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Strategic Variety and Seedling Management for Enhancing Rice Productivity in Coastal Saline Ecosystem

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Abstract

Climate change accelerated the intensity and frequency of occurrences of salinity in the coastal region of Bangladesh. Increasing soil salinity is one of the major limiting factors that negatively affect rice yields. The adoption of salt-tolerant inbred and hybrid rice varieties and a higher adaptive capacity for seedling management options can enhance rice productivity and profitability. To enhance productivity and profitability, on-farm experiments were conducted over two years in coastal saline soils using a Randomized Complete Block Design with four replications. The study evaluated salt-tolerant and salt-sensitive inbred and hybrid rice varieties under two seedling management options: recommended seedlings at standard density versus older seedlings at a higher planting density. The agronomic results revealed that adopting salt-tolerant varieties significantly increased grain yields compared to salt-sensitive varieties. Furthermore, combining salt-tolerant inbred or hybrid varieties with older seedlings at a higher planting density maximized crop productivity. Multi-location validation trials confirmed that this integrated crop management package yielded a higher gross margin across diverse production environments. This technological package can be promoted in the rice-rice and rice-fish (*ghers*) farming systems to boost climate resilience. However, prior to large-scale regional dissemination, this package of salt-tolerant varieties and optimized seedling management should be systematically evaluated across diverse saline soil gradients to ensure stable, widespread performance.

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Introduction

The dry season irrigated rice (boro) occupies about 23 million ha (M ha) in South Asia, of which 20.7% is in Bangladesh. It plays an important role in food security and is a source of employment, income, and livelihoods for hundreds of millions of rural and urban poor (BBS, 2021). Boro occupied about 42% of the rice area and contributed about 54% in production, which enabled Bangladesh to achieve rice self-sufficiency (BBS, 2021). For the rice requirement of the predicted 210M population in 2050, Bangladesh will require more than 47 Mt of rice from a decreasing rice-production land area (Kabir *et al.*, 2021; BRRI, 2023). However, maintaining the current surplus of rice in the coming decades is a great challenge because of increasing population, decreasing resources, and increasing climate vulnerability (Akter *et al.*, 2025). Besides this, the Bangladesh Government is committed to achieving the SDGs by 2030, which includes doubling crop productivity. There is no alternative other than expanding rice areas with higher productivity, i.e., Boro areas in the stressed ecosystem, such as saline areas, while reducing their environmental impacts.

More than 1,381 M ha of land throughout the world are salt-affected, representing 10.7% of global land area (FAO, 2024), of which a substantial proportion comprises irrigated agricultural lands. The coastal saline soils of Bangladesh affected by varying degrees of salinity increased from 0.83 M ha to 1.09 M ha in recent years and are expected to increase further due to climate change (SRDI, 2012; Islam *et al.*, 2021). Agricultural land use in this area is poor, which is 103–181% whereas the country's average is 200%. Soil salinity is one of the major constraints affecting rice production worldwide, especially in the coastal area (Ismail and Thomson, 2022; Sánchez-García *et al.*, 2023). Salt-affected soil causes reduced plant growth, development, and productivity worldwide due to a lack of availability of water, nutrients, and oxygen in the root zone (Isayenkov and Maathuis, 2019; Mukhopadhyay *et al.*, 2021). As a salt-sensitive crop, the magnitude of rice yield reduction depends on rice variety, soil type, and crop management (Zheng *et al.*, 2023; Liu *et al.*, 2023). Rice varieties differ in their susceptibility to salinity due to their physiological mechanism to adjust to osmotic pressure (Chen *et al.*, 2021; Reddy *et al.*, 2022). The reduction in rice grain yield under saline conditions can range from 30 to 64% depending on stress intensity, and can be ameliorated through crop management and the use of salt-tolerant varieties (Zheng *et al.*, 2023; Ismail and Thomson, 2022). Plant vigour is one of the major determinants of salt tolerance in rice, which can help avoid the toxic effects of salinity at early growth stages (Korres et al., 2022). Inbuilt vigour in hybrid rice makes the plant more vigorous in the vegetative phase, which is most desirable to increase the production capacity of rice under saline conditions (Huang et al., 2023). Hybrid rice can produce a similar or higher grain yield than that of salt-tolerant inbred rice in a saline environment (Sheng et al., 2023).

The use of aged seedlings might withstand and produce more effective tillers in the saline environment, which is a challenge for younger seedlings (Ling *et al.*, 2024). Again, an increase in plant population can produce higher grain yields in saline soil (Lee et al., 2023). However, studies are lacking with packages of options including salt-tolerant, hybrid rice varieties, seedling age, and density in the diverse saline environment with a view to increased productivity.

Therefore, the study was conducted to determine whether the packaging of salt-tolerant and hybrid rice with older seedlings and greater seedling density was comparable in yield and profitability to younger seedlings and lower seedling density in saline soil.

Materials and Methods

Experimental Sites and Seasons

Two on-farm participatory experiments were conducted at the farmers' rice field in two consecutive winter seasons (known as the Boro season) during 2019–22. Experiment 1 was conducted at Marka village in Kaligonj Upazila (sub-district), Satkhira district (22.48° N and 89.01° E) in Bangladesh during 2019-2021. The results of experiment 1 were validated in boro rice under the rice-rice or rice-fallow cropping system in the rice fields of Daulatpur (22.70° N and 89.04° E), Marka (22.49° N and 89.03° E), and Sreefalkathi (22.28° N and 89.13° E), villages under Satkhira Sadar, Kaligonj, and Shaymnagar Upazilas, respectively, in the same district during 2021-22 (experiment 2). The validation was also done in the *ghers* of Daulatpur (22.70◦ N and 89.04° E) and Shibpur (22.52° N and 89.02° E), villages under Satkhira Sadar and Kaligonj Upazilas. Gher farming is considered a method of combining aquaculture and agriculture on one plot. The *gher* is an enclosure made for shrimp cultivation by modifying rice fields through building higher dykes around the field and excavating a canal 1 to 2 m deep inside the periphery to retain water during the dry season. During the rainy season, the whole plot is used for shrimp and fish cultivation, whereas the trenches are used for shrimp and fish cultivation and the central plot for rice in the dry season. The experimental sites belong to the Ganges Tidal Flood Plain agro-ecological zone. The climate of the area is subtropical, with an average annual rainfall of 1710 mm and a peak in July and August, a minimum mean temperature of 12.5 ˚C in January, and a maximum mean temperature of 35.5 ˚C in April and May.

The soils of the experimental fields of experiment 1 at 0–15 cm depth were clay loam in texture, pH of 7.65 (1:2.5 with water), organic C of 12.4 g/kg), total N of 1.1 g/kg, available P of 30 mg/kg, exchangeable K of 0.36 mmol/kg, available S of 33 mg/kg and extractable Zn of 0.87 mg/kg. The texture of the experiment fields of experiment 2 was clay loam with a pH of 7.4–7.7, organic C of 9.2-11.2 g/kg, total N of 0.9–1.1 g/kg, available P of 23.9–39.6 mg/kg, exchangeable K of 0.4–0.8 m mol/kg, available S of 16.6-26.5 mg/kg and extractable Zn of 1.0–1.1 mg/kg.

Experimental Design and Treatments

Both experiments tested Boro rice varieties and seedling management options, i.e., recommended younger seedlings with lower density and older seedlings with higher density. The details of the treatments have been presented in Table 1. The experiments were set in the farmers' fields in a randomized complete block design with four replications. Recommended seedling density, i.e., 2-3 seedlings/hill for high yielding variety (HYV) and 1-2 seedling/hill for hybrid variety (HV); 5-6 seedlings/hill in HYV and 2-3 in HV as a higher seedling density, was used in the package of treatments. The row-to-row and plant-to-plant distances were maintained at 20 cm x 20 cm. In experiment 2, the treatments were the same as experiment 1 except BRRI dhan61, and a newly released, higher salt-tolerant, and better grain quality variety, BRRI dhan67, was used (Akter et al., 2025; Ahmed et al., 2024).

Table 1. Boro rice varieties, seedling age and density used in Experiments 1 and 2.

Expt.	Year	Treatment ID	Variety	Seedling age (day)	Seedling density (no./m^2)
1	2019-20 (Y1) and 2020-21 (Y2)	STV1YSLD	Binadhan-10	35	50-75
		STV1OSHD	Binadhan-10	45	125-150
		STV2YSLD	BRRI dhan61	35	50-75
		STV2OSHD	BRRI dhan61	45	125-150
		HVYSLD[5]	BRRI hybriddhan3	30	25-50
		HVOSHD	BRRI hybriddhan3	40	50-75
		SCVYSLD	BRRI dhan28	35	50-75

Expt.	Year	Treatment ID	Variety	Seedling age (day)	Seedling density (no./m^2)
		SCVOSHD	BRRI dhan28	45	125-150
2	2021-22	STV1YSLD	BRRI dhan67	35	50-75
		STV1OSHD	BRRI dhan67	45	125-150
		STV2YSLD	Binadhan-10	35	50-75
		STV2OSHD	Binadhan-10	45	125-150
		HVYSLD	BRRI hybriddhan3	30	25-50
		HVOSHD	BRRI hybriddhan3	40	50-75

STV1YSLD = Salt tolerant variety 1, younger seedling, low seedling density; STV1OSHD = Salt tolerant variety 1, older seedling, high seedling density; STV2YSLD = Salt tolerant variety 2, younger seedling, low seedling density; STV2OSHD = Salt tolerant variety 2, older seedling, high seedling density; HVYSLD = Hybrid variety, younger seedling, low seedling density; HVOSHD = Hybrid variety, older seedling, high seedling density; SCVYSLD = Susceptible check variety, younger seedling, low seedling density; SCVOSHD = Susceptible check variety, older seedling, high seedling density

Crop Establishment and Management

Seedlings were raised and transplanted as per treatment, and crop management practices were applied as recommended by BRRI (2019). The plots were irrigated with water from a shallow tube well except Shaymnagar, where irrigation was provided by pumping water from the nearby canal using a 4 HP pump and plastic delivery pipe.

Sampling and data collection

The electrical conductivity (EC) of irrigation water was measured at source from the day of transplanting to physiological maturity. The EC of the topsoil (0-15 cm) was measured in each unit plot of all experimental sites using a 1:5 soil: water suspension (EC 1:5) and was converted to soil saturation extract EC (ECse) by multiplying by conversion factors of 10 for clay loam and 9 for light clay soil following the method of Watling (2007).

The number of days from seeding in the seedbed to physiological maturity is defined as growth duration. Yield-contributing characters (number of panicles/m^2, grains/panicle and 1000-grain weight) were recorded at harvest from a sample of 12 hills (0.48 m^2). Grain yields were determined from an area of 15 m^2 comprising three samples of 5 m^2 each. The grains were threshed, and grain moisture was determined immediately after weighing. The grain yield of rice was reported at 140 g water content per kg.

Farm gate grain and straw prices were recorded for different treatment combinations and were compared on a total variable cost (TVC), gross return, and gross margin. The TVC was calculated by taking into account the costs of all inputs. Gross return was calculated by multiplying the amount of grain by its corresponding price at harvest, plus straw yield multiplying by its corresponding price of straw. The gross margin was computed by subtracting the total variable cost from the gross return.

Statistical Analysis

All the data on growth duration, yield, and yield components of rice were analysed with the CROPSTAT 7.2 version. The least significant difference (LSD) was used at $P<0.05$ to test the differences among the treatment means. Unless indicated otherwise, differences were considered significant only at $P \leq 0.05$.

Results and Discussion

Irrigation Water and Soil Salinity

The EC of the irrigation water applied to the rice field during the transplanting to grain filling (dough) stages of experiment 1 ranged from 1.73 to 2.89 dS/m. In the case of experiment 2, irrigation water salinity was 1.65 and 1.73 dS/m at transplanting in *ghers* of Daulatpur and Shibpur, which were gone up to 1.96 and 2.08 dS/m, respectively, at grain filling stage. On the other hand, among the sites of rice fields, irrigation water salinity ranged from 1.42 to 1.98, 2.31 to 3.00, and 2.18 to 2.99 dS/m at Daulatpur, Marka, and Sreefalkathi sites, respectively. The soil salinity did not vary among the treatments during the crop period but varied in experimental years (Table 2). In experiment 2, both in *gher* and rice fields, all the treatment combinations faced a similar salinity. Between the two *gher* locations, the soil salinity of Shibpur was significantly higher at all the stages of rice than those of Daulatpur (Table 3). Among the sites of rice fields, the soil salinity followed the trends of Shreefalkathi > Marka > Daulatpur at all the stages of rice (Table 4).

Table 2. Electrical conductivity of the soils of treatment plots at different dates after transplanting (Experiment 1).

Treatment/Year	Electrical conductivity (dS/m)					
	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
Treatment (T)[1]						
STV1YSLD	3.32	3.58	4.26	4.37	4.46	4.86
STV1OSHD	3.60	3.84	4.53	4.30	4.53	4.98
STV2YSLD	3.53	3.74	4.39	4.29	4.46	4.91
STV2OSHD	3.43	3.68	4.36	4.33	4.45	4.90
HVYSLD	3.57	3.82	4.51	4.36	4.53	4.97
HVOSHD	3.37	3.58	3.28	4.15	4.38	4.83

Treatment/Year	Electrical conductivity (dS/m)					
	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT
SCVYSLD	3.58	3.83	4.48	4.46	4.43	4.88
SCVOSHD	3.62	3.87	4.56	4.45	4.58	5.03
LSD $_{0.05}$ (T)	ns	ns	ns	ns	ns	ns
Year (Y)						
Y1	3.59	3.81	4.48	4.26	4.35	4.78
Y2	3.42	3.68	4.36	4.42	4.60	5.05
LSD $_{0.05}$(Y)	0.14	0.12	0.11	012	0.10	0.10
LSD $_{0.05}$ (TxY)	ns	ns	ns	ns	ns	ns

[1]Refer to Table 1 for details of variety and seedling management option, ns = no significant differences at 5% level of probability, DAT = days after transplanting

Table 3. Electrical conductivity of soil at different days after transplanting of rice in *ghers* as affected by variety and seedling management options (Experiment 2).

Treatment/ Location	Electrical conductivity (dS/m)							
	0 DAT	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT
Treatment (T)[1]								
STV1YSLD	1.87	2.02	2.36	2.70	3.11	3.43	3.79	4.30
STV1OSHD	1.86	2.00	2.32	2.67	3.21	3.46	3.85	4.45
STV2YSLD	1.86	2.03	2.34	2.66	3.06	3.48	3.85	4.44
STV2OSHD	1.83	1.99	2.27	2.66	3.15	3.45	3.88	4.48
HVYSLD	1.85	2.04	2.32	2.68	3.08	3.45	3.88	4.49
HVOSHD	1.84	2.01	2.35	2.74	3.15	3.51	3.97	4.48
LSD $_{0.05}$ (T)	ns	ns	ns	ns	ns	ns	ns	ns
Location (L)								
Daulatpur	1.31	1.39	1.54	1.87	2.80	3.02	3.25	3.58
Shibpur	2.40	2.64	3.11	3.50	3.45	3.90	4.49	5.29
LSD $_{0.05}$ (L)	0.02	0.04	0.06	0.06	0.08	0.07	0.08	0.10
LSD $_{0.05}$ (Tx L)	ns	ns	ns	ns	ns	ns	ns	ns

[1]Refer to Table 1 for details of variety and seedling management option; ns = no significant differences at 5% level of probability; DAT = days after transplanting

Table 4. Electrical conductivity of soil at different days after transplanting of rice in rice fields as affected by variety and seedling management options (Experiment 2).

Treatment/ Location	Electrical conductivity (dS/m)							
	0 DAT	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT
Treatment (T)[1]								
STV1YSLD	2.94	3.21	3.54	5.05	4.56	4.56	4.91	5.16
STV1OSHD	2.97	3.24	3.55	5.03	4.61	4.60	4.93	5.23
STV2YSLD	2.95	3.22	3.53	5.05	4.56	4.59	4.91	5.22
STV2OSHD	2.97	3.25	3.56	5.06	4.89	4.60	5.00	5.22
HVYSLD	2.97	3.24	3.52	5.06	4.56	4.60	4.97	5.29
HVOSHD	2.98	3.27	3.50	4.98	4.57	4.61	4.97	5.20
$LSD_{0.05}$ (T)	ns	ns	ns	ns	ns	ns	ns	ns
Location (L)								
Daulatpur	1.59	1.79	1.93	2.18	3.32	2.94	2.98	3.04
Marka	2.87	3.24	3.72	4.15	4.32	4.62	5.41	5.93
Sreefalkathi	4.43	4.68	4.95	8.79	6.09	6.23	6.46	6.69
$LSD_{0.05}$(L)	0.04	0.04	0.05	0.15	0.04	0.07	0.14	0.09
$LSD_{0.05}$ (Tx L)	ns	ns	ns	ns	ns	ns	ns	ns

[1] Refer to Table 1 for details of variety and seedling management option, ns = no significant differences at 5% level of probability; DAT= days after transplanting

Growth Duration

Irrespective of variety, growth duration decreased significantly by 4-5 days at older seedlings with high density compared to younger seedlings at lower density in experiment 1. Growth duration of rice was 4 days more in Y2 than that of Y1. In experiment 2, irrespective of varieties, growth duration was decreased by 4-5 days in older seedlings with higher density (139-142 days) compared to younger seedlings with lower density (135-137 days) in *ghers* while it was 3-5 days (138-143 vs. 133-140 days) in rice fields. Growth duration was higher in Shibpur (140 days) compared to Daulatpur (137 days) in *ghers,* whereas in rice fields, the trend was Shreefalkathi (141 days) > Marka (138 days) > Daulatpur (136 days).

Growth duration is a genetical character that varies from variety to variety. In the climate-vulnerable salt-stressed area, the shorter duration variety is preferable as it takes less irrigation water, which is a crisis in the area. Moreover, the earlier harvest has a chance to avoid the tidal storm at the maturity stage of Boro rice. The crop management option, such as older seedlings with high density, shortened the growth duration of rice by 4 to 5 days in experiment 1. This is explained by the faster establishment of older seedlings at higher density in the saline environment compared to younger seedlings at lower density. The growth duration varied from year to year due to the occurrence of rainfall that resulted in variation in soil salinity. Growth duration varied in the different locations for differences in salinity gradient. The higher saline sites increased the growth duration both in *ghers* and rice fields in Ext. 2. The higher growth duration was explained by higher soil salinity in different locations and the less rainfall occurring year. Several studies have reported that salinity delays reproductive growth and extends crop duration; under saline conditions of 4–12 dS m^{-1}, physiological maturity of rice is delayed because of impaired pollination and slowed grain filling (Zheng et al., 2023; Liu et al., 2023). In a greenhouse study at 4.4 and 8.2 dS m^{-1} EC, the reproductive growth was delayed by salinity in all genotypes and anthesis was further delayed at the highest salt level (Ismail and Thomson, 2022). The findings of the field experiments in diverse saline soils were in agreement with this finding

Yield and Yield Components

All the tested varieties with older seedlings at higher density produced significantly higher grain yield than the younger seedling at a lower density in expt. 1 (Table 5). The highest grain yield was produced by BRRI hybrid dhan3 with older seedlings at higher density, significantly followed by the same variety with younger seedlings at lower density and Binadhan-10 with older seedlings and higher density. The higher grain yield was recorded in Y1 than that of Y2. Straw yield followed the same trend as grain yield, though there was no significant difference between the seedling management options except Binadhan-10. Older seedlings with higher density tended to produce higher panicle density. Irrespective of seedling management options, salt-tolerant varieties produced higher panicle density. On the other hand, hybrid rice produced higher-filled spikelet panicle^{-1}. BRRI hybrid dhan3 and Binadhan-10 produced heavier grain. The salt sensitive variety showed inferior performance in all the yield components. Panicle density and filled spikelet panicle^{-1} significantly reduced in Y2 compared to Y1.

The response and adaptation of rice to salt stress is a complex process. The salt-tolerant variety tended to have a higher panicle density, and the hybrid variety had a higher filled spikelet panicle^{-1}. However, the 100-grain weight of the salt-tolerant varieties Binadhan-10 and BRRI hybriddhan3 was similar but higher than other varieties. The older seedlings at higher density produced higher panicle density, and filled spikelet panicle^{-1} might be due to higher main stem and primary tiller production. Combining salt-tolerant varieties with older seedlings and higher seedling density resulted in higher panicle density and filled spikelets panicle^{-1} in different levels of salinity sites of *ghers* and rice fields. A similar trend was also observed for yearly variation of soil salinity due to variation in rainfall during the cropping season.

The varieties that can be established faster can produce higher panicle density and filled spikelet/panicle, and having a higher or similar individual grain weight results in a higher grain yield in a saline environment. Several recent studies have documented that salt-tolerant varieties can enhance grain yield by 1.0–1.5 t ha^{-1} over susceptible varieties under moderate salinity stress in coastal soils (Ahmed et al., 2024; Akter et al., 2025). Rashid and Nasrin (2014) reported higher grain yield in salt-tolerant rice varieties in saline fields. In saline-sodic soil, increasing seedling density from 3–5 to 9 seedlings $hill^{-1}$ produced significantly higher grain yield due to the tolerance of main stems to salinity and alkalinity compared with sub-tillers (Wang et al., 2010). Under saline conditions, older seedlings are better established and can compensate for the reduced tiller number by producing higher main-stem panicle density (Ling et al., 2024; Lee et al., 2023). Higher plant populations in saline environments have been found to produce higher panicle numbers and filled spikelets per panicle, as well as compensation for unfilled tillers under moderate salinity (Lee et al., 2023; Dongarwar et al., 2018). This study reports findings with salt-tolerant and hybrid rice varieties along with seedling age and density in two production systems — the saline rice field and the rice-fish system (*gher*) — for the first time to our knowledge. The significantly higher trend of soil salinity in different locations, both in *ghers* and rice fields, showed a significantly decreasing trend of grain yield. A similar trend was also observed for yearly variation of soil salinity due to variation in rainfall during the cropping season. The results are in line with the findings of several other studies with the production of rice in saline soils (Zheng et al., 2023; Liu et al., 2023; Ismail and Thomson, 2022; Sánchez-García et al., 2023).

Table 5. Grain yield, panicle density, grain weight and straw yield of Boro rice as affected by variety and seedling management option (Experiment 1).

Treatment/year	Panicle density (no./m^2)	Filled spikelet/ panicle	1000- grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Treatment (T)[1]					
STV1YSLD	309	64.24	23.1	5.21	5.91
STV1OSHD	321	69.03	23.1	5.60	6.30
STV2YSLD	327	65.95	21.8	5.28	5.98
STV2OSHD	334	67.32	21.6	5.43	6.13
HVYSLD	315	70.34	22.9	5.67	6.39
HVOSHD	319	73.30	23.2	5.93	6.63
SCVYSLD	310	54.69	21.2	4.41	5.11
SCVOSHD	314	57.25	21.2	4.60	5.30
$LSD_{0.05}$ (T)	13	3.14	0.4	0.15	0.25
Year (Y)					
Y1	336	67.73	22.3	5.40	6.10

Treatment/year	Panicle density (no./m^2)	Filled spikelet/ panicle	1000- grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Y2	301	63.81	22.2	5.14	5.84
LSD $_{0.05}$(Y)	6	1.57	ns	0.12	0.12
LSD $_{0.05}$ (TxY)	ns	ns	ns	ns	ns

[1]Refer to Table 1 for details of variety and seedling management option, ns = no significant differences at a 5% level of probability

In Experiment 2, grain yield was significantly enhanced in all varieties, with older seedlings at greater density both in *ghers* and rice fields (Table 6). The higher grain yield was produced by BRRI dhan67 with older seedlings at a higher density in *ghers* which was significantly higher than BRRI hybrid dhan3 but similar to Binadhan-10 with the same seedling management option in *ghers* while higher than both the varieties with the same seedling management option in the rice field. BRRI hybrid dhan3 gave a similar yield of Binadhan-10 in *ghers* but higher than that in rice fields. The grain yield was greater in the experimental location, Daulatpur, than that of Shibpur in *ghers* and followed the trend of Daulatpur > Marka > Sreefalkathi in rice fields. Straw yield also followed a similar trend of grain yield. The panicle density and filled spikelet/panicle tended to be higher in older seedlings at higher density in all the varieties in *ghers*. The higher panicle density was found in salt-tolerant varieties than hybrids, whereas the trend was reversed in the case of filled spikelet/panicle. The higher panicle density, filled spikelet/panicle, and the heavier grain were found in Daulatpur than that of Shibpur. In the case of rice fields, higher panicle density and filled spikelet/panicle were found in older seedlings at higher density than the younger seedling at lower seedling density. Irrespective of seedling management options, panicle density was higher in salt-tolerant varieties, with the highest in BRRI dhan67 than hybrid rice. Filled spikelet/panicle was higher in the hybrid rice and salt-tolerant variety, Binadhan-10, compared to BRRI dhan67. The same trend was also found in the case of 1000-grain weight. The production of panicle density, filled spikelet/panicle, and individual grain weight followed the trend in different locations as Daulatpur>Marka>Sreefalkathi (Table 7).

Table 6. Grain yield, yield components and straw yield of Boro rice in *ghers* as affected by variety and seedling management option (Experiment 2).

Treatment/location	Panicle density (no./m^2)	Filled spikelet/ panicle	1000- grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Treatment[1]					
STV1YSLD	357	81.2	22.1	5.78	6.44
STV1OSHD	364	81.8	22.2	6.05	6.69

Treatment/location	Panicle density (no./m^2)	Filled spikelet/ panicle	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
STV2YSLD	341	82.9	23.0	5.77	6.42
STV2OSHD	346	84.1	22.7	5.98	6.63
HVYSLD	314	88.3	23.0	5.71	6.36
HVOSHD	320	88.8	22.5	5.89	6.54
LSD $_{0.05}$ (T)	9	2.2	0.6	0.15	0.15
Location (L)					
Daulatpur	351	87.2	22.9	6.12	6.77
Shibpur	330	81.8	22.3	5.60	6.25
LSD $_{0.05}$(Y)	5	1.3	0.3	0.09	0.09
LSD $_{0.05}$ (Tx L)	ns	ns	ns	ns	ns

[1]Refer to Table 1 for details of variety and seedling management option, ns = no significant differences at a 5% level of probability

Table 7. Grain yield and yield components and straw yield of Boro rice in rice fields as affected by variety and seedling management option (Experiment 2)

Treatment/location	Panicle density (no./m^2)	Filled spikelet/ panicle	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
Treatment[1]					
STV1YSLD	347	76.72	21.7	5.72	6.10
STV1OSHD	356	79.21	21.7	5.91	6.60
STV2YSLD	333	76.96	22.7	5.49	6.18
STV2OSHD	341	79.16	22.4	5.69	6.39
HVYSLD	292	80.43	22.5	5.67	6.37
HVOSHD	301	81.76	22.2	5.80	6.49
LSD $_{0.05}$ (T)	5	1.40	0.3	0.06	0.06
Location (L)					
Daulatpur	332	80.52	22.4	5.91	6.59
Marka	333	79.53	22.2	5.80	6.49
Sreefalkathi	320	77.06	22.1	5.44	6.14
LSD $_{0.05}$(L)	4	0.98	0.2	0.04	0.04
LSD $_{0.05}$ (Tx L)	ns[‡]	ns	ns	ns	Ns

[†]Refer to Table 1 for details of variety and seedling management option, [‡]ns = no significant differences at a 5% level of probability

Profitability

The total variable cost (TVC) of producing BRRI hybriddhan3 was about 3-4% higher with a higher gross return in experiment 1 (Table 8). Gross return was the lowest in BRRI dhan28 with both the seedling management options, and gross margin was mostly negative. Gross return was increased in all the varieties at older seedlings with the higher seedling density, which was on an average of two years, 3-13%. Irrespective of seedling management options, the gross margin from BRRI hybriddhan3 was consistently higher, followed by BRRI dhan61. Similarly, older seedlings with higher seedling density earned a higher gross margin in BRRI hybrid dhan3 and Binadhan-10, which was not the case in BRRI dhan61 in Y2. There was a fairly small variation in the TVC among the treatments, with a higher trend in BRRI hybriddhan3 with both the seedling management options in experiment 2 (Tables 9 and 10).

Table 8. Cost, return and gross margin of Boro rice under different combination of variety and seedling management option (Experiment 1)

Variety and seedling management[1]	Total variable cost (USD/ha)		Total Return[2] (USD/ha)		Gross margin (USD/ha)	
	Y1	Y2	Y1	Y2	Y1	Y2
STV1YSLD	1119	1123	1235	1167	117	44
STV1OSHD	1137	1146	1340	1240	203	94
STV2YSLD	1121	1125	1283	1281	162	155
STV2OSHD	1138	1147	1353	1281	215	134
HVYSLD	1152	1156	1339	1246	187	90
HVOSHD	1169	1179	1406	1495	237	316
SCVYSLD	1113	1122	1060	1084	- 53	- 38
SCVOSHD	1134	1143	1141	1093	7	- 50

[1]Table 1 to refer the details of variety and seedling management options; Y1 = 2016-17 and Y2= 2017-18, [2]Price of grain plus straw; farm gate grain price/t of experimental years, USD 209 for V1, USD 221 for V2 and V3 and USD 206 for hybrid variety (HV), straw price = 19 USD/t

Table 9. Cost, return and gross margin of Boro rice under different combination of variety and seedling management option in *ghers* (Experiment 2)

Variety and seedling management[1]	Total variable cost (USD/ha)		Return[2] (USD/ha)		Gross margin (USD/ha)	
	Daulatpur	Shibpur	Daulatpur	Shibpur	Daulatpur	Shibpur
STV1YSLD	1054	1067	1465	1332	411	265
STV1OSHD	1066	1079	1526	1402	460	323
STV2YSLD	1051	1068	1387	1271	336	203

Variety and seedling management[1]	Total variable cost (USD/ha)		Return[2] (USD/ha)		Gross margin (USD/ha)	
	Daulatpur	Shibpur	Daulatpur	Shibpur	Daulatpur	Shibpur
STV2OSHD	1065	1082	1449	1303	384	221
HVYSLD	1089	1106	1338	1257	248	151
HVOSHD	1108	1124	1396	1279	289	154

[1]Table 1 to refer the details of variety and seedling management options; [2]Price of grain plus straw; farm gate grain price/t of experimental year, USD 209 for Binadhan-10, USD 221 for BRRI dhan61 and BRRI dhan28 and USD 206 for HV, straw price = 19 USD/t

Table 10. Cost, return and gross margin of Boro rice under different combination of variety and seedling management option in rice fields (Experiment 2)

Variety and seedling management[1]	Total variable cost (USD ha^{-1})			Total Return (USD/ha)[2]			Gross margin (USD ha^{-1})		
	Daulatpur	Marka	Sreefalkathi	Daulatpur	Marka	Sreefalkathi	Daulatpur	Marka	Sreefalkathi
STV1YSLD	1117	1117	1121	1437	1413	1314	319	295	193
STV1OSHD	1130	1130	1133	1477	1443	1377	347	313	243
STV2YSLD	1115	1119	1119	1306	1283	1215	191	165	96
STV2OSHD	1129	1132	1132	1345	1322	1276	216	190	144
HVYSLD	1153	1156	1156	1288	1325	1213	135	169	56
HVOSHD	1171	1175	1175	1372	1332	1251	200	157	76

[1]Table 1 to refer the details of variety and seedling management options; [2]Price of grain plus straw; farm gate grain price/t of experimental year, USD 221 for V1, USD 209 for V2 and USD 206 for HV, straw price = 19 USD/t

Irrespective of seedling management options, the gross return was the highest in BRRI dhan67, which was 5-10% higher than Binadhan-10 and BRRI hybrid dhan3 in *ghers* (Table 9). Gross return was higher in older seedlings with higher density by 4-5, 3-5, and 2-4% in BRRI dhan67, Binadhan-10, and BRRI hybrid dhan3, respectively. Like gross return, gross margin was the highest in BRRI dhan67, which was 20-46% and 59-110% higher than Binadhan-10 and BRRI hybrid dhan3, respectively. Gross margin was higher in older seedlings with higher density by 12-22, 10-14, and 2-17% in BRRI dhan67, Binadhan-10, and BRRI hybrid dhan3, respectively. While in rice fields, irrespective of seedling management options, the gross return was 8-10% and 7-12% higher in BRRI dhan67 than Binadhan-10 and BRRI hybrid dhan3, respectively (Table 10). Gross return was higher in older seedlings with higher density by 2-5, 3-5, and 3-7% in BRRI dhan67, Binadhan-10, and BRRI hybrid dhan3, respectively. Like gross return, gross margin was the highest in BRRI dhan67, which was 61-101% and 74-245% higher than Binadhan-10 and BRRI hybrid dhan3, respectively, across the locations. Gross margin was higher in older seedlings with higher density by 6-26, 13-50, and negative to 48% in BRRI dhan67, Binadhan-10, and BRRI hybrid dhan3, respectively. The gross margin was the highest in Daulatpur across the treatment, followed by Marka, and the lowest in Sreefalkathi (Table 10).

Growth duration varied in different locations for differences in salinity gradient, and thus irrigation events and diesel required for that were higher in higher saline sites both in *ghers* and rice fields. The lesser growth duration in older seedlings at higher density required less irrigation event, which required less diesel for irrigation. The seed cost was increased by 50–100% in higher seedling density, which was consistent with Dongarwar *et al.* (2018). Hybrid rice establishment (labour for seedling uprooting and transplanting) required one additional person-day ha^{-1} compared to other varieties for using younger seedlings with shorter height and fewer seedlings per hill. The establishment of older seedlings with higher density in all the cases required an additional person day ha^{-1}. The net result was that on average, the total cost of seed and seedling management, establishment, and irrigation was higher in older seedlings at higher density compared to younger seedlings at lower density in inbreeds and hybrid rice (USD 17-18 and USD 23 ha^{-1}, respectively). Although the older seedlings at higher density decreased a little cost for establishment and irrigation, the seed and seedling raising cost outweighed the saved costs from establishment and irrigation. The higher gross return from the better salt-tolerant rice variety in saline sites of *ghers* and rice fields with older seedlings at higher density was best explained by higher grain yield. With both positive and negative effects on cost in seedling management, establishment, and irrigation, the gross margin was higher in older seedlings with higher density in diverse production systems, *ghers* and rice fields than younger seedlings with lower density.

Conclusion

Combining older seedlings with higher planting density enhances rice yield in saline environments by increasing panicle density and filled spikelets per panicle. For optimal results in saline rice fields and *ghers* (rice-fish systems), salt-tolerant or hybrid varieties could be prioritized, as they establish faster, shorten the growth cycle by 4-5 days, and tolerate salt stress better than sensitive varieties. Given the irrigation scarcity and the risk of tidal storms in coastal saline areas, adopting management strategies like older seedlings and selecting shorter-duration varieties offers a vital pathway to harvest timely, reducing production risks. Environmental variables, particularly year-to-year rainfall fluctuations and spatial salinity gradients, further dictate duration; higher soil salinity and lower rainfall consistently extend the time to maturity.

Cultivating BRRI hybriddhan3 incurs slightly higher variable costs, but its higher yield and market price consistently generate better gross margins than susceptible traditional inbred like BRRI dhan28, which often yield negative margins. Among the tested salt-tolerant and hybrid varieties, BRRI dhan67 consistently outperforms Binadhan-10 and BRRI hybrid dhan3 in both gross return and gross margin across production systems. On the other hand, higher seedling density and older seedlings increase seed and labour costs, but they optimize growth duration and reduce irrigation needs in saline environments. Thus, older seedlings of salt tolerant variety, BRRI dhan67, offer the most economically viable and resource-efficient option for coastal *gher* and rice field farming.

The package of salt-tolerant inbred and hybrid rice varieties and seedling management options has not been sufficiently evaluated in a diverse gradient of soil salinity and irrigation with different levels of salinity. A single inbred or hybrid rice variety cannot universally withstand all levels of soil and irrigation water salinity, and requires matching site-specific variety selection with tailored seedling management.

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References

Ahmed, R., Islam, M.A., Hossain, M.I., & Rahman, M.A. (2024). Performance of newly released salt-tolerant rice variety BRRI dhan97 and BRRI dhan99 in coastal saline environments of Bangladesh. *PLOS One*, 19(1), e0294573. https://doi.org/10.1371/journal.pone.0294573

Akter, S., Rahman, M.H., Sarkar, M.A.R., Pede, V.O. & Kabir, M.S. (2025). Farmers' adoption of newly released climate-resilient rice varieties in the coastal ecosystem of Bangladesh: Effectiveness of a head-to-head adaptive trial. *Food and Energy Security*, e70075. https://doi.org/10.1002/fes3.70075

BBS (Bangladesh Bureau of Statistics). (2021). Year Book of Agricultural Statistics. Statistics and Informatics Division, Ministry of Planning, People's Republic of Bangladesh.

BRRI (Bangladesh Rice Research Institute). (2019). Modern Rice Cultivation (22nd ed.). Bangladesh Rice Research Institute, Gazipur. 96 p.

BRRI (Bangladesh Rice Research Institute). (2023). Annual Report 2022–2023. Bangladesh Rice Research Institute, Joydebpur, Gazipur.

Chen, T., Shabala, S., Niu, Y., Chen, Z.H., Shabala, L., Meinke, H., Bhui, F. & Peng, M. (2021). Molecular mechanisms of salinity tolerance in rice. *The Crop Journal*, 9(3), 506–520. https://doi.org/10.1016/j.cj.2021.03.005

Dongarwar, U.R., Patke, N., Dongarwar, L.N. & Kashiwar, S.R. (2018). Impact of different seed rates on yield and economics of direct seeded rice in eastern Vidharbha zone of Maharashtra, India. *International Journal of Current Microbiology and Applied Sciences*, 7(3), 32–42.

FAO (Food and Agriculture Organization of the United Nations). (2024). Global Status of Salt-Affected Soils. FAO, Rome. https://doi.org/10.4060/cd3628en

Huang, Z., Ye, J., Zhai, R., Wu, M., Yu, F., Zhu, G., Wang, Z., Zhang, X. & Ye, S. (2023). Comparative transcriptome analysis of the heterosis of salt tolerance in inter-subspecific hybrid rice. International Journal of Molecular Sciences, 24(3), 2212. https://doi.org/10.3390/ijms24032212

Islam, M.R., Faruquee, M., Sarker, M.S.A., & Rahman, H. (2021). Salinity intrusion increases in Bangladesh. In Climate Change and Agriculture in Bangladesh. *Bangladesh Journal of Agricultural Research*, Special Issue.

Ismail, A.M., & Thomson, M.J. (2022). Molecular breeding of rice for salinity tolerance: advances and prospects for coastal agriculture. In Plant Salinity Tolerance: Methods and Protocols (2nd ed.). Springer, New York.

Isayenkov, S.V., & Maathuis, F.J.M. (2019). Plant salinity stress: Many unanswered questions remain. Frontiers in Plant Science, 10, 80. https://doi.org/10.3389/fpls.2019.00080

Kabir, M.S., Sarkar, M.A.R., Rahman, N.M.F., Mamun, M.A.A. & Chowdhury, A. (2021). Risk of rice cultivation under current and future environment and market. *Bangladesh Rice Journal*, 25(1). https://doi.org/10.3329/brj.v25i1.55182

Korres, N.E., Cici, S.Z.H., Travlos, I. & Varanasi, A. (2022). Salinity effects on rice, rice weeds, and strategies to secure crop productivity and effective weed control: A review. *Agronomy for Sustainable Development*, 42, 75. https://doi.org/10.1007/s13593-022-00794-4

Lee, S.Y., Kim, M.R., Baek, J.H., Lee, J.H. & Park, S.G. (2023). Changes in the growth and yield of an extremely early-maturing rice variety according to transplanting density. Agriculture, 13(3), 717. https://doi.org/10.3390/agriculture13030717

Ling, X., Liu, H., Wu, H., Chen, Y., Zhu, G., Dai, Q. & Zhang, H. (2024). Optimum seeding density and seedling age for the outstanding yield performance of japonica rice using crop straw boards for seedling cultivation. *Frontiers in Plant Science*, 15, 1295822. https://doi.org/10.3389/fpls.2024.1295822

Liu, H., Wang, X., Wang, G., Cui, P., Wu, S., Ai, C. & Zhang, H. (2023). Effect of salinity stress on rice yield and grain quality: A meta-analysis. *European Journal of Agronomy*, 144, 126748. https://doi.org/10.1016/j.eja.2023.126748

Mukhopadhyay, R., Sarkar, B., Jat, H.S., Sharma, P.C. & Bolan, N.S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. Journal of Environmental Management, 280, 111736. https://doi.org/10.1016/j.jenvman.2020.111736

Rashid, M.H., & Nasrin, S. (2014). Productivity and preference of salt tolerant Boro rice varieties in saline rice field and gher ecosystems. *Bangladesh Rice Journal*, 18(1&2), 19–24.

Reddy, I.N.B., Kim, B.K., Kim, K.H. & Kwon, T. (2022). Salt tolerance in rice: Focus on mechanisms and approaches. *Rice Science*, 24(3), 123–144. https://doi.org/10.1016/j.rsci.2022.03.006

Sánchez-García, M., Royo, C., García-Aparicio, M.P. & Soriano, J.M. (2023). Salinity effects on rice production and mitigation strategies: A global meta-analysis and systematic review. *Field Crops Research*, 290, 108766. https://doi.org/10.1016/j.fcr.2023.108766

Sheng, X., Ai, Z., Tan, Y., Hu, Y., Guo, X., Liu, X., Sun, Z., Yu, D., Chen, J., Tang, N., Duan, M. & Yuan, D. (2023). Novel salinity-tolerant third-generation hybrid rice developed via CRISPR/Cas9-mediated gene editing. *International Journal of Molecular Sciences*, 24(9), 8025. https://doi.org/10.3390/ijms24098025

SRDI (Soil Resources and Development Institute). (2012). Saline Soils of Bangladesh. Soil Resources and Development Institute, Mrittika Bhaban, Dhaka, Bangladesh. pp. 6–7.

Wang, M., Liang, Z., Yang, F., Ma, H., Huang, L. & Liu, M. (2010). Effects of number of seedlings per hill on rice biomass partitioning and yield in a saline-sodic soil. *Journal of Food, Agriculture & Environment,* 8, 628–633.

Watling, K. (2007). Measuring salinity. Fact Sheet, Department of Natural Resources and Water. Queensland Government, Australia.

Zheng, H., Liu, Y., Zhang, X., Xu, Y., Wang, L., Shao, X., Sheng, S., Meng, T., Chen, L., Li, J., Dai, Q. & Shi, Y. (2023). Effect of salinity stress on rice yield and grain quality: A meta-analysis. *European Journal of Agronomy*, 144, 126748. https://doi.org/10.1016/j.eja.2023.108768