identified as promising lines. Crosses among clusters I, II, III and IV especially involving cluster IV are recommended for future hybridization to exploit heterosis in breeding programs.

Keywords: Cluster analysis, Genetic variability, Heritability, Path analysis, Yield associated traits.

Introduction

Rice (*Oryza sativa* L.) commonly said "Dhan" in Bangladesh, forms the basic staple food of Asia. It is grown in a variety of cultural environments and over vast

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geographical ranges. Asia produces and consumes most of the world's rice. Rice is the staple food of nearly 165,000,000 people in Bangladesh and it is predicted that in 2050 about 44.6 MT of clean rice will be required for 215.4 million population (Kabir *et al.*, 2015). It provides about 48% employment for rural people contributing about one-sixth of the national income and one-half of the agricultural GDP in Bangladesh. In 2021, total production of rice was 518.8 million tons covering the area of 165.25 million hectares all over the world (FAO, 2022). Bangladesh placing third in rice production and in 2021, the production was about 35.5-million tones on 11.42 million hectares (BBS, 2022). Rice productivity is growing by 1% a year, but that needs to be 2.4% to meet the demand in 2050 (Rejeth *et al.*, 2020). Boro season in Bangladesh covers the most area as opposed to the other two (Aus and Aman). Therefore, it will be necessary to develop some Boro rice cultivars that will be suitable to fulfill our demand.

There are different qualitative and quantitative characters that contribute to the yield of crops. The association of different characters and existence of genetic variability in a population is pre-requisite for a breeding program. A breeding program can only be so efficient by gathering the knowledge of genotypic and phenotypic co-efficient of variation and heritability with genetic advance among the genotypes for the desired character (Islam *et al.*, 2020). Genetic divergence is necessary for the development of elite recombinants which is the basis of any crop improvement program (Remme *et al.*, 2024). So, genotype choice among the clusters could be based on the largest areas of the favorable attributes, which would then be utilized for the improvement through interparietal hybridization (Banumathy *et al.*, 2010). Therefore, the investigation was carried out to generate information on genetic diversity, variability, heritability, genetic advance, character association and path analysis for improving the Boro rice genotypes.

Materials and Methods

Twenty-three Boro rice genotypes (Table 1) were collected from BRRI (Bangladesh Rice Research Institute) and Dept. of Genetics & Plant Breeding, SAU. Sprouted seeds were sown in the seedbed. Single seedlings of thirty-nine days aged per hill having 20 cm×20 cm spacing were transplanted to the experimental plot. Each plot size is 8m². Fertilizers were applied 150:60:60:10 kg N:P:K:S per hectare (Ahmed *et al.*, 2018). All fertilizers were applied at final land preparation except the urea. Urea was splitted into three portions (one portion during final land preparation and other two doses were applied in 30 and 45 DAT, respectively). Data recorded on days to 50% flowering, flag leaf length (cm), leaf blade length (cm), leaf sheath length (cm), stem length (cm), number of effective tillers, number of total tillers, number of filled grain per tiller, number of unfilled grain per tiller, number of primary branches per panicle, number of secondary branches per panicle, panicle length (cm), thousand grain weight (g) and grain yield per hill (g).

Table 1. List of the genotypes used in the study and their sources of collection

Genotypes	Varieties	Source	Genotypes	Varieties	Source
G1	BR1	BRRRI	G13	BRRRI dhan67	GEPB, SAU
G2	BR2	GEPB, SAU	G14	BRRRI dhan68	GEPB, SAU
G3	BR5	GEPB, SAU	G15	BRRRI dhan74	GEPB, SAU
G4	BR9	GEPB, SAU	G16	BRRRI dhan81	GEPB, SAU
G5	BR14	BRRRI	G17	BRRRI dhan88	GEPB, SAU
G6	BR16	BRRRI	G18	BRRRI dhan89	GEPB, SAU
G7	BRRRI dhan28	GEPB, SAU	G19	BRRRI dhan92	BRRRI
G8	BRRRI dhan29	GEPB, SAU	G20	BRRRI dhan96	BRRRI
G9	BRRRI dhan50	GEPB, SAU	G21	BRRRI dhan97	BRRRI
G10	BRRRI dhan55	GEPB, SAU	G22	BRRRI dhan99	BRRRI
G11	BRRRI dhan63	GEPB, SAU	G23	SAU Purple 1	GEPB, SAU
G12	BRRRI dhan64	GEPB, SAU	-	-	-

Statistical analysis

Significant difference among the genotypes was computed by using statistix 10 software program. Analysis of variance was found by the F test. The significant differences among the genotypes achieved at 5% level of probability by the least significant difference (LSD) test (Gomez and Gomez, 1984). The variance was estimated by the formula of Johnson *et al.* (1955). According to Burton's (1952) PCV and GCV were conducted. Broad sense heritability was computed by using the formula provided by Singh and Chaudhary (1985). For computing genetic advance, Allard's (1999) formula was used. Genetic advance (% mean) was estimated by the procedure given by Comstock and Robinson (1952). Correlation co-efficient analysis was done by the formula of Al-Jibouri *et al.* (1958). Path analysis was obtained by following Dewey and Lu's (1959) method. Multivariate analysis, biplot analysis, cluster distance and cluster mean performance were analyzed by using Origin Pro 2023(b) software.

Results and Discussion

Analysis of variance (ANOVA) presented in Table 2. revealed a highly significant level of variation (at 1% significance) among twenty-three rice genotypes across fourteen quantitative traits. The presence of such significant differences indicating considerable genetic variability within the genotypes, which was essential for the improvement of desired traits through selection and hybridization.

Table 2. Analysis of variance for 14 characters of 23 rice genotypes

Source of variation	Replication	Genotype	Error	CV (%)
df	2	22	44	
FFL	0.10	68.02**	1.07	1.62
FLL	6.18	11.92**	5.47	9.15
LBL	126.57	25.79**	10.74	10.23
LSL	9.06	27.43**	2.36	5.99
SL	134.00	161.18**	21.57	7.82
NET	0.41	8.62**	3.28	16.65
NTT	0.88	8.14**	2.75	9.07
NFG	3.96	290.51**	42.81	5.77
NUnFG	3.93	108.64**	1.79	11.22
NPB	0.93	94.49**	2.96	9.43
NSB	10.01	16.54**	5.38	5.98
PL	0.22	78.33**	3.61	12.01
TGW	4.01	40.58**	4.96	9.79
YPH	4.07	92.78**	31.52	20.03

*= Significant at 5 % level of probability, **= Significant at 1 % level of probability and df=Degree of freedom

Here, PCV= Phenotypic co-efficient variation, GCV= Genotypic co-efficient variation, GA= Genetic Advance, h^2b = Broad sense heritability and GA (%) = Genetic Advance in percent of mean FFL=50% flowering; FLL= Flag leaf length (cm); LBL= Leaf blade length (cm); SL= Stem length (cm); NPB= Number of primary branches per panicle; NSB= Number of secondary branches per panicle; PL =Panicle length (cm); TGW= Thousand grain weight (g); YPH= Yield per hill (g); NET= Number of effective tillers; NTT= Number of total tillers; NFG= Number of filled grain per tiller; NUnFG= Number of unfilled grain per tiller and LSL= Leaf sheath length (cm);

Mean performance, variability, heritability and genetic advance of studied traits

Further statistical estimations including mean, range, variance, PCV and GCV, heritability, genetic advance (GA) and genetic advance as a percentage of mean (GAM) were presented in Table 3. In all the studied traits, the PCV (7.52-48.90%) was consistently higher than the GCV (4.97-47.92%), suggesting that environmental influences play a notable role in the expression of these traits which was earlier reported by Islam *et al.* (2020) found similar results of having high range of PCV (5.74% - 32.77%) than GCV (5.68% - 30.76%). Among the measured traits, the number of unfilled grains per tiller exhibited the highest GCV (47.72%) and PCV (48.90%), indicating substantial variability which was followed by panicle length (31.24% GCV, 33.43% PCV) and number of primary branches per panicle (30.42% GCV, 31.86% PCV), highlighting their potential for selection. Similar results were reported by Beena *et al.* (2021) and Meena *et al.* (2019) having the highest GCV (63.86%), PCV (66.50%) and GCV (74.27%), PCV (74.67%), respectively in case of number of unfilled grains per panicle.

Heritability estimates in the broad sense are important indicators of the proportion of total variation that is genetic in nature. High heritability was observed in most traits, excluding number of primary branches per panicle, total tillers, yield per hill, effective tillers and leaf blades and flag leaf length. Similar observations studied by Akshaya *et al.* (2020) for leaf sheath length, Limbani *et al.* (2017) for number of unfilled grains per tiller, Longjam *et al.* (2019) for number of primary branches per panicle, Surjaye *et al.* (2022) for stem length, Singh *et al.* (2026) for number of filled grain per tiller. Notably, the highest heritability was recorded in 50% flowering (95.42%), while the lowest was in flag leaf length (28.20%). The highest genetic advance as percentage of mean was found in the number of unfilled grains per tiller (95.92%) and the lowest in flag leaf length (6.28%). Traits exhibiting both high heritability (>60%) and high genetic advance (>20%) are likely governed by additive gene effects, making them ideal targets for selection. Such trends were also noticed by Beena *et al.* (2021) for numbers of unfilled grain per tiller and by Islam *et al.* (2020) for 1000 grains weight. In contrast, traits like flag leaf length with low genetic advance despite moderate heritability are likely controlled by non-additive gene actions.

Table 3. Estimation of genetic parameters of 23 rice genotypes for 14 yield associated traits

Character	Mean	Range	V _p	V _g	PCV	GCV	h ² _b	GA	GA (%)
FFL	64.27	59.33-76.67	23.39	22.32	7.52	7.35	95.42	9.51	14.79
FLL	25.55	21.37-29.60	7.62	2.15	10.81	5.74	28.20	1.60	6.28
LBL	32.11	28.07-37.70	15.75	5.02	12.36	6.98	31.86	2.60	8.11
LSL	25.62	19.40-31.33	10.71	8.36	12.78	11.29	78.01	5.26	20.53
SL	59.34	46.37-71.83	68.10	46.54	13.91	11.50	68.33	11.62	19.57
NET	11.05	9.00-17.00	5.06	1.78	20.36	12.07	35.15	1.63	14.74
NTT	18.23	14.00-21.33	4.55	1.80	11.70	7.36	39.55	1.74	9.53
NFG	113.61	90.33-144.00	125.37	82.57	9.86	8.00	65.86	15.19	13.37
NUnFG	12.51	7.33-31.00	37.41	35.61	48.90	47.72	95.21	12.00	95.92
NPB	18.16	10.33-24.00	33.47	30.51	31.86	30.42	91.16	10.86	59.83
NSB	38.79	34.67-42.33	9.10	3.72	7.78	4.97	40.89	2.54	6.55
PL	15.97	11.17-24.06	28.52	24.90	33.43	31.24	87.33	9.61	60.14
TGW	22.53	12.05-27.45	16.83	11.87	18.22	15.30	70.51	5.96	26.46
YPH	28.09	14.29-43.17	51.94	20.42	25.66	16.09	39.31	5.84	20.78

Here, PCV= Phenotypic co-efficient variation, GCV= Genotypic co-efficient variation, GA= Genetic Advance, h²_b= Broad sense heritability and GA (%) = Genetic Advance in percent of mean FFL=50% flowering; FLL= Flag leaf length (cm); LBL= Leaf blade length (cm); SL= Stem length (cm); NPB= Number of primary branches per panicle; NSB= Number of secondary branches per panicle; PL =Panicle length (cm); TGW= Thousand grain weight (g); YPH= Yield per hill (g); NET= Number of effective tillers; NTT= Number of total tillers; NFG= Number of filled grain per tiller; NUnFG= Number of unfilled grain per tiller and LSL= Leaf sheath length (cm).

Correlations of measured attributes

Correlations for yield and yield components at both genotypic and phenotypic level were shown in Table 4. Thousand grains weight ($r_g = 0.821$, $r_p = 0.673$), number of

filled grains ($r_g = 0.504$, $r_p = 0.379$) and unfilled grains per tiller ($r_g = 0.604$, $r_p = 0.365$) showed positively significant association with yield per hill at genotypic along with phenotypic level. These traits should be given priority for rice improvement because of their major influence on yield. This finding was in accordance with Chakrabarty *et al.* (2019) and Islam *et al.* (2020). Furthermore, leaf sheath length and flag leaf length showed significant but negative association with yield per hill at genotypic level.

Table 4. Genotypic (r_g) and phenotypic (r_p) correlation co-efficient for 14 yield-associated traits of 23 rice genotypes

Character		FLL	FLL	LBL	LSL	SL	NET	NTT	NFG	NUnFG	NPB	NSB	PL	TGW
FLL	r_g	0.246*												
	r_p	0.098												
LBL	r_g	0.765**	0.748**											
	r_p	0.380**	0.522**											
LSL	r_g	0.397**	0.737**	0.905**										
	r_p	0.347**	0.382**	0.506**										
SL	r_g	0.513**	0.327**	0.819**	0.853**									
	r_p	0.392**	0.287*	0.600**	0.693**									
NET	r_g	-0.023	-0.759**	-0.252*	-0.579**	-0.471**								
	r_p	0.007	-0.259*	-0.267*	-0.252*	-0.278*								
NTT	r_g	-0.529**	0.067	-0.165	-0.255*	-0.125	0.184							
	r_p	-0.320**	0.101	-0.006	-0.182	0.002	0.041							
NFG	r_g	-0.232	0.315**	-0.190	-0.028	0.005	-0.586**	0.399**						
	r_p	-0.213	0.255*	0.162	0.025	0.080	-0.297*	0.201						
NUnFG	r_g	-0.396**	0.013	-0.508**	-0.322**	-0.404**	-0.060	0.521**	0.853**					
	r_p	-0.381**	-0.001	-0.220	-0.281*	-0.311**	-0.055	0.327**	0.721**					
NPB	r_g	0.212	0.143	0.023	0.166	0.002	-0.143	-0.249*	0.219	0.278*				
	r_p	0.207	0.089	-0.028	0.135	-0.002	0.028	-0.100	0.177	0.260*				
NSB	r_g	-0.641**	-0.491**	-0.846**	-0.651**	-0.688**	0.580**	0.791**	0.092	0.497**	-0.581**			
	r_p	-0.386**	0.023	-0.127	-0.256*	-0.305*	0.077	0.360**	0.098	0.329**	-0.411**			
PL	r_g	-0.149	-0.016	0.142	-0.028	0.114	-0.075	0.153	-0.212	-0.369**	-0.981**	0.423**		
	r_p	-0.155	-0.030	0.102	-0.000	0.103	-0.089	0.045	-0.161	-0.348**	-0.958**	0.307*		
TGW	r_g	-0.092	-0.439**	-0.039	0.048	0.259*	-0.350**	0.117	0.304*	0.147	-0.017	-0.057	0.039	
	r_p	-0.072	-0.148	-0.046	0.054	0.178	-0.071	-0.021	0.223	0.117	-0.007	-0.055	0.020	
YPH	r_g		-0.654**	-0.280*	-0.380**	-0.102	-0.019	0.461**	0.504**	0.604**	0.037	0.388**	-0.154	0.821**
	r_p	-0.118	-0.162	-0.167	-0.148	-0.071	0.535**	0.113	0.379**	0.365**	0.8126	0.047	-0.146	0.673**

In a column, values having *, ** indicates significant at 5% and 1% levels, respectively,

Here, PCV= Phenotypic co-efficient variation, GCV= Genotypic co-efficient variation, GA= Genetic Advance, h^2b = Broad sense heritability and GA (%) = Genetic Advance in percent of mean FFL=50% flowering; FLL= Flag leaf length (cm); LBL= Leaf blade length (cm); SL= Stem length (cm); NPB= Number of primary branches per panicle; NSB= Number of secondary branches per panicle; PL =Panicle length (cm); TGW= Thousand grain weight (g); YPH= Yield per hill (g); NET= Number of effective tillers; NTT= Number of total tillers; NFG= Number of filled grain per tiller; NUnFG= Number of unfilled grain per tiller and LSL= Leaf sheath length (cm).

Path coefficient analysis

Path coefficient analysis (Table 5) helps the assessment of the net effect that one attribute has on another. The results depicted in the table showed that panicle length had the highest positive direct effect (16.929) and the least positive direct effect of the

number of secondary branches in a panicle was found (0.698). It also stated that positively direct effect on yield per hill exists between stem length, leaf blade length, number of effective tillers per hill, number of unfilled grains per tiller, number of primary branches per panicle, number of secondary branches per panicle and panicle length. The results are consistent with Islam *et al.* (2020). The analysis revealed that 4.4% (residual effects = 0.044) out of total variation for yield was not reported in the present study for fourteen yield contributing traits.

Table 5. Partitioning of genotypic into direct (bold) and indirect effects of morphological characters of 23 rice genotypes by path co-efficient analysis

Traits	FFL	FLL	LBL	LSL	SL	NET	NTT	NFG	NUnFG	NPB	NSB	PL	TGW	Genotypic correlation with YPH
FFL	-0.535	-0.619	1.325	-0.423	0.686	-0.018	0.021	0.414	-1.749	3.591	-0.447	-2.524	0.068	-0.210
FLL	-0.131	-2.521	1.296	-0.784	0.437	-0.571	-0.003	-0.563	0.058	2.420	-0.342	-0.273	0.323	-0.654**
LBL	-0.409	-1.885	1.733	-0.962	1.096	-0.190	0.007	0.340	-2.240	0.381	-0.590	2.412	0.029	-0.280*
LSL	-0.213	-1.859	1.568	-1.064	1.142	-0.435	0.010	0.049	-1.420	2.807	-0.454	-0.477	-0.035	-0.380**
SL	-0.274	-0.824	1.419	-0.908	1.338	-0.354	0.005	-0.010	-1.781	0.026	-0.480	1.931	-0.190	-0.102
NET	0.013	1.914	-0.438	0.616	-0.631	0.751	-0.007	1.047	-0.263	-2.418	0.405	-1.265	0.257	-0.019
NTT	0.283	-0.170	-0.285	0.271	-0.167	0.139	-0.040	-0.712	2.298	-4.216	0.552	2.594	-0.086	0.461**
NFG	0.124	-0.795	-0.330	0.029	0.007	-0.441	-0.016	-1.786	3.765	3.701	0.064	-3.596	-0.224	0.504**
NUnFG	0.212	-0.033	-0.880	0.342	-0.540	-0.045	-0.021	-1.524	4.413	4.695	0.347	-6.255	-0.108	0.604**
NPB	-0.114	-0.361	0.039	-0.177	0.002	-0.107	0.010	-0.391	1.225	16.909	-0.406	-16.606	0.013	0.037
NSB	0.343	1.237	-1.465	0.692	-0.920	0.436	-0.031	-0.165	2.193	-9.829	0.698	7.157	0.042	0.388**
PL	0.080	0.041	0.247	0.030	0.153	-0.056	-0.006	0.379	-1.630	16.586	0.295	16.929	-0.029	-0.154
TGW	0.049	1.108	-0.068	-0.051	0.346	-0.263	-0.005	-0.544	0.649	-0.292	-0.040	0.666	-0.736	0.821**
Residual effect = 0.04434														

In a column, values having *, ** indicates significant at 5% and 1% levels, respectively,

Here, PCV= Phenotypic co-efficient variation, GCV= Genotypic co-efficient variation, GA= Genetic Advance, h^2_b = Broad sense heritability and GA (%) = Genetic Advance in percent of mean FFL=50% flowering; FLL= Flag leaf length (cm); LBL= Leaf blade length (cm); SL= Stem length (cm); NPB= Number of primary branches per panicle; NSB= Number of secondary branches per panicle; PL =Panicle length (cm); TGW= Thousand grain weight (g); YPH= Yield per hill (g); NET= Number of effective tillers; NTT= Number of total tillers; NFG= Number of filled grain per tiller; NUnFG= Number of unfilled grain per tiller and LSL= Leaf sheath length (cm).

Genetic diversity among rice genotypes

The genetic structure of the studied genotypes based on the hierarchical cluster analysis of 14 yield associated traits was described in fig. 1. Multivariate analysis revealed four closely related groups among 23 rice genotypes. There were about seven genotypes in cluster 1 demonstrating 36.36% of total genotype in the study area, cluster 2 had about thirteen genotypes (56.52%) and the study area was represented by only one genotype in cluster 3 that is 4.35% while cluster 4 had about two genotypes making 8.70% of the total genotypes. Cluster 2 was the largest positioned cluster, while 1 was the smallest. This finding was recognized by Akhtar *et al.* (2022) and Diploma and Khanna (2018) found the similar result for cluster 2 positioning the highest one.

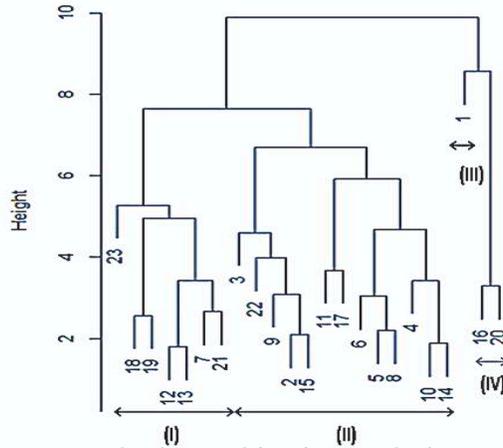


Fig. 1. Dendrogram generated using multivariate analysis among 23 rice genotypes.

Principal component analysis

From the biplot analysis (Fig. 2) it was obtained that yield had significant positive correlations with number of total tillers per hill, number of filled grains per tiller, number of unfilled grains per tiller, length of the leaf blade, length of the leaf sheath, length of plants stem, length of flag leaf, 1000 grains weight and days to flowering at 50% level as those lines with arrow were close to the yield. And yield had negative correlations with number of secondary branches per panicle, panicle length (cm) and number of effective tillers. Besides that, the first two coordinates PC1 and PC2 explained 30.17% and 19.60% variations, respectively and in total both contribute 49.77% variation. The contribution of two dimensions in together also supported the work done by Khalequzzaman *et al.* (2023).

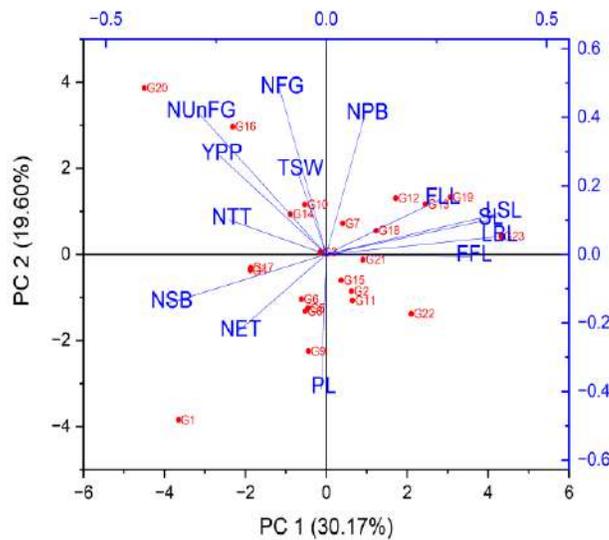


Fig. 2. Biplot analysis of the first two principal components (PC1 and PC2).

Here, FFL=days of 50% flowering; FLL= Flag leaf length (cm); LBL= Leaf blade length (cm); LSL= Leaf sheath length (cm); SL=Stem length (cm); NET= Number of effective tillers; NTT= Number of total tillers; NFG= Number of filled grain per tiller; NUnFG= Number of unfilled grain per tiller; NPB= Number of primary branches per panicle; NSB= Number of secondary branches per panicle; PL = Panicle length (cm); TGW= Thousand grain weight and YPH = Yield per hill (g).

The genetic distance within and between clusters, as shown in Table 6 revealed substantial genetic divergence among the twenty-three rice genotypes. The greatest inter-cluster distance was recorded between Cluster III and Cluster IV (61.46), followed by Cluster II and Cluster IV (54.02), and Cluster I and Cluster IV (52.02), highlighting the significant genetic dissimilarity among these groups. Similar findings were also reported by Takar *et al.* (2024), who observed maximum divergence between Cluster III and Cluster IV. The lowest inter-cluster distance was observed between Cluster I and Cluster II suggesting this group was genetically almost similar. Among the intra-cluster distances, the highest value was found in Cluster III (32.61) indicating high genetic variability within this cluster.

Table 6. Inter and Intra (bold) cluster distance

Cluster	Cluster			
	1	2	3	4
1	25.00			
2	31.08	19.80		
3	42.18	40.12	32.61	
4	52.02	54.02	61.46	18.77

Based on cluster means (Table 7), Cluster I exhibited the highest mean values for key yield-related traits, including grain yield (37.63 g/hill), 1000 grain weight, number of secondary branches per panicle, number of filled grains per tiller and total tillers per hill. Conversely, Cluster IV showed the lowest mean values for most traits, including yield and yield-contributing parameters. In summary, Cluster I emerged as the most desirable for selecting high-yielding genotypes. For maximum heterosis in breeding programs, crosses between genotypes from Cluster I and Cluster IV are promising, particularly for traits like the number of effective tillers per plant, 1000 grain weight and number of filled grains per tiller, hybridization between Clusters I and IV may produce beneficial outcomes.

Table 7. Mean cluster values for fourteen yield contributing traits

	FFL	FLL	LBL	LSL	SL	NET	NTT	NFG	NUnFG	NPB	NSB	PL	TSW	YPH
Cluster I	60.33	25.4	29.83	23.28	52.52	12.58	20	138.16	9.5	21.83	41.66	11.32	24.92	37.63
Cluster II	63.25	26.11	33.27	27.37	63.31	10.24	18.29	112.75	9.5	11.54	39.75	22.26	23.57	27.21
Cluster III	66.26	26.1	33.28	27.37	63.31	10.7	17.81	112.33	10.03	23.11	36.63	11.86	23.37	27.95
Cluster IV	61.91	24.37	29.58	22.27	49.57	10.83	18.41	104.16	12	18.91	40.33	14.15	18.71	25.05

Conclusion

The study revealed significant variability among 23 Boro rice genotypes. High heritability with high genetic advance was observed for leaf sheath length, unfilled grains per tiller, primary branches per panicle, panicle length and 1000 grain weight, indicating potential for effective selection. PCV exceeded GCV for all traits, suggesting environmental influence. Yield per hill showed a highly significant positive correlation with filled grains per tiller, unfilled grains per tiller and 1000-grain weight. These traits are key contributors to yield. Crosses between genetically divergent genotypes may result in maximum heterosis. However, crosses among genotypes from Cluster I and Cluster IV are more suitable for hybridization, as they are expected to exhibit high heterotic potential and serve as valuable breeding materials.

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Authors' contribution

Conceptualization was carried out by TI, KMKH, and SP. TI was responsible for methodology, investigation, and preparation of the original draft. Supervision was provided by TI and MHR. Formal analysis was performed by TI, FTJ, MZI, and RI. Data curation was undertaken by KMKH, MZI, and RI. Writing-review and editing were contributed by TI, KMKH, MHR, SP, RR, and RI.

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GENETIC VARIABILITY, CORRELATION AND PATH COEFFICIENT ANALYSIS OF EXOTIC WHITE MAIZE (*Zea mays* L.) GENOYTPES

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Abstract

Seventeen exotic white maize (*Zea mays* L.) inbred lines collected from CIMMYT, Mexico were evaluated at the experimental farm of Sher-e-Bangla Agricultural University, Dhaka in a Randomized Complete Block Design (RCBD) with three replications, during October 2016 to April 2017. The mean performance, variability, correlation matrix and path analysis on different yield parameters and yield were estimated. Maximum grain yield plant⁻¹ (170.01 g) was recorded in the genotype, CLTHW15008, whereas the minimum grain yield plant⁻¹ (44.52 g) was recorded in CLTHW15007. The phenotypic co-efficient of variation was higher than the genotypic co-efficient of variation for all the yield contributing traits. In the correlation study, a significant positive association was recorded for grain yield plant⁻¹ with the base diameter of the plant (1.00), leaf breadth (1.00), cob length (0.979), cob diameter (0.930), number of rows cob⁻¹ (0.979), number of grains row⁻¹ (0.999), 100-grain weight (0.992). Path analysis revealed that plant height (0.412), leaf breadth (0.073), days to 50% flowering (0.280), number of rows cob⁻¹ (0.462), number of grains row⁻¹ (0.209) had a positive direct effect on yield plant⁻¹. The results indicated that for improving white maize grain yield, selection based on plant height, cob length, cob diameter, number of rows cob⁻¹, number of grains row⁻¹, 100-grain weight would be useful for future breeding program.

Keywords: Correlation coefficients, Path analysis, Variability, White maize.

Introduction

Maize is the supreme food and feed crop in the world and in terms of global production, maize ranks third after rice and wheat (Muhammad *et al.*, 2023). It is known as the queen of cereals, because of its highest genetic yield potential (Shree *et al.*, 2018). It is also referred to as a “contingency crop” since it may be used at any every stage of development like tender green fodder in the early stages, baby corn in the very early stages of cob development, green cob in the slightly later stages, and maize grain in the fully developed stages (Yadav *et al.*, 2014). Substantial genetic variability was found among various maize cultivars. Generally, yellow and white maize based on endosperm

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color are predominantly grown around the world. Yellow-colored maize is largely grown in the Southeast Asian region and is predominantly used for poultry and animal feed. However, white maize is widely cultivated in Africa and America where it is used as a staple food due to its nutritional properties (Arora *et al.*, 2024). The demand for white maize flour is notably increasing in the Indo-Bangladesh regions due to the higher consumer preference in recent years.

In Bangladesh, maize cultivation is also increasing rapidly because of its versatile uses as food, feed, raw materials for industry, and edible oil with low cholesterol levels for human and livestock consumption. It is a short-duration crop cultivated in the spring and summer seasons to meet the desirable yield and boost the economy (Dogar *et al.*, 2023). The area and production of maize in both seasons in 2022-23 were 1227 thousand acres and 45.63 lac million tons, respectively (BBS, 2023) while the demand is almost 2.0 million tons (Islam *et al.*, 2022). The acreage and production of maize in the country are increasing but not encouraging enough compared to the world perspective and the demand for crops in the country is increasing at a higher rate. Additionally, the coverage of white maize production is very low, resulting in Bangladesh paying a sheer amount of foreign exchange to export maize products. To meet the ever-increasing demand of the increasing population of Bangladesh, maize breeders need to pay special attention to investigating the genetic variability of white maize that could help to isolate promising inbred lines.

Determination of genetic variation is a prerequisite for crop improvement programs. The production capabilities of a plant are largely contributed by the interaction effects of genetic factors and environmental conditions. The variability components are effective tools for plant breeding that estimate the transmission capabilities of a trait over the environment and set a sound basis for plant breeders to formulate effective breeding strategies (Ahmed *et al.*, 2020). Furthermore, the yield performance of a variety, which is the ultimate goal of breeding programs, is reflected by the joint effects of multiple traits. Hence, pair wise association among the yield-attributing traits is an urgent need in varietal improvement programs. Proper knowledge of such interrelationships between yield and its attributing traits thus helps to efficiently improve the yield performance and the selection indices (Amin *et al.*, 2022). Correlation analyses are used to determine such interrelationships, such that the values of two characters are analyzed on a paired basis, the results of which may be either positive or negative (Prasad and Shivani, 2017). As the number of variables increases, the measurement of the contribution of each variable towards the observed correlations is imperative. Therefore, partitioning the observed correlation coefficients into components of direct and indirect influences provides perceptions in the characterization of more complex traits like yield (Shikha *et al.*, 2020). The technique of path coefficient analysis developed by Wright (1921) and demonstrated by Dewey and Lu (1959) facilitates the partitioning of correlation coefficients into direct and indirect contributions of various characters to yield. Keeping these in mind, seventeen white maize genotypes were evaluated addressing the following objectives: The genetic variability among the collected germplasms of white maize and analyze the correlation and path coefficient analysis among the yield contributing traits that can be employed in future varietal improvement programs.

Materials and Methods

The experiment was conducted using seventeen (17) exotic white maize inbred lines collected from CIMMYT, Mexico and local open-pollination white maize variety, Suvra (Table 1.) to investigate the genetic variability, heritability, correlation and path coefficient analysis for yield and its contributing factors and genetic diversity at Sher-e-Bangla Agricultural University (SAU), Sher-e-Bangla Nagar, Dhaka, Bangladesh. The field experiment was carried out from October to April 2016-2017.

Table 1. Name and origin of the white maize (*Zea mays*) inbred lines and variety used in the present study

Sl.	Genotypes	Source of collection
1.	CLTHW15004	CIMMYT, Mexico
2.	CLTHW15005	CIMMYT, Mexico
3.	CLTHW15006	CIMMYT, Mexico
4.	CLTHW15007	CIMMYT, Mexico
5.	CLTHW15008	CIMMYT, Mexico
6.	CLTHW15009	CIMMYT, Mexico
7	CLTHW15003	CIMMYT, Mexico
8	CLTHW15010	CIMMYT, Mexico
9	CLTHW15011	CIMMYT, Mexico
10	CLTHW15012	CIMMYT, Mexico
11	CLTHW15001	CIMMYT, Mexico
12	CLTHW15014	CIMMYT, Mexico
13	CLTHW15015	CIMMYT, Mexico
14	CLTHW14001	CIMMYT, Mexico
15	CLTHW14003	CIMMYT, Mexico
16	CLTHW13001	CIMMYT, Mexico
17	Suvra	BARI, Gazipur

Location of the experimental site

The investigation was carried out at the experimental field of Sher-e-Bangla Agricultural University, Dhaka. The location of the site is 23⁰74'N latitude and 90⁰35'E longitude with an elevation of 8.2 meters from sea level with a sub-tropical climate.

Soil

The soil of the experimental site belongs to “The Madhupur Tract”, AEZ-28 (FAO, 1988). Topsoil was silty clay in texture, olive-gray with common fine to medium

distinct dark yellowish-brown mottles, the pH was 5.6 and had an organic matter of 0.45%. The soil analyses were done by the Soil Resource and Development Institute (SRDI), Dhaka. The experimental area was flat having an available irrigation and drainage system and above flood level. The selected plot was medium-high land.

Experimental design and layout

The experiment was laid out in randomized complete block design (RCBD) with three replications. The field was partitioned into three blocks. The individual block size was 33.15 m × 2.5 m. Each plot was 2.5 m in length and 2 m in breadth containing three rows. The plant spacing provided was 65 cm between rows and 25 cm between plants of the same row. All the recommended intercultural operations (weeding, thinning, gap filling, fertilizer application, irrigation, and plant protection) were followed.

Data recording

Five individual plants from each genotype from every replication were randomly selected to measure various yield-contributing traits. Thirteen parameters were measured viz., plant height (cm), base to cob distance (cm), base diameter of plant (cm), leaf length (cm), leaf Breadth (cm), days of 50% flowering, days to maturity, cob length (cm), cob diameter (cm), number of rows cob⁻¹, number of grains cob⁻¹, 100-grain weight yield plant⁻¹(g).

Statistical analysis

The mean values of all the thirteen characters were evaluated and analysis of variance was performed by the 'F' test. Genotypic and phenotypic variances were estimated with the help of the formula suggested by Johnson *et al.* (1955). The genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were calculated by the formula suggested by Burton (1952). Heritability in broad sense was estimated by the formula as suggested by Johnson *et al.* (1955). The formula suggested by Allard (1960) was used to estimate the expected genetic advance for different characters under selection. Genetic advance in percentage of mean was calculated by the formula given by Comstock and Robinson (1952). Simple correlation was estimated for different traits with the formula (Singh and Chaudhary, 1985). Path co-efficient analysis was carried out according to the procedure employed by Dewey and Lu (1959) also quoted in Singh and Chaudhary (1985), using simple correlation values. The data collected were subjected to statistical analysis using Statistix10 and Genstat v. 2017 to determine the genetic variability of test genotypes.

Results and Discussion

Performance analysis of 17 white maize varieties

The analysis of variance indicated a significant amount of genetic variation among all the characters studied, leveraging ample opportunity of improving white maize high-yield varieties (Table 2). Moreover, the white maize varieties assessed in the current study revealed that the test genotype varied substantially in yield and yield-attributing traits (Table 3). Among the growth-related characters, plant height ranged from 172.67 cm (CLTHW14001) to 223.93 cm (CLTHW15010). The maturity indicating traits viz., the days to 50% flowering extended from 78.13 (CLTHW15008) to 84.87 DAS (CLTHW15011). Furthermore, inbred line CLTHW15012 showed the earliest maturity duration whereas the longest maturity duration was noted in CLTHW15014 (151.67). Collectively, inbred CLTHW15004, CLTHW15008, CLTHW15011, CLTHW15001 and CLTHW14001 can be selected as potential resources to develop early maturing and short-stature white maize varieties.

In maize production, cob length and diameter are two important traits, those provide an indication of yield performance. In the present study, the highest cob length was recorded in CLTHW15008 (16.47 cm) while the lowest was in CLTHW15007 (13.17 cm). Moreover, the maximum cob diameter was recorded in CLTHW15008 (4.85 cm) whereas inbred CLTHW15007 exhibited the minimum diameter of the cobs. Again, the highest number of seed row cob^{-1} was 16.57, produced by the CLTHW15008 and the lowest number of seed row cob^{-1} was 12.11, found in CLTHW15007. The maximum number of grains row^{-1} was found in the genotype CLTHW15008 (30.14) with an average of number 23.54. In case of grain yield performance, the yield plant^{-1} varied from 44.52g (CLTHW15006) to 170.01 g (CLTHW15008) whereas inbred lines CLTHW15004 (137.30 g), CLTHW15011 (127.08 g) and CLTHW15015 (117.23 g) out performed in yielding. Additionally, the maximum 100-seed weight was found in CLTHW15008 (34.10 g) and minimum in CLTHW15007 (20.54g). Ahmed *et al.*, (2020) and Muhammad *et al.*, (2023) also evaluated different maize genotypes on their morphological and yield contributing characteristics and suggested the best varieties for further maize improving scheme. Ahmed *et al.*, (2020) found maximum value 21.60 for cob length, 5.50 for cob diameter, 18 for number of rows cob^{-1} , 748 for number of seeds cob^{-1} , 9.25 for yield. Considering the agronomic performances of the maize genotypes it could be suggested that CLTHW15004, CLTHW15005, CLTHW15006, CLTHW15008, CLTHW15001 and CLTHW15015 are the promising lines for their higher yield, number of seed row cob^{-1} , cob length and number of grains row^{-1} . Therefore, these selected lines can be utilized in breeding programs for developing high-yielding maize-inbred lines in the future.

Variability components among the yield-attributing traits

In crop improvement programs, determining the genetic variability among the desired traits is the foremost objective of plant breeders, and it allows them to get an

insight into the inheritance patterns that aid in fabricating an effective breeding program to improve the crop further. Additionally, the estimation of variance components provides an understanding of the genetics or interaction of the genetics with surrounding environmental factors that regulate the expression of the phenotypic variance (Shompa *et al.*, 2020). In the present investigation, there were significant genotypic and phenotypic differences among maize genotypes for yield and other morphological attributes (Table 4). Among the traits study, phenotypic coefficient variation (PCV) is higher or slightly higher than genotypic coefficient variation (GCV) in almost all parameters except plant height (PCV-10.48, GCV- 4.18) and leaf length (PCV-11.63, GCV-1.82). Conversely, a minimal fluctuation between PCV and GCV was noted in base diameter of plant (PCV-8.75, GCV-8.55), leaf breadth (PCV-8.87, GCV-8.72), days to 50% flowering (PCV-3.35, GCV-3.33), cob length (PCV-6.87, GCV-6.54), cob diameter (PCV-4.63, GCV-4.50), no of grains row⁻¹ (PCV-13.50, GCV-13.20), 100-grain weight (PCV-12.51, GCV-12.50) and yield plant⁻¹ (PCV-32.89, GCV-32.77) indicated that genes controlling the inheritance of these traits were largely influenced by the genetic factors rather than the environmental interactions on the phenotypic expressions of these traits (Bartaula *et al.*, 2019). Therefore, the direct selection of these selected traits could be beneficial in formulating efficient breeding programs. Moreover, utilizing heritability estimates alongside genetic advance enhances the reliability and utility of selection procedures (Reddy *et al.*, 2024). In this present study, the joint effects of high heritability and genetic advance (%) were recorded in yield plant⁻¹ (99.24, 64.24), leaf breadth (96.56, 17.65), cob length (90.67, 12.83), number of grains row⁻¹ (95.54, 26.58). Reddy *et al.*, (2024) documented similar results for yield. On the other hand, plant height and leaf length showed low heritability coupled with low GA mean percentage (15.90, 3.43) and (2.45, 0.59) respectively. Direct selection would not be effective in this case and these characteristics were controlled by non-additive genes. Previously, Magar *et al.*, (2021) and Kumar *et al.*, (2024) suggested that traits possessing broad sense higher heritability (>60%) and genetic advance in percentage of mean (>20%) are highly advantageous during selection as these traits are regulated by the fixable additive genes and can be transmitted over the generations. Hence, the aforesaid traits can be considered in future breeding programs in developing high-yielding white maize cultivars.

Table 2. Analysis of variance (ANOVA) of different characters in white maize

Sources of variation	df	Mean sum of squares												
		Plant Height (cm)	Distance between base to cob (cm)	Base diameter of plant (cm)	Leaf length (cm)	Leaf breadth (cm)	Days to 50% flowering	Days to maturity	Cob length (cm)	Cob diameter (cm)	No. of row cob ⁻¹	No of grains row ⁻¹	100-grain weight	Yield plant ⁻¹
Genotypes	16	604.78**	369.84**	0.82	63.47**	1.44	24.03**	96.45**	2.97**	0.13	3.93**	29.41**	34.57**	15505.68**
Replications	2	1079.99	181.017	1.311	177.361	0.739	12.505	55.902	0.090	0.013	0.032	2.013	115.006	300.233
Error	32	385.926	6.123	0.013	59.024	0.017	0.088	17.860	0.099	0.003	0.085	0.451	0.010	77.477

Table 3. Mean performance of 13 yield and yield components of 17 white maize Genotypes

Genotypes	Plant height (cm)	Distance between base to cob	Base diameter of plant (cm)	Leaf length (cm)	Leaf breadth (cm)	Days to 50% flowering (DAS)	Days to maturity (DAS)	Cob length (cm)	Cob diameter (cm)	No of rows cob ⁻¹	No of grains row ⁻¹	100-grain weight	Yield plant ⁻¹ (g)
CLTHW15004	203.73	89.80	6.90	63.53	8.90	86.17	130.33	16.23	4.82	15.73	27.40	31.85	137.30
CLTHW15005	201.53	99.00	6.19	67.00	8.09	87.17	136.00	15.40	4.67	15.00	24.53	27.85	102.57
CLTHW15006	208.27	97.40	6.33	60.60	8.31	81.17	131.33	15.73	4.72	15.20	25.43	29.25	113.23
CLTHW15007	210.53	121.80	5.10	60.00	6.63	82.17	134.67	13.17	4.06	12.11	17.89	20.54	44.52
CLTHW15008	195.81	75.20	7.20	72.21	9.39	78.17	131.67	16.47	4.85	16.57	30.14	34.10	170.01
CLTHW15009	215.03	100.60	6.13	68.21	7.94	86.17	130.33	15.23	4.65	15.00	24.22	27.45	99.80
CLTHW15003	221.60	106.67	5.81	66.26	7.59	86.17	129.33	14.22	4.53	14.07	22.27	26.14	82.00
CLTHW15010	223.93	104.67	5.95	76.19	7.66	84.17	129.67	14.96	4.58	14.62	23.05	26.94	90.77
CLTHW15011	202.68	90.73	6.53	69.83	8.51	87.83	133.67	16.15	4.81	15.70	26.77	30.25	127.08
CLTHW15012	216.60	102.93	6.08	66.13	7.78	85.83	129.00	15.08	4.62	14.85	23.47	27.25	95.00
CLTHW15001	200.27	97.93	6.23	66.00	8.20	85.83	130.33	15.55	4.70	15.07	24.97	28.85	108.54
CLTHW15014	181.93	109.67	5.61	73.78	7.44	86.83	151.67	13.98	4.48	13.43	21.20	24.74	70.39
CLTHW15015	208.53	95.40	6.39	59.47	8.43	85.83	139.33	15.98	4.77	15.53	25.70	29.35	117.23
CLTHW14001	172.67	109.33	5.75	66.87	7.53	85.83	129.33	14.21	4.51	14.00	21.47	24.94	74.86
CLTHW14003	195.40	117.20	5.47	64.47	6.98	79.83	133.33	13.75	4.28	12.84	19.10	22.94	56.46
CLTHW13001	192.47	105.80	5.90	67.68	7.65	87.83	135.00	14.45	4.58	14.30	22.55	26.14	84.40
Suvra	223.87	112.33	5.57	68.94	7.23	85.83	139.33	13.83	4.35	13.40	20.07	22.99	61.85
Minimum	172.67	75.20	5.10	59.47	6.63	78.17	129.00	13.17	4.06	12.11	17.89	20.54	44.52
Maximum	223.93	121.80	7.20	76.19	9.39	87.83	151.67	16.47	4.85	16.57	30.14	34.10	170.01
Mean	204.40	102.15	6.07	66.89	7.90	84.87	133.78	14.96	4.59	14.55	23.54	27.15	96.24
SE (±)	2.96	1.86	0.10	3.16	0.13	0.77	0.98	0.53	0.09	0.08	0.89	0.76	3.78

Table 4. Estimation of genetic parameters for 13 characters of 17 white maize (*Zea mays*) genotypes

Parameters	Gen MS	σ^2_g	σ^2_e	σ^2_p	GCV	PCV	h^2_b	GA	GA (% mean)	CV (%)
Plant height (cm)	604.78	72.95	385.92	458.87	4.18	10.48	15.90	7.02	3.43	9.61
Distance between base to cob	369.84	121.23	6.12	127.36	10.78	11.05	95.19	22.13	21.66	2.42
Base diameter of plant (cm)	0.82	0.26	0.01	0.28	8.55	8.75	95.36	1.04	17.19	1.89
Leaf length (cm)	63.47	1.48	59.02	60.50	1.82	11.63	2.45	0.39	0.59	11.49
Leaf breadth (cm)	1.43	0.47	0.01	0.49	8.72	8.87	96.56	1.39	17.65	1.64
Days to 50% flowering (DAS)	24.03	7.98	0.08	8.07	3.33	3.35	98.91	5.79	6.82	0.35
Days to maturity (DAS)	96.45	26.19	17.86	44.05	3.83	4.96	59.46	8.13	6.08	3.16
Cob length (cm)	2.97	0.95	0.09	1.05	6.54	6.87	90.67	1.92	12.83	2.10
Cob diameter (cm)	0.13	0.04	0.002	0.04	4.50	4.63	94.47	0.41	9.02	1.10
No. of rows cob ⁻¹	3.93	1.28	0.08	1.36	7.78	8.04	93.80	2.26	15.53	2.00
No. of grains row ⁻¹	29.41	9.65	0.45	10.10	13.20	13.50	95.54	6.26	26.58	2.85
100-grain weight (g)	34.57	11.52	0.01	11.53	12.50	12.51	99.91	6.99	25.74	0.37
Yield plant ⁻¹	2991.01	994.45	7.64	1002.10	32.77	32.89	99.24	64.71	67.24	2.87

Table 5. Genotypic and phenotypic correlation coefficients among different pairs of yield and yield contributing characters for different genotypes of white maize

Traits	Correlations	Distance between base to cob	Base diameter of plant	Leaf length (cm)	Leaf breadth (cm)	Days to 50% flowering	Days to maturity	Cob length (cm)	Cob diameter (cm)	No of rows cob ⁻¹	No of grains row ⁻¹	100-grain weight	Yield plant ⁻¹
Plant height (cm)	r _g	0.013	-0.022	-1.000**	-0.129	0.010	-0.391	0.031	-0.048	-0.028	0.013	-0.044	-0.025
	r _p	0.041	-0.030	-0.066	-0.069	0.004	-0.285	0.040	-0.046	0.031	-0.020	-0.032	-0.026
Distance between base to cob	r _g		-0.999**	-0.570*	-1.000**	0.093	0.273	-0.990**	-0.931**	-0.989**	-1.000**	-0.992**	-1.000**
	r _p		-0.986**	-0.160	-0.990**	0.093	0.226	-0.948**	-0.924**	-0.966**	-0.993**	-0.985**	-0.995**
Base diameter of plant (cm)	r _g			0.241	1.000**	-0.087	-0.332	0.994**	0.945**	0.986**	1.000**	0.999**	1.000**
	r _p			0.088	0.993**	-0.087	-0.284	0.962**	0.932**	0.967**	0.989**	0.991**	0.993**
Leaf length (cm)	r _g				0.259	0.500*	0.779**	0.211	0.502*	0.234	0.608**	0.546*	0.410
	r _p				0.079	0.127	0.172	0.013	0.140	0.123	0.111	0.113	0.100**
Leaf breadth (cm)	r _g					-0.067	-0.239	0.979**	0.962**	0.976**	1.000**	0.998**	1.000**
	r _p					-0.065	-0.220	0.961**	0.941**	0.967**	0.993**	0.991**	0.993**
Days to 50% flowering (DAS)	r _g						0.232	-0.002	0.181	0.042	-0.048	-0.060	-0.125
	r _p						0.207	0.000	0.178	0.044	-0.047	-0.060	-0.124
Days to maturity (DAS)	r _g							-0.299	-0.264	-0.346	-0.300	-0.310	-0.308
	r _p							-0.280	-0.225	-0.309	-0.258	-0.280	-0.271
Cob length (cm)	r _g								0.989**	1.000**	0.993**	0.986**	0.979**
	r _p								0.953**	0.976**	0.973**	0.968**	0.961**
Cob diameter (cm)	r _g									1.000**	0.969**	0.965**	0.930**
	r _p									0.977**	0.952**	0.956**	0.921**
No of rows cob ⁻¹	r _g										1.000**	0.989**	0.979**
	r _p										0.982**	0.977**	0.966**
No of grains row ⁻¹	r _g											1.000**	0.999**
	r _p											0.995**	0.995**
100-grain weight	r _g												0.992**
	r _p												0.991**

Note: *= significant at 5% and **= significant at 1% whereas r_g = Genotypic correlation coefficient and r_p = Phenotypic correlation coefficient

Table 6. Path coefficient analysis showing direct and indirect effects of different characters on yield of white maize.

Characters	Direct effect	Indirect effect											Genotypic correlation with yield	
		PH	DBC	BD	LL	LB	DF	DM	CL	CD	RPC	GPR		SGW
PH	0.412		-0.030	-0.204	0.031	-0.005	-0.052	-0.005	-0.023	-0.067	-0.120	-0.078	0.116	-0.025
DBC	-0.214	-0.023		-0.153	-0.122	-0.068	-0.210	-0.037	-0.113	-0.067	-0.066	-0.099	0.174	-1.000**
BD	-0.614	0.234	0.108		0.079	0.122	0.085	0.235	0.221	0.073	0.120	0.125	0.212	1.000**
LL	-0.467	0.007	0.030	-0.021		0.042	0.094	0.073	0.427	0.081	0.057	0.050	0.037	0.410
LB	0.073	-0.120	0.111	-0.002	0.049		0.110	0.067	0.181	0.294	0.073	0.106	0.059	1.000**
DF	0.280	-0.072	0.051	0.081	-0.103	-0.018		-0.029	-0.095	0.021	-0.163	-0.028	-0.050	-0.125
DM	-0.262	-0.054	-0.014	0.325	0.031	-0.038	-0.020		-0.088	-0.087	-0.060	-0.086	0.045	-0.308
CL	-0.725	0.107	0.095	0.189	0.339	0.105	0.131	0.088		0.046	0.181	0.091	0.330	0.979**
CD	-0.355	0.165	0.119	0.038	0.158	0.126	0.094	0.093	0.019		0.155	0.135	0.183	0.930**
RPC	0.462	-0.027	0.093	0.103	0.077	0.096	-0.023	0.110	-0.083	0.048		0.109	0.015	0.979**
GPR	0.209	-0.132	0.116	0.080	0.061	0.082	0.058	0.176	0.157	0.019	0.123		0.052	0.999**
HSW	-0.472	-0.020	0.144	0.197	0.074	0.079	0.098	0.113	0.421	0.136	0.134	0.088		0.992**

Note: *= significant at 5% and **= significant at 1% whereas PH- Plant height (cm), DBC- Distance between base to cob (cm), BD- Base diameter, LL- Leaf length (cm), LB- Leaf breadth (cm), DF- Days to 50% flowering (DAS), DM- Days to maturity (DAS), CL- Cob length (cm), CD- Cob diameter (cm), RPC- Number of row cob⁻¹, GPR- Number of grains row⁻¹, HSW- 100 seeds weight (g).

Correlation analysis of quantitative traits

The study of the interrelationship among the yield components with yield and their direct and indirect contribution to yield is of immense importance in crop improvement programs. Correlation generally helps in identifying the traits that are mutually contributing to enhance each other or impair each other (Shettigar *et al.*, 2024). Direct improvement of yield is difficult as yield is a complicated trait, as a result of the combined effect of several component characters and environment. In the present study, we noted the genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients in most of the cases indicated that the association is largely due to genetic reasons (Table 5). Among the traits under study, yield plant⁻¹ showed a highly significant positive correlation with cob length (rg-0.979**, rp-0.961**), base diameter of plant (rg-1.00**, rp-0.993), leaf breadth (rg-1.00**, rp-0.993**), cob diameter (rg-0.930**, rp-0.921**), no of grains row⁻¹ (rg-0.999**, rp-0.966**), no. of rows cob⁻¹ (rg-0.979**, rp-0.966**) and 100-grain weight (rg-0.992**, rp-0.991**) at the both genotypic and phenotypic levels, respectively, suggesting that simultaneous improvement of these traits could enhance the yield performance of the maize cultivars. Falconer (1981) previously recommended that a positive correlation between two traits is evolving in the same direction and *vice versa*. Khan and Mahmud (2021) also found a strong and positive correlation of yield plant⁻¹ with 100-grain weight, cob length and no. of rows cob⁻¹. Therefore, these traits could be effective for the direct selection of white maize improvement program. On the contrary, yield plant⁻¹ had a non-significant negative correlation with plant height (rg: -0.025, rp: -0.026), days to maturity (rg: -0.308, rp: -0.271), days to 50% flowering (rg: -0.125, rp: -0.124) at both genotypic and phenotypic levels suggesting that early and short-statured white maize cultivars could be bred in the future.

Path coefficient analysis

The estimation of path coefficient analysis provides a clear indication of the influence of yield-contributing traits on the total yield performance of a plant by separating the correlation coefficient into direct and indirect effects and indicates the relationship in a more meaningful way by providing a cause-effect relationship of the characters (Ara *et al.*, 2015). The results of the path coefficient analysis are presented in Table 6. The present investigation revealed that five out of twelve characters had a positive direct effect on grain yield plant⁻¹. The characters which had a positive direct effect are plant height (0.412), leaf breadth (0.073), days to 50% flowering (0.280), no. of row cob⁻¹ (0.461) and no. of grains row⁻¹ (0.209) suggesting that these traits had a significant contribution in increasing the grain yields. Therefore, these traits can be considered during selection. Besides, path coefficient analysis revealed that grain yield plant⁻¹ was directly influenced by plant height, leaf breadth, days to 50% flowering, no. of rows cob⁻¹ and no of grains row⁻¹. Hence, selection for any of these independent traits also leads to improving the genotypes for grain yield plant⁻¹. These findings are consistent with that of Yahaya *et al.*, (2021) and Reddy *et al.*, (2022). However, character *viz.* the distance between base to cob (-0.214), base diameter of the plant (-0.614), leaf length (-0.467), days to maturity (-0.262), cob length (-0.725), cob diameter (-0.355) and

100-seed weight (-0.472) had a negative direct effect on grain yield plant⁻¹. These traits can also exert positive effects on yield and can indirectly contribute to enhancing yield performance. Among the negatively influencing traits, cob length, leaf length, and cob diameter showed a positive indirect effect and strong association with yield plant⁻¹. Therefore, in the next breeding programs, the traits possessing positive direct effects and also traits having positive indirect effects should be focused to improve the overall grain yield of the white maize cultivars.

Conclusion

The present study revealed that there are highly significant differences among the accessions for all the traits under study. Characters like plant height (cm), base to cob distance (cm), base diameter of plant (cm), leaf breadth (cm), number of rows cob⁻¹, number of grains row⁻¹, 100-grain weight (gm), yield plant⁻¹ exhibited high genotypic and phenotypic coefficient of variation. High heritability, high genetic advance and high genetic percent of mean were noted for the 100-grain weight. In case of correlation and path analysis, high positive and direct effects exerted by plant height, leaf breadth, days to 50% flowering, number of rows cob⁻¹ and the number of grains row⁻¹ were noted on yield plant⁻¹. Therefore, selection on these traits could bring a key role in the crop improvement program for the continuous yield enhancement.

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Conflicts of interest

The authors declare no conflicts of interest regarding publication of this paper.

Authors' contribution

Roy, G. designed, planned, and executed the experiment and drafted the manuscript; Shompa, B. N., Emu, I. A. and Fatima, K. edited and reviewed the manuscript; Rahman, J. supervised the experiment, analyzed the data, and edited and reviewed the manuscript.

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ASSESSMENT OF GENETIC VARIABILITY AND CHARACTER ASSOCIATION FOR YIELD CONTRIBUTING TRAITS IN MUNGBEAN (*Vigna radiata* L.)

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Abstract

The study was conducted to evaluate the genetic variability and correlation between several yield contributing features in mungbean (*Vigna radiata* L.). Fourteen mungbean varieties from different Institutes, were evaluated with nine quantitative traits during the Kharif I season from March to June, 2020 at the Sher-e-Bangla Agricultural University's research farm. The analysis of variance showed significant variation among all the varieties in all the traits studied. The phenotypic variances were greater than the genotypic variances. The Phenotypic coefficient of variance and genotypic coefficient of variance were higher for the no. of branches /plant (19.671; 18.309) followed by weight of 1000 seed (g) (25.339; 25.254) and yield/plant (g) (31.296; 31.049) respectively. High heritability coupled with high genetic advance as a percent of mean was observed for plant height (cm) (96.073; 21.421), followed by no. of leaves/plant (95.977 ; 31.950), no. of branches /plant (86.636 ; 35.107), no. of pods/plant (99.335; 55.623), pods length/plant (cm) (98.389 ; 29.455), no. of seeds/pod (92.371 ;33.375), weight of 1000 seed (g) (99.331; 51.848) and yield/plant (g) (98.427 ; 63.456), respectively which indicated the effect of additive genes effect. In the correlation co-efficient analysis yield/plant had significant positive relation at both the genotypic and phenotypic level with the number of leaves/plants followed by number of branches/plants, number of pods/plants, number of pods cluster/plant, pods length/plant (cm), number of seeds/pod and weight of 1000 seed (g) which indicates this character can be considered for future improvement program of mungbean. Path analysis revealed that number of seeds/pod (0.689), number of leaves/plant (0.338), number of branches/plant (0.196), number of pods/plant (0.435) and weight of 1000 seed (g) (0.016) showed positive direct effect on yield/plant. These results suggest that the direct selection of these characters will facilitate the chance of simultaneous improvement of other traits in mungbean. Evaluating the performance among the studied varieties, BINA mung5 and BINA mung8 considered the elite variety.

Keywords: Correlation, Genetic advance, Heritability, Mungbean, Path coefficient.

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Introduction

In Bangladesh mungbean is one of the most important pulse crops because of its easy digestibility and high protein percentage (Azam *et al.* 2018). It is mainly grown for its high protein and consumed as ‘Mungdal’ along with cereals in South Asian countries also consider it as a vital ingredient for the human diet. Its seeds are also consumed as sprouts in many countries (Singh *et al.* 2014). Dry seeds contain 27% protein (Day, 2013). Mungbean is a very good source of protein, amino acids, carbohydrates, antioxidants and fibers (Bangar *et al.* 2018). One cup of (202 g) boiled mungbean contain 212 calories, 14.2 g of protein, 38.7 g of carbohydrate, 15.4 g of fiber, 0.8 g of fat. It also contains manganese, magnesium, vitamin B1, phosphorus, zinc, vitamin B2, B3, B5, B6 and selenium (Hrubska *et al.*, 2022)

In Bangladesh, the total production is 42000 million tons on 114000 acres of land (BBS, 2022). Singh *et al.* (2014) stated that mungbean production (90%) is mainly located in Asia. Over the last three decades, the global mungbean consumption has increased by 60% with a corresponding growth in production area up to 6 million hectares, concentrated mainly in South, East, and Southeast Asia (Kim *et al.*, 2015). Although mungbean is a nutritious crop, overall production is low due to abiotic and biotic stresses, a low level of crop management by farmers and the shortage of suitable varieties for varying geographical conditions (Singh *et al.* 2015). The present yield is not high enough to meet the demand of consumers and farmers because of its low yield potential, small seed size and susceptibility to disease (Srivastava & Singh, 2013).

A critical survey of genetic variability is necessary before initiating an improvement program aiming to develop high yielding varieties of mungbean. The correlation co-efficient between yield components usually show a complex chain of interacting relationships. Path coefficient analysis split the components of the correlation coefficient into direct and indirect effects and visualizes the relationship in a more meaningful way. Considering these above problems and prospects the following objectives were considered; To estimate the nature and magnitude of genetic variations among the mungbean varieties in respect of different yield and yield contributing characters; To estimate the extent of correlation between pairs of characters at genotypic and phenotypic level; and assess the direct and indirect effect of different characters on yield of mungbean.

Materials and Methods

The present study was performed with 14 varieties of mungbean. The varieties were collected from The Pulse Research Centre of Bangladesh Agricultural Research Institute (BARI), Gazipur, BSMRAU, BINA, Lalmonirhat and Barisal. The name and source of studied varieties are presented in Table 1.

Table 1. Sources of 14 (fourteen) varieties of mungbean

Serial number	Variety name	Source
1	BARI mung1	Pulse Research Centre, BARI
2	BARI mung2	Pulse Research Centre, BARI
3	BARI mung3	Pulse Research Centre, BARI
4	BARI mung4	Pulse Research Centre, BARI
5	BARI mung5	Pulse Research Centre, BARI
6	BARI mung6	Pulse Research Centre, BARI
7	BARI mung7	Pulse Research Centre, BARI
8	BARI mung8	Pulse Research Centre, BARI
9	BU mung1	Department of Agronomy, BSMRAU
10	BINA mung5	Plant Breeding Division, BINA
11	BINA mung8	Plant Breeding Division, BINA
12	BINA mung9	Plant Breeding Division, BINA
13	Chaitamung	Lalmonirhat
14	Sonamung	Barishal

Experimental design

The experiment was laid out in randomized complete block design (RCBD) with three replications. Then it was sub-divided into three blocks where 14 varieties were randomly assigned. The plot size was 2.5m with single line. Row to row distance was 30 cm and plant to plant distance was 10 cm. All the recommended agronomic package of practices was followed (thinning, fertilizer application, irrigation, weeding etc.), as recommended for commercial mungbean production according to BARI.

Data recording and analysis

Ten random plants were selected and recorded based on nine yield contributing characters, viz. plant height, number of leaves/plants, number of branches/plants, number of pods/plants, number of pod clusters/plant, pod length, number of seeds/pods, weight of 1000 seed (g). The analysis of variance for different characters was done by using mean data in order to determine the genetic variability among the varieties as given by Cochran and Cox (1957). The level of significance was tested at 5% and 1% using the F test. Estimation of genotypic and phenotypic variance, heritability, and genetic advance in percent of mean were done according to Comstock and Robinson (1952). Genotypic and phenotypic correlation co-efficient was estimated by the formula given by Singh and Chaudhary (1985). Path coefficient was done by the procedure suggested by Dewey and Lu (1959) using phenotypic correlation coefficient values. For statistical analysis statistix 10 software was used.

Results and Discussion

Mean performance

Analysis of variance showed highly significant differences among varieties for all the traits considered. The LSD test also showed that almost all the varieties were significantly different from each other for all the traits studied (Table 2) The mean performance of fourteen varieties is presented in Table-2. The variety BINA mung5 showed the heights mean performance in number of leaves/plant (13.660), number of pod clusters/plant (7.033), number of seeds/pod (13.667) and yield/plant (g) (6.06). BARI mung7 showed maximum performance for the number of branches/plant (3.773) and yield/plant (5.25) whereas Chaitamung performed the lowest (2.440; 2.22). BARI mung6 performed the highest value in case of pod length (10.567) and weight of 1000 seed (51.667) (Table 2) respectively. So, for selection of the elite variety these characters should give more emphasize.

Table 2. Mean performance of nine characters of 14 (fourteen) varieties of mungbean

varieties	Plant height (cm)	Number of leaves/plants	Number of branches /plants	Number of pods	Number of pods cluster/plant	Pod length(cm)	Number of seeds/pods	Weight of 1000 seed (g)	Yield/plant (g)
BARI mung1	49.300 c	7.553 j	2.777 fg	8.567 g	4.667 d	7.300 f	8.667 hi	27.66f	2.62 h
BARI mung2	48.833 c	8.440 i	2.553 g	8.767 g	5.133 cd	7.367 f	8.333 i	27.333 f	2.52 hi
BARI mung3	53.967 b	10.440 g	3.440 cde	12.913 d	5.600 bcd	8.633 de	9.667 fg	28.333 f	3.84 g
BARI mung4	56.233 a	11.667 ef	3.550 cd	10.303 f	5.533 bcd	8.867 d	10.333 ef	31.000 d	3.94 fg
BARI mung5	45.300 d	12.440 cd	2.660 g	11.417 e	5.333 bcd	10.333 a	11.333 d	40.333 c	4.14 ef
BARI mung6	44.033 de	13.220 ab	3.773 bc	18.327 a	5.667 bcd	10.567 a	12.333 bc	51.667 a	4.85 d
BARI mung7	42.943 ef	12.997 bc	3.773 bc	18.330 a	5.767 bcd	10.333 a	9.333 gh	50.000 b	5.25 c
BARI mung8	41.383 fg	9.773 h	3.440 cde	18.527 a	5.833 bc	8.433 e	10.333 ef	31.667 d	4.95 d
BU mung1	42.403 efg	10.773 g	3.220 de	11.310 e	4.667 d	9.433 bc	11.000 de	29.667 e	4.34 e
BINA mung5	49.187 c	13.660 a	4.110 ab	11.407 e	7.033 a	9.700 b	13.667 a	39.333 c	6.06 a
BINA mung8	41.233 g	12.220 de	4.440 a	15.813 b	5.333 bcd	9.300 c	13.000 ab	30.667 de	6.06 a
BINA mung9	45.257 d	12.333 d	3.107 ef	14.000 c	6.300 ab	8.400 e	11.667 cd	31.000 d	5.55 b
Chaitamung	40.927 g	10.440 g	2.440 g	10.360 f	5.633 bcd	6.467 g	8.333 i	26.000 g	2.22 j
Sonamung	41.703 fg	11.440 f	2.660 g	11.000 e	5.667 bcd	7.567 f	8.333 i	25.667 g	2.32 ij
lsd _{0.05}	1.653	0.612	0.396	0.481	1.145	0.271	0.850	1.169	0.29
Mean	45.907	11.243	3.282	12.931	5.583	8.764	10.452	33.595	4.19
Std Error	0.804	0.2976	0.1927	0.2341	0.5572	0.132	0.4134	0.5688	0.14
Stdv	4.852	1.773	0.632	3.429	0.824	1.243	1.797	8.302	1.32
Minimum	40.927	7.553	2.44	8.567	4.6667	6.467	8.333	25.667	2.22
Maximum	56.233	13.66	4.44	18.527	7.0333	10.567	13.667	51.667	6.06

Coefficients of genotypic and phenotypic variations

In this study phenotypic coefficient of variance (PCV) appeared to be higher than the genotypic coefficient of variance (GCV) in case of all the traits viz. plant height, number of leaves/plant, number of branches/plant, number of pod, number of pods cluster/plant, pod length (cm), number of seeds/pod, weight of 1000 seed (g), yield/plant

(g) which suggested negligible influence of environment on the expression of genes controlling these traits (Table 3). High magnitude of PCV and GCV were found in number of branches/plant (PCV: GCV= 19.671:18.309;), number of pods/plant (27.182: 27.092), number of seeds/pod (17.540: 16.857), Yield/plant (32.48: 32.22), weight of 1000 seed (25.339: 25.254) (Table 3). The result signifies that selection can be applied for these characters will be more helpful to develop elite variety. Makeen *et al* (2007), Rao *et al.* (2006), Pandey *et al.* (2002) also studied about genotypic and phenotypic coefficient of variations in mungbean.

Table 3. Genetic parameters for nine yield and yield contributing characters of mungbean

Serial number	Characters	Phenotypic variance (δ_p^2)	Genotypic variance (δ_g^2)	PCV	GCV	Heritability (h^2b)	GA	GA (%)
1	Plant height (cm)	24.690	23.720	10.824	10.609	96.073	9.834	21.421
2	Number of leaves/plants	3.301	3.168	16.160	15.831	95.977	3.592	31.950
3	Number of branches/plants	0.417	0.361	19.671	18.309	86.636	1.152	35.107
4	Number of pods	12.355	12.273	27.182	27.092	99.335	7.193	55.623
5	Number of pods cluster/plant	0.675	0.209	14.716	8.194	31.007	0.525	9.400
6	Pod length (cm)	1.622	1.596	14.533	14.415	98.389	2.582	29.455
7	Number of seeds/pods	3.361	3.104	17.540	16.857	92.371	3.488	33.375
8	Weight of 1000 seed (g)	72.463	71.978	25.339	25.254	99.331	17.418	51.848
9	Yield/plant (g)	1.85	1.82	32.48	32.22	98.427	2.76	65.85

GCV= Genotypic co-efficient of variation, PCV= Phenotypic coefficient of variation,

GA= Genetic advance, GA (%) = Genetic advance in percent of mean,

δ_g^2 = Genotypic variance, δ_p^2 = Phenotypic variance

Heritability and genetic advance

The high heritability was found in plant height (96.073), number of leaves/plant (95.977), number of branches/plant (86.636), number of pod (99.335), pod length (98.389), number of seeds/pod (92.371), weight of 1000 seed (99.331) and yield/plant (98.427) in Table 3. The assessment of heritability alone fails to indicate the response to selection (Shompa *et al.*, 2020). Therefore, estimation of heritability will be more efficient when it coexists with estimation of genetic advance and the genetic advance as percent of the mean. High heritability combined with high genetic advance is a good index of genotype selection. Here, selection based on the number of branches/plants, number of pods, number of seeds/pods, weight of 1000 seeds (g) and yield/plant (g) will be effective. High heritability and genetic advance in percent of mean were estimated in 1000-seed weight by Sandhu *et al.* (1979). In case of yield/plant, high heritability estimates coupled with high genetic advance were observed by Rao *et al* (2006), Rohman

et al. (2003) and Sharma *et al.* (1999). However, genetic advance for the trait number of pod clusters/plant is low that means it revealed non-additive gene action and low heritability. So selection of varieties considering this trait may not be impactful because the trait exhibits low heritability, indicating heavy influenced by the environmental factors as well as non-additive gene action also complicates the selection efforts (Azam *et al.*, 2018).

Genotypic and phenotypic correlations

The phenotypic and genotypic correlation indicates the degree of association between different characters, which is helpful for selection. In the majority of cases the genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients which indicating strong inherent association between the characters. However, genetic correlation can result from either pleiotropy or linkage or by Falconer, 1996, while phenotypic correlation is a non-additive combination of both genetic and environmental correlations.

In the present investigation the results showed that the number of leaves/plant showed a highly significant positive correlation with number of branches /plant (0.595 and 0.543), number of pods/plant (0.488 and 0.476), number of pods clusters/plant (0.843 and 0.453), pod length (cm) (0.746 and 0.727), number of seeds/pod (0.704 and 0.663), weight of 1000 seed (0.676 and 0.657) and yield/plant (0.697 and 0.662) (Table 4) at both the genotypic and phenotypic levels. These findings were supported by Govindraj (2001), Parameswarappa (2005) reported the grain yield/plant was showed a highly significant positive correlation with plant height, number of branches/plant, number of pods, number of seeds/pod. The number of branches/plant showed a highly significant positive correlation with the number of pods/plant (0.627 and 0.567), pod length/plant (0.655 and 0.612), number of seeds/pod (0.761 and 0.699), weight of 1000 seed (0.481 and 0.445) and yield/plant (0.872 and 0.799). These findings were supported by Gouda (1977), Govindraj (2001), Parameswarappa (2005) reported the grain yield/plant was showed highly significant positive correlation with number of branches/plant, number of pod, number of seed/pod. The number of pods showed highly significant positive correlation with pod length (0.569 and 0.564), number of seeds/pod (0.394 and 0.372), weight of 1000 seed (0.634 and 0.631) and yield/plant (g) (0.658 and 0.653). Makeen *et al.* (2007) evaluated correlations in respect of various desirable characters in 20 genotypes of mungbean and indicated that pods/plant had significantly positive correlation with seed yield.

Table 4. Genotypic (r_g) and phenotypic (r_p) correlation co-efficient among different pairs of yield and yield contributing characters for 14 varieties of mungbean

Characters		Plant height (cm)	Number of leaves/plant	Number of branches /plant	Number of pod	Number of pods cluster/plant	Pod length (cm)	Number of seeds/pod	Weight of 1000 seed (g)
Number of leaves/plant	r_g	-0.163 ^{NS}							
	r_p	-0.156 ^{NS}							
Number of branches /plant	r_g	0.045 ^{NS}	0.595**						
	r_p	0.056 ^{NS}	0.543**						
No of pod	r_g	-0.438**	0.488**	0.627**					
	r_p	-0.431**	0.476**	0.567**					
Number of pods cluster/plant	r_g	0.047 ^{NS}	0.843**	0.523**	0.382*				
	r_p	0.038 ^{NS}	0.453**	0.265 ^{NS}	0.235 ^{NS}				
Pod length (cm)	r_g	-0.021 ^{NS}	0.746**	0.655**	0.569**	0.260 ^{NS}			
	r_p	-0.018 ^{NS}	0.727**	0.612**	0.564**	0.167 ^{NS}			
No of seeds/pod	r_g	-0.049 ^{NS}	0.704**	0.761**	0.394**	0.586**	0.709**		
	r_p	-0.026 ^{NS}	0.663**	0.699**	0.372*	0.353*	0.668**		
Weight of 1000 seed (g)	r_g	-0.123 ^{NS}	0.676**	0.481**	0.634**	0.400**	0.835**	0.457**	
	r_p	-0.121 ^{NS}	0.657**	0.445**	0.631**	0.228 ^{NS}	0.827**	0.436**	
Yield/plant (g)	r_g	-0.116 ^{NS}	0.697**	0.872**	0.658**	0.656**	0.736**	0.878**	0.541**
	r_p	-0.108 ^{NS}	0.662**	0.799**	0.653**	0.405**	0.722**	0.843**	0.537**

* and ** indicate significant at 5% and 1% level of probability and NS indicates non-significant respectability. r_g = genotypic correlation co-efficient, r_p = phenotypic correlation co-efficient

The number of pods cluster/plant showed highly significant positive correlation with Number of seeds/pod (0.586 and 0.353) and yield/plant (g) (0.656 and 0.405) (Table 4) at both genotypic and phenotypic level. Pod length showed a highly significant positive correlation with number of seeds/pod (0.709 and 0.668), weight of 1000 seed (0.835 and 0.827) and yield/plant (0.736 and 0.722) at both genotypic and phenotypic level. The number of seeds/pods showed a highly significant positive correlation with weight of 1000 seed (0.457 and 0.436) and yield/plant (0.878 and 0.843) at both genotypic and phenotypic level. Thousand seed weight showed significant positive correlation with yield/plant (0.541 and 0.537) at both genotypic and phenotypic level. A higher number of pods per plant with longer pod and seed size and diameter directly contributed towards the seed yield. Moreover, high correlation of 100-seed weight and with seed yield also obtained in mungbean mentioned by Anwari and Sochandi (1999); Makeen *et al.* (2007); Tabassum *et al.* (2010). For selection of the best variety the component characters viz. number of pods clusters/plant, number of seeds/pods, weight of 1000 seed are very important.

Path coefficient analysis

In order to find out a clear picture of the interrelationship between yield/plant and other yield attributes, path analysis was done. Direct and indirect effects were worked out using path analysis at the genotypic level which also measured the relative importance of each component. From the present study it was clear that the number of branches/plants

showed positive indirect effect on yield/plant via number of seeds/pod (0.524), number of pod (0.273), number of leaves/plant (0.201), weight of 1000 seed (0.008) and plant height (cm) (0.007) (Table 5). Kritika and Yadav (2017) revealed that, path co-efficient analysis indicated number of pods/plants, number of seeds/pods, biological yield/plot and harvest index had the maximum direct contribution to seed yield and these characters should be given importance while formulating selection criteria for seed yield. Plant height (0.160) and number of branches /plant (0.338) were recorded as having a high positive indirect effect on seed yield via number of pods/plants. The number of pods showed a positive direct effect (0.435) on yield/plant via number of leaves/plant (0.165), number of branches /plant (0.123), number of seeds/pod (0.271) and weight of 1000 seed (0.010). Alom *et al.* (2014) showed that pods/plant contributed the maximum positive direct effects on seed yield. Plant height, pod length and 1000 seed weight had also positive direct effect on seed yield. Thus, selection based on pods/plant, days to first flowering, plant height and 1000 seed weight might be effective for improving seed yield in mungbean. Garje *et al.* (2014) reported that number of pod/plants had the maximum direct effect on seed yield followed by number of cluster/plant and Number of secondary branches/plant. The number of seeds/pods showed positive direct effect (0.689) on yield/plant. Path analysis revealed that number of pod/ plant and 100-seed weight exerted a high magnitude of positive direct effect on seed yield. These results were corroborating with the findings of Rohman *et al.* (2003) and Makeen *et al.* (2007). Weight of 1000 seed showed a positive direct effect (0.016) on yield/plant. Path analysis revealed that number of 1000-seed weight exerted a high magnitude of positive direct effect on seed yield. These results were corroborating with the findings of Rohman *et al.* (2003) and Makeen *et al.* (2007). The residual effect (R) of path co-efficient analysis was noted as 0.10 which indicated that there were also some other characters which although not studied in the present investigation but have an impact on the yield per plant.

Table 5. Path analysis showing direct and indirect effects of different characters on fruit yield of 14 mungbean varieties

Trait	Plant height	Number of leaves/plant	Number of branches /plant	Number of pods/plant	Number of pods cluster/plant	Pod length	Number of seeds/pod	Weight of 1000 seed	Genotypic correlation with yield/plant
Plant height (cm)	0.160	-0.055	0.009	-0.190	-0.011	0.007	-0.034	-0.002	-0.116 ^{NS}
Number of leaves/plant	-0.026	0.338	0.116	0.212	-0.193	-0.247	0.485	0.011	0.697**
Number of branches /plant	0.007	0.201	0.196	0.273	-0.120	-0.217	0.524	0.008	0.872**
Number of pod	-0.070	0.165	0.123	0.435	-0.088	-0.188	0.271	0.010	0.658**
Number of pods cluster/plant	0.008	0.285	0.102	0.166	-0.229	-0.086	0.403	0.006	0.656**
Pod length (cm)	-0.003	0.252	0.128	0.248	-0.060	-0.331	0.488	0.013	0.736**
Number of seeds/pod	-0.008	0.238	0.149	0.171	-0.134	-0.235	0.689	0.007	0.878**
Weight of 1000 seed (g)	-0.020	0.229	0.094	0.276	-0.092	-0.276	0.314	0.016	0.541**

Conclusion

The variation is present among the varieties. The variety BINA mung5 and BINA mung8 could be selected for the number of leaves/plants, number of branches /plants, number of pods cluster/plant, number of seeds/pod and yield/plant as they have strong positive correlation on yield. For future hybridization program, the traits, number of branches /plants, number of pods cluster/plant, number of seeds/pods, weight of 1000 seed (g) will be a good selection index for future breeding program of mungbean.

Author's contribution

Sharmin, S. designed, planned, and executed the experiment and drafted the manuscript; Shompa, B.N. and Parveen, S. edited and reviewed the manuscript; Siddikee, M.A. supervised the experiment, analyzed the data, and edited and reviewed the manuscript.

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IMPACT OF BARI AAM3 MANGO VARIETY ADOPTION ON THE GROWERS' LIVELIHOOD

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Abstract

BARI aam3 is one of the 18 mango varieties that Bangladesh Agricultural Research Institute (BARI) released. It gained popularity throughout the country mainly due to its delightful taste and flavour. The study assessed the impact of BARI aam3 adoption on the growers' livelihood. The research was purposively conducted in Porsha Upazila under Naogaon district and Nachole Upazila under Chapainawabganj district based on the abundance of cultivation of BARI aam3. Data were collected from 111 growers selected following a proportionate random sampling technique. Descriptive statistics and paired t-test were used for data analysis. BARI aam3 growers' access to livelihood capitals increased by 49.4-91.7%. Growers' access to human, social, natural, physical, and financial capitals was increased by 87.5%, 91.7%, 50.7%, 49.4%, and 52.8% respectively, due to the adoption of BARI aam3. They experienced an improvement in their knowledge, access to information, employment generation, decision-making, clothing, health care, attitude, social status, and respect. There was increased involvement in social activities. Increases were also noticed in their forestry/trees, safe drinking water use, leased cultivable land, use of electricity, electronic communication devices, livelihood assets, furniture, agricultural tools, and annual agricultural income after BARI aam3 cultivation. Its cultivation also significantly influenced their increase in participation in income-generating activities.

Keywords: BARI aam3, Livelihood, Natural capital, Physical capital, Social capital.

Introduction

Bangladesh Agricultural Research Institute (BARI) is the largest agricultural research institute in Bangladesh. BARI has generated a good number of crop varieties including fruits for growing at the farm level. Bangladesh is one of the major mango producing countries (Islam *et al.*, 2018). According to BBS (2024) the production of mango in Bangladesh was 14,82,937 MT from 3,06,274 acres area in 2022-23. The production of mango was 3,46,539 MT from 42,412 acres area under garden in Naogaon district and the production of mango was 1,17,354 MT from 66,133 acres area under garden in Chapainawabganj district in 2022-23. Among the 18 mango varieties developed

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by BARI, BARI aam3 (Amrapali) gained notable popularity (Rahman *et al.*, 2022) due to its lovely taste and flavour. This mango variety was developed in 1971. Dr. Pijush Kanti Majumdar developed this mango variety as a hybrid variety of 'Dashehari' and 'Neelum' at the Indian Agriculture Research Institute in Delhi (Uddin, 2012; Wikipedia, 2021). The Amrapali mango variety was later released by Bangladesh Agricultural Research Institute as BARI aam3 in 1996 by introduction (Azad *et al.*, 2020). The fruit is very tasty, very sweet (TSS 23.4%) with a sweet flavour when ripe. The fruit is fibreless, moderately juicy and the flesh is 71.0% of the fruit. BARI aam3 is a late variety with a regular bearing habit. The yield of this variety is 20 MT/ha. The variety is commercially cultivable in all areas of Bangladesh (Uddin, 2012; Azad *et al.*, 2020). Farmers became solvent, and their lives were changed because of BARI aam3 cultivation. It was also observed that their human capital, physical capital, social capital, natural capital and financial capital were increased due to cultivation of BARI aam3 mango variety (Rahman *et al.*, 2019). BARI aam3 was the most adopted variety (57%) among all mango varieties, and 47.5 percent of the total mango production was covered by BARI aam3 (Rahman and Khatun, 2018). A study conducted by Uddin *et al.* (2018) revealed that a large portion (77%) of the farmers adopted this variety due to its sweetness, flavour, and high market demand, followed by BARI aam4 (22.1%) and BARI aam8 (15.9%). Amrapali mango variety is also popular in our neighbouring country India, and about 12 percent of the total mango production was occupied by this variety (Sarkar *et al.*, 2018). Ghosh *et al.* (2024) also observed that the majority of the growers cultivated Amrapali.

BARI, being the largest agricultural research institute in Bangladesh, is involved in formulating policy guidelines for the betterment of farmers. Hence, it was expedient to determine the impact of the research and development activities of BARI on the livelihoods of growers. Few studies have been conducted so far, regarding the impact of the popular mango variety BARI aam3 on growers' livelihoods in certain locations of Bangladesh. Specifically, there were no studies regarding the impact of BARI aam3 on growers' livelihood in Porsha Upazila under Naogaon district, and Nachole Upazila under Chapainawabganj district, located in High Barind Tract, where the areas of mango are expanding rapidly. Therefore, it was important to explore the impact of BARI aam3 adoption on the livelihoods of the growers in those areas.

Methodology

Study area

The study was purposively conducted in Porsha Upazila under Naogaon district and Nachole Upazila under Chapainawabganj district based on the abundance of cultivation of BARI aam3 variety (Rahman and Khatun, 2018; DAE, 2019a; DAE, 2019b; DAE, 2020a; DAE, 2020b; DAE, 2021).

Research design

The population of the study was the growers in the study areas who cultivated BARI aam3 for at least five years.

Sample and sampling technique

The sampling population under study was 589 (472 and 117 in Porsha and Nachole Upazilas, respectively). Among them, 111 growers (89 and 22 in Porsha and Nachole Upazilas, respectively) (19.0% of population) were selected as respondents (Loki *et al.*, 2019) using a proportionate random sampling technique.

Methods and tools of data collection

Data were collected during January to April, 2021 with the aid of a pre-tested interview schedule by the researcher herself through face-to-face interview of the selected growers.

Variables and their measurement

Fifteen selected characteristics of the respondents – age, level of education, family size, farm size, annual income, training experience, extension contact, farming experience, access to credit, off-farm activities, availability of irrigation water, organizational membership, cosmopolitaness, innovativeness and knowledge on mango cultivation were the independent variables of the study. The independent variables were measured following standard procedure.

The impact of BARI aam3 adoption on growers' livelihood was the dependent variable of the study. The impact of BARI aam3 adoption on growers' livelihood was measured in terms of five livelihood capitals namely human capital, social capital, natural capital, physical capital, and financial capital known as asset pentagon (DFID, 2000). The livelihood assets parameters were selected through extensive literature review and pretesting of interview schedule. Necessary correction and modification were made in the interview schedule based on pretest. After correction, the interview schedule was finalized for data collection. The impact was measured by the changes in assets position of the growers before and after the adoption of BARI aam3 and the changes in assets position were measured in nominal scale where increase/improvement was denoted as (2), decrease was denoted as (1) and no change was denoted as zero (0) (Rahman *et al.*, 2019). The changes in participation in income-generating activities were measured in terms of participation in different income-generating activities scores before and after the adoption of BARI aam3. The income-generating activities listed in the instrument were production and marketing of quality seed, fish culture in pond, cattle, goat and poultry rearing, establishing nursery and selling saplings, leasing land/pond for cultivation, tree plantation, homestead gardening, preparation and selling of handicrafts, business, tailoring, labour, service and farm. Each respondent was asked to mention the frequency of his/her extent of participation in different income-generating activities. His/her participation in different income-generating activities score was obtained by adding the weights for his/her responses to all the income-generating activities listed in the instrument. It was measured by assigning scores and the scoring was conducted in the following manner: '3', '2', '1', and '0' were assigned for 'regularly', 'occasionally', 'rarely', and 'not at all' respectively. The basis of categorization of participation in income-generating activities was mean \pm sd. The respondents' observed score of participation in income generating activities before cultivation of BARI aam3 ranged from 0 to 20 and the observed score of participation in income generating activities after

cultivation of BARI aam3 ranged from 3 to 20. The participation in income-generating activities scores before and after the adoption of BARI aam3 were computed, and a comparison between the scores before and after the adoption of technology was assessed by a paired t-test. The research framework of the study has been presented in a schematic diagram (Fig. 1).

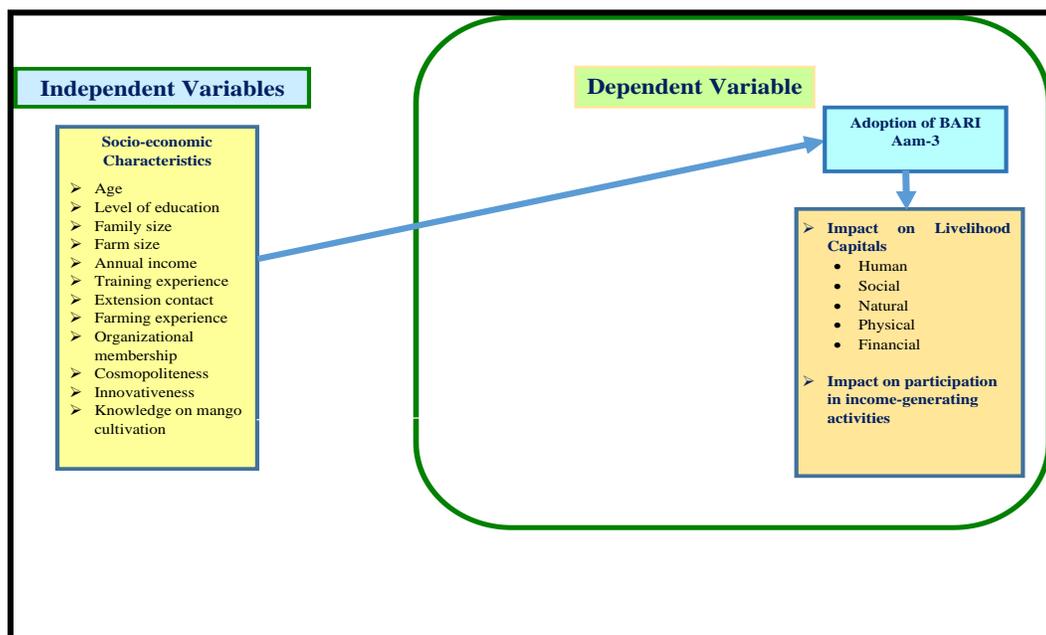


Fig. 1. Research framework of the study

Data analysis

Data were coded, compiled, tabulated, and analyzed according to the objectives of the study using SPSS v20. Descriptive statistical measures like number and percentage distribution, range, mean, standard deviation etc. were used.

Results and Discussion

Socio-economic profiles of the respondents

Table 1 shows that around half (49.5%) of the respondents were middle-aged. Ninety-one percent of them were literate, and the highest percentage (43.2%) of them belonged to the higher secondary education level. The majority of the respondents (45.0%) had small-sized family. More than ninety percent (91.9%) of the respondents had medium to large farms. More than half (53.2%) of them had large farm. The average annual income of the respondents was BDT 766.6 thousand, which was much higher than the national average (BDT 137.8 thousand) (BBS, 2021), and most of them (80.2%) belonged to the medium to low annual income category. About half (43.2%) of the respondents had a medium annual income. About two-fifths (36.0%) of the respondents had high training experience.

Table 1. Socioeconomic profiles of the respondents

Sl#	Characteristics (Measurement unit)	Possible and observed range	Respondents (n=111)		Mean
			Categories	%	
01	Age (Year)	Unknown (24-73)	Young (up to 35)	34.2	40.7
			Middle aged (36-50)	49.5	
			Old (above 50)	16.3	
02	Level of education (years)	Unknown (0-18)	Illiterate (0)	1.0	10.2
			Can sign only (0.5)	8.1	
			Primary (1-5)	10.8	
			Secondary (6-10)	36.9	
03	Family size (Number)	Unknown (2-12)	Higher secondary (>10)	43.2	5.2
			Small (up to 4)	45.0	
			Medium (5-6)	37.0	
04	Farm size (Hectare)	Unknown (0.3-32.8)	Large (above 6)	18.0	4.7
			Small (0.21-1.00)	8.1	
			Medium (1.01-3.00)	38.7	
05	Annual income ('000' Tk.)	Unknown (79-4500)	Large (above 3.00)	53.2	766.6
			Low (up to 353)	37.0	
			Medium (354-1180)	43.2	
06	Training experience (Number of days)	Unknown (0-276)	High (above 1180)	19.8	18.0
			No training (0)	22.6	
			Low (1-5)	29.7	
			Medium (6-10)	11.7	
07	Extension contact (Score)	0 to 72 (10-55)	High (above 10)	36.0	38.9
			Low (up to 28)	18.0	
			Medium (29-50)	70.3	
08	Farming experience (years)	Unknown (5-60)	High (above 50)	11.7	20.8
			Low (up to 9)	16.2	
			Medium (10-32)	65.8	
09	Access to credit	-	High (above 32)	18.0	-
			No	2.7	
10	Off-farm activities	-	Yes	97.3	-
			No	45.0	
11	Availability of irrigation water	-	Yes	55.0	-
			No	10.8	

Sl#	Characteristics (Measurement unit)	Possible and observed range	Respondents (n=111)		Mean
			Categories	%	
12	Organizational membership (Score)	Unknown (0-213)	Low (up to 7)	37.8	22.4
			Medium (8-38)	42.3	
			High (above 38)	19.9	
13	Cosmopolitaness (Score)	0 to 15 (1-15)	Low (up to 8)	18.9	10.6
			Medium (9-14)	75.7	
			High (above 14)	5.4	
14	Innovativeness (Score)	0 to 21 (0-15)	Low (up to 3)	50.5	4.6
			Medium (4-6)	27.9	
			High (above 6)	21.6	
15	Knowledge on mango cultivation (Score)	0 to 30 (16-30)	Low (up to 22)	18.0	25.2
			Moderate (23-28)	68.5	
			High (above 28)	13.5	

The large majority of them (77.4%) received agricultural training, which was an opportunity for the growers in the study area. The highest portion of the respondents (70.3%) had medium extension contact. Most of them (65.8%) had medium farming experience. Most of the respondents (97.3%) had access to credit. More than half (55.0%) of them had some kinds of off-farm activities. Most of the respondents (89.2%) had available irrigation water. The majority of them (42.3%) had medium organizational membership. The majority of the respondents (75.7%) had medium cosmopolitaness. Most of the respondents (78.4%) had low to medium innovativeness. More than half of them (50.5%) had low innovativeness. The majority of them (68.5%) had moderate knowledge of mango cultivation.

Impact of BARI aam3 adoption on growers' livelihood

The overall livelihood status of a grower depends on different types of socio-economic activities of the grower as well as the society in which he lives. In this study, different changes in the livelihood assets position of the respondents were measured before and after the cultivation of BARI aam3. However, the findings related to the impact of BARI aam3 adoption on growers' livelihood have been discussed in the following sections.

Perceived changes in livelihood status

Human capital

The findings presented in Table 2 indicate that 87.5 percent of the respondents' access to human capital was increased after the cultivation of BARI aam3, which represents a good range of improvement in knowledge (100.0%), access to information (99.1%), self-employment generation (98.2%), decision-making (97.3%), employment generation (hired) (93.7%), clothing (91.9%), health care (88.3%), quality of food intake

(84.7%), and dietary diversity (82.9%). It may be because growers had greater access to human capital as a result of being more solvent after BARI aam3 cultivation. However, the lowest percentage (61.3%) of the respondents experienced increase in training. Thirty five percent of the respondents experienced no change in training. The possible explanation could be that those growers did not get the opportunity to get training or had limited access to various training sessions organized by DAE and other organizations. Rahman *et al.* (2019) also observed that the majority of the medium BARI aam3 mango orchard owners (80%) and the majority of the large BARI aam3 mango orchard owners (83.8%) experienced constant change in training. Seventy five percent of the respondents experienced increase in education. Some respondents (15.3%) experienced decrease in education after BARI aam3 cultivation. The reason could be that some of the respondents did not increase their educational expenses for their children due to a lack of necessity. Perhaps their children's education was completed after BARI Aam-3 cultivation. Therefore, their education was decreased after BARI aam3 cultivation. Rahman *et al.* (2019) revealed that some of the small BARI aam3 mango orchard owners (27.3%), some of the medium BARI aam3 mango orchard owners (20%) and some of the large BARI aam3 mango orchard owners (27%) experienced constant change in education.

Table 2. Perceived changes in human capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Health care	88.3	3.6	8.1
Education	74.8	15.3	9.9
Training	61.3	3.6	35.1
Decision-making	97.3	-	2.7
Employment generation (Self)	98.2	0.9	0.9
Employment generation (Hired)	93.7	4.5	1.8
Knowledge	100.0	-	-
Access to information	99.1	-	0.9
Clothing	91.9	3.6	4.5
Nutrition	77.5	0.9	21.6
Dietary diversity	82.9	-	17.1
Quality of food intake	84.7	-	15.3
Average	87.5	2.7	9.8

Sarker *et al.* (2017) observed that lemon farmer's livelihoods were improved to some extent in terms of health care, education, and decision-making ability due to lemon production in Mymensingh district. In another study, it was observed that human capital increased by 54.3, 68.0, and 60.5 percent of the small, medium, and large category farmers, respectively, due to BARI aam3 cultivation. It was also revealed that the large

mango farmers experienced a good range of improvement in health and sanitation (70.3%), education (72.97%) and nutrition (78.4%). The medium type BARI aam3 farmers experienced a cent percent increase in health and sanitation. The small orchard owners experienced increases in education (72.7%) and training (81.8%) (Rahman *et al.*, 2019).

Social capital

The results (Table 3) indicate that 91.7 percent of the respondents' access to social capital was increased after BARI aam3 cultivation. This includes improvement in attitude (99.1%), social status and respect (99.1%), involvement in social activities (99.1%), social prestige (98.2%), cooperation from others (98.2%), management (98.2%), networking (96.4%), and leadership roles (92.8%). It could be because the growers' increased income from BARI aam3 made them more solvent than they had been previously, which in turn made them more socially acceptable. In a research, it was observed that social capital was increased by 28.5, 43.0, and 46.0 percent for small, medium, and large farmers, respectively, due to BARI aam3 cultivation (Rahman *et al.*, 2019). Farmers' livelihoods were found to be improved in term of social networks due to their engagement in lemon production (Sarker *et al.*, 2017). However, the lowest percentage (51.4%) of the respondents experienced increase in organizational participation. About half (46.8%) of the respondents experienced no change in organizational participation. The reason could be that those growers did not get any opportunity to enhance their organizational participation or had no organizational participation at all.

Table 3. Perceived changes in social capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Organizational participation	51.4	1.8	46.8
Networking	96.4	-	3.6
Social prestige	98.2	-	1.8
Attitude	99.1	-	0.9
Social status and respect	99.1	-	0.9
Involvement in social activities	99.1	-	0.9
Cooperation from others	98.2	-	1.8
Leadership roles	92.8	-	7.2
Management	98.2	-	1.8
Women empowerment	84.7	-	15.3
Average	91.7	0.2	8.1

Natural capital

Table 4 indicates that 50.7 percent of the respondents' access to natural capital was increased after BARI aam3 cultivation. Their forestry/trees (98.2%), safe drinking water (73.9%), leased cultivable land (55.0%), and availability of irrigation water (54.1%) were increased or improved more compared to other natural capital. This could be attributed to higher earnings from BARI aam3 and improved financial stability. About half (48.4%) of the respondents experienced no change in different types of natural capital. Majority of the respondents experienced no change in their homestead land (80.2%), pond (79.3%), and own cultivable land (65.8%).

Table 4. Perceived changes in the natural capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Own cultivable land	33.3	0.9	65.8
Leased cultivable land	55.0	0.9	44.1
Homestead land	19.8	-	80.2
Pond	20.7	-	79.3
Availability of irrigation water	54.1	3.6	42.3
Safe drinking water	73.9	-	26.1
Forestry/trees	98.2	0.9	0.9
Average	50.7	0.9	48.4

This may be attributed to the fact that the natural capital of the growers, such as homestead land, own cultivable land, ponds, etc., typically remains unchanged. The possession of one's own land, pond, etc., is usually fixed. They either inherited those assets from their parents or acquired them through limited purchases. Perhaps, therefore, a considerable portion of the respondents experienced no change in their natural capital. In a study, it was observed that natural capital was increased by 13.7, 33.3, and 33.3 percent for small, medium, and large farmers, respectively, due to the cultivation of BARI aam3. Some of the small farmers (25.8%) experienced constant change in natural capital. About half (45.5%) of the small farmers experienced constant change in pond (Rahman *et al.*, 2019). Farmers' livelihoods were improved in terms of access to land due to their involvement with lemon production (Sarker *et al.*, 2017).

Physical capital

The results presented in Table 5 indicate that 49.4 percent of the respondents' access to physical capital was increased after BARI Aam-3 cultivation. They experienced more increases or improvement in electricity use (93.7%), digital/electronic communication devices (82.0%), livelihood assets (74.8%), furniture (72.1%), agricultural tools (68.5%), toilet (53.2%), housing condition (52.3%), and personal vehicles (51.4%) compared to other physical capital. It is possible that the growers'

increased income from BARI aam3 made them more solvent than before, leading to more access to physical capital. About half (46.1%) of them experienced no change in different types of physical capital. The lack of change in the growers' housing condition, toilet, furniture, agricultural tools, cattle, poultry, personal vehicles, and livelihood materials like refrigerators, tube wells, etc., after BARI aam3 cultivation may be attributed to their perceived lack of necessity for upgrades or improvements of those. They had enough physical capital in suitable condition before BARI Aam-3 cultivation. After cultivation of this variety, they did not need to increase or improve those. Some of the respondents experienced a decrease in different types of physical capital, especially in agricultural tools (7.2%), jewelry (3.6%), and living assets like cattle (27.0%) and poultry (14.4%). Perhaps they were more involved in mango and crop cultivation and might not have had enough time for livestock rearing. Therefore, they sold their livestock, and thus their livestock decreased. Perhaps the respondents sold their jewelry for different purposes or gifted those to their daughters. They may have also sold their agricultural tools for different purposes.

Table 5. Perceived changes in the physical capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Housing condition	52.3	-	47.7
Toilet	53.2	-	46.8
Furniture	72.1	0.9	27.0
Agricultural tools	68.5	7.2	24.3
Cattle	42.3	27.0	30.6
Poultry	33.3	14.4	52.3
Personal vehicles	51.4	0.9	47.7
Digital/electronic communication devices	82.0	1.8	16.2
Livelihood assets	74.8	0.9	24.3
Jewelry	43.2	3.6	53.2
Electricity use	93.7	0.9	5.4
Shop	11.7	2.7	85.6
Market	3.6	0.9	95.5
Cattle/poultry farm	9.9	0.9	89.2
Average	49.4	4.4	46.1

Rahman *et al.* (2019) observed that BARI aam3 growers' physical capital was increased by 48.2, 58.0, and 50.0 percent for small, medium, and large farmers, respectively. Farmers also experienced improvement in household condition and access to safe drinking water, i.e., the presence of a tube well, electricity, and a sanitary toilet. Some small (10%) and medium (10%) farmers experienced constant change in their physical capital. Some small (18.2%), medium (20%), and large (43.2%) BARI aam3 farmers also experienced decrease in livestock. Sarker *et al.* (2017) found that farmers' livelihoods were improved in terms of well house due to getting engaged with lemon production. Most of the lemon growers (58.0%) were self-employed and had improved housing accommodation, sanitation, and better physical assets.

Financial capital

The results (Table 6) indicate that 52.8 percent of respondents' access to financial capital was increased after BARI aam3 cultivation. The majority of them experienced increases in annual agricultural income (97.3%), cash in hand (84.7%), and savings (55.0%) compared to other financial capital. The potential reason could be that the greater economic returns from BARI aam3 assisted the growers to increase their financial capital. About half (43.1%) of them experienced no change in different types of financial capital. The reason many growers reported no change in remittances from household members working outside the area (98.2%), annual non-agricultural income (50.5%), and business investment (50.5%) could be that they did not have any source of getting remittance or any means to earn non-agricultural income or invest in businesses. Perhaps some growers did not experience any change in their non-agricultural income because they had a small-scale non-agricultural income source. Some respondents also experienced decrease in annual non-agricultural income (6.3%), cash in hand (5.4%), savings (5.4%), and business investment (5.4%). The reason could be that they lacked a source of non-agricultural income after BARI Aam-3 cultivation for different reasons. Their cash in hand, savings and investment in business might have reduced after BARI aam3 cultivation due to their different socio-economic conditions. The cash in hand and savings usually fluctuate over time. Perhaps they experienced loss in mango cultivation, therefore, their cash in hand and savings decreased. Perhaps other social and economic factors might have had an influence on their decrease in cash in hand and savings. Rahman *et al.* (2019) revealed that financial capital increased by 20.5, 60.0, and 44.6 percent for small, medium, and large farmers, respectively, due to BARI aam3 cultivation. It was also observed in their study that the cash in hand increased by 36.4, 100.0, and 78.4 percent for small, medium, and large mango orchard owners, respectively. Their income and, thereby, their savings were also increased. Some large BARI aam3 mango orchard owners (24.3%) also experienced constant change in their financial capital. The majority of the small BARI aam3 orchard owners (63.6%) experienced decrease in cash in hand. The majority of the small BARI Aam-3 orchard owners (81.8%) and medium BARI aam3 orchard owners (60%) experienced decrease in bank/savings.

Table 6. Perceived changes in the financial capital of respondents

Livelihood Assets	Degree of change		
	Increased/ Improved (%)	Decreased (%)	No change (%)
Annual agricultural income	97.3	2.7	-
Annual non-agricultural income	43.2	6.3	50.5
Cash in hand	84.7	5.4	9.9
Savings	55.0	5.4	39.6
Business investment	44.1	5.4	50.5
Remittances from household members working outside the area	1.8	-	98.2
Average	52.8	4.1	43.1

However, all (100.0%) of the mango farmers mentioned that mango production was profitable in Dinajpur district (Alam *et al.*, 2017). Farmers' livelihoods were improved in terms of income and savings patterns due to lemon production. The financial assets of lemon producers increased gradually (Sarker *et al.*, 2017). Commercial pulse production increased the household farm income of the pulse farmers in rural China (Jiliang *et al.*, 2022). Cash crop cultivation had a positive and significant impact on household income. Their farm income was significantly increased due to cash crop cultivation (Meng *et al.*, 2020).

Changes in participation in income-generating activities

The respondents' observed score of participation in income-generating activities before cultivation of BARI aam3 ranged from 0 to 20 with an average score of 7.6 and the observed score of participation in income-generating activities after cultivation of BARI aam3 ranged from 3 to 20 with an average score of 12.0. Findings presented in Table 7 indicate that the majority of the respondents had medium participation in income-generating activities before and after the cultivation of BARI aam3. The respondents' average score of participation in income generating activities after cultivation of BARI aam3 was higher than the average score of participation in income generating activities before cultivation of BARI aam3, and the change was significant at the 1.0% level of probability. It can be concluded that BARI aam3 cultivation significantly influenced on the respondents' increase in participation in income generating activities.

Table 7. Changes in participation in income generating activities of the respondents after cultivation of BARI aam3

Category	Before			Category	After			% Change	t-value (df=110)
	No.	%	Mean		No.	%	Mean		
Low (up to 4)	23	20.7		Low (up to 8)	16	14.4			
Medium (5-11)	66	59.5	7.6	Medium (9-16)	79	71.2	12.0	57.9	10.724**
High (>11)	22	19.8		High (>16)	16	14.4			

** Significant at 0.01 level

Conclusion

The respondent growers experienced a remarkable improvement in all of their livelihood assets due to the adoption of BARI aam3 mango variety. This improvement might be due to the increase of their household income. However, the highest improvement was observed in the social capital and the lowest improvement was observed in the physical capital. The growers experienced increases or improvement in knowledge, access to information, employment generation, decision-making, clothing, health care, quality of food intake, and dietary diversity after BARI aam3 cultivation. They also experienced improvement in attitude, social status and respect, involvement in social activities, social prestige, cooperation from others, management, networking, and leadership roles. Their forestry/trees, safe drinking water use, leased cultivable land, and availability of irrigation water were increased after BARI aam3 cultivation. Additionally, they noted increases or improvements in electricity use, digital/electronic communication devices, livelihood assets, furniture, agricultural tools, toilet, housing condition, and personal vehicles. The majority of growers reported an increase in annual agricultural income, cash in hand, and savings after BARI aam3 cultivation. BARI aam3 cultivation also significantly influenced the respondents' increase in participation in income-generating activities. BARI, Horticulture Wing of Department of Agricultural Extension (DAE), and Bangladesh Agricultural Development Corporation (BADC) may collaborate to raise and distribute saplings of BARI aam3 and organize campaigns to plant and maintain orchards of BARI aam3 in large scale to ensure availability of this delicious mango variety to consumers. The concerned authorities may also take necessary steps to bring the suitable fallow lands of Barind Tract, hill districts and other areas under cultivation of BARI aam3. The concerned authorities may encourage contract farming for exporting BARI aam3 to the overseas ethnic markets.

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Authors' contribution

The research was a collaborative effort by S. T. Jannat, M. S. I. Afrad, M. E. Haque, S. S. Hasan, and N. A. Ivy, who worked together on the conception, planning, design, and methodology aspects of the research. Data collection and analysis were carried out by S. T. Jannat. The interpretation of the results was a joint effort by S. T. Jannat, M. S. I. Afrad, M. E. Haque, and S. S. Hasan. All authors made more or less equal contributions to the manuscript writing.

Conflicts of interest

There are no conflicts of interest regarding the publication of this paper.

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