International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4, 2025
https://theaspd.com/index.php

Growth And Yield Performance Of Sorghum Germplasm In Coastal Saline Habitat Of Bangladesh

Md. Eakramul Haque[a*], Md. Atikur Rahman[b] A.K.M. Golam Sarwar[c], Abdur Razzak[c], Md. Rashedul Islam[d], Biplob Kumar Saha[e], A. K. M. Zakir Hossain[c]

[a]On Farm Research Division, Bangladesh Agricultural Research Institute (BARI), Alamnagar, Rangpur-5400, Bangladesh, Mobile No-+8801715319409, email- eakramul.bari@gmail.com
[b]Agricultural Research Station, Bangladesh Agricultural Research Institute (BARI), Benarpota, Satkhira, Bangladesh
[c]Department of Crop Botany, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh
[d]Department of Agricultural Extension (DAE), Rangpur-5400, Bangladesh
[e]Department of Agricultural Chemistry, Bangladesh Agricultural University (BAU), Mymensingh-2202, Bangladesh
Corresponding Author Email: eakramul.bari@gmail.com

ABSTRACT

Sorghum (Sorghum bicolor L. Moench) is a climate-resilient crop with potential for saline-affected regions, yet field-based evaluations in coastal ecosystems remain limited. This study assessed the agronomic and physiological performance of ten sorghum germplasms under natural saline conditions in Satkhira, Bangladesh, during 2016–2017. A randomized complete block design was employed, with growth, ion homeostasis, and yield parameters measured at critical stages. Results revealed significant genotypic variation: Sorghum BD-737 produced the highest grain yield (6.41 t ha^{-1}), followed by Hybrid Sorgo (6.27 t ha^{-1}) and Sorghum BD-701 (4.84 t ha^{-1}). Superior salinity tolerance in BD-737 and BD-701 was linked to elevated K^+/Na^+ ratios (root: 325.97 mg; leaf: 282.93 mg) and lower Na^+ accumulation (root: 5.10–7.67 mg). Sorghum BD-730 exhibited robust Ca^{++} (444.87 mg leaf^{-1}) and Mg^{++} (177.40 mg leaf^{-1}) retention, while Hybrid Sorgo demonstrated high panicle length (29.05 cm). Yield stability correlated with ionic regulation, as susceptible genotypes (e.g., Sorghum BD-720) showed reduced K^+/Na^+ ratios and lower grain weight (254.22 g plant^{-1}). The study identifies Sorghum BD-737, Hybrid Sorgo, Sorghum BD-701, and Sorghum BD-730 as promising for saline coastal cultivation and breeding programs, advocating their integration into climate-smart agriculture to enhance productivity in salinity-prone regions.

KEYWORDS:*Sorghum, salinity, ionic composition, and yield*

INTRODUCTION

Sorghum (Sorghum bicolor L. Moench) is a versatile and drought-resilient C_4 cereal that ranks fifth among the world's most important cereal crops after rice, wheat, maize, and barley due to its adaptability to harsh environments and its multifunctional uses in food, fodder, and bio-industrial applications (Rutto et al., 2013; FAO, 2021; Rakshit et al., 2023). Its tolerance to abiotic stresses, particularly drought and high temperatures, positions sorghum as a climate-resilient crop ideal for sustainable agriculture in marginal lands (Rooney, 2016). Recent attention has also focused on its capacity to endure salinity stress, supported by physiological mechanisms such as osmotic adjustment, ion homeostasis, and antioxidant defenses (Ashraf & Harris, 2005; Mansour et al., 2021). These attributes make sorghum a promising candidate for introduction into salinity-affected coastal regions, especially in countries like Bangladesh, where climate-induced soil salinization poses a growing threat to agricultural productivity.

Salinity is one of the most detrimental abiotic stresses affecting global food production, with over 20% of irrigated lands already impacted and more areas being added annually, particularly in arid, semi-arid, and coastal zones (Munns & Tester, 2008; Zörb et al., 2019). In Bangladesh, salinity intrusion has become increasingly severe due to sea-level rise, reduced upstream freshwater flow, and tidal inundation, especially during the rabi (dry) season (Mahmuduzzaman et al., 2014; SRDI, 2021). According to the Soil Resource Development Institute (SRDI), approximately 1.02 million hectares across 19 coastal districts are affected by salinity, severely limiting the productivity of conventional crops such as rice and wheat (Haque, 2006; Islam et al., 2020). Consequently, resource-poor farmers face reduced yields, restricted cropping choices, and increased vulnerability. This necessitates the identification and promotion of alternative, salt-tolerant crops like sorghum to restore productivity and sustainability in these stressed environments.

Despite the crop's potential, the cultivation of sorghum in salinity-prone regions of Bangladesh remains limited, partly due to the lack of empirical data on its performance under natural saline conditions. While controlled-environment studies have confirmed sorghum's tolerance to salt stress through mechanisms like sodium exclusion, potassium retention, and maintenance of photosynthetic efficiency (Netondo et al., 2004; Gupta & Huang, 2014), field-based validation under real saline environments is lacking. Global studies have reported genotypic differences in salinity tolerance, often highlighting traits such as high K^+/Na^+ ratios, chlorophyll stability, and antioxidant activity as key contributors to salinity resilience (Ashraf & Harris, 2005; Mansour et al., 2021). Recent research by Rakshit et al. (2023) identified sorghum genotypes capable of maintaining yield and physiological stability under saline conditions. However, these findings are yet to be contextualized in Bangladesh's coastal ecosystem, where saline stress fluctuates across seasons and soil types. As a result, little is known about the actual agronomic performance, ion accumulation patterns, and physiological responses of sorghum germplasm under such field conditions.

There are several key gaps in current research. Firstly, most studies on sorghum's salinity response are confined to greenhouse or pot experiments, offering limited relevance for field-scale applications. Secondly, few studies have examined the interaction between salinity stress and grain yield under fluctuating natural salinity levels. Thirdly, there is insufficient data on ion dynamics (e.g., Na^+, K^+, $Ca2^+$, $Mg2^+$) across genotypes in field settings. Fourth, in the specific context of Bangladesh, no comprehensive trials have been conducted to evaluate sorghum as a viable rabi season crop in saline-prone coastal areas. This limits the development of region-specific varietal recommendations or agronomic packages. Moreover, without field-level data, policy and extension efforts to promote sorghum as a climate-smart crop remain constrained.

Addressing these gaps presents both challenges and opportunities. Conducting research in natural saline environments entails considerable variability due to site-specific soil salinity, seasonal changes, and environmental interactions. These challenges can be mitigated by selecting well-characterized saline sites, conducting trials during peak salinity periods, and integrating both physiological and agronomic measurements to identify salt-tolerant germplasm. Traits such as ion exclusion, high K^+/Na^+ ratios, and yield stability under stress should be prioritized. The inclusion of farmer participation in variety selection and feedback also enhances the relevance and eventual adoption of promising genotypes.

This study is significant in that it aims to assess the field performance of diverse sorghum germplasm under naturally saline soil conditions in the coastal region of Bangladesh. It provides critical insights into the crop's physiological and yield responses under real stress scenarios, thereby supporting its integration into climate-resilient cropping systems. The novelty of this research lies in its field-based approach, as it is the first to evaluate the combined agronomic and ion uptake characteristics of sorghum genotypes under natural salinity in Bangladesh. The outcomes are expected to inform breeding strategies, varietal recommendations, and sustainable intensification efforts in salt-affected regions.

Materials and methods

Study site and period

With view to identify suitable germplasm in terms of growth, yield components and yield under natural saline soils in costal belt of Bangladesh, the field trial was conducted under natural saline ecosystem at Agricultural Research Station, Bangladesh Agricultural Research Institute, Benerpota, Satkhira during 2015-16 and 2016-17.

Research design and details of planting materials

The experiment was laid out in Randomized Complete Block Design with three replications. The unit plot size was 3m×2.7m and spacing was 50cm×30cm. Based on the result of a previous lab experiment where 35 germplasm was evaluated in germination stage and hydroponic culture. Among the 35 germplasm, ten (10) Sorghum germplasms such as Hybrid Sorgo, Sorghum BD-701, Sorghum BD-703, Sorghum BD-706, Sorghum BD-713, Sorghum BD-720, Sorghum BD-730, Sorghum BD-731, Sorghum BD-733 and Sorghum BD-737 were taken for the trial in natural salinity condition. All germplasms were sown on 8 December 2016.

Crop development

The research land was prepared by disc plough with two cross harrowing. Then it was ploughed well by cultivator with further double cross ploughings. Later on, the land was finally prepared and leveled by rotovator with two cross ploughings. The weed and other stubble were removed from the field. Recommended fertilizers rate of 115-30-125-25-2-1.5 kg ha^{-1} respectively of Urea, TSP, MoP, Zypsum, Zinc and Boric acid were used in the experiment based on soil test result (Table 1 & 2). Half dose of nitrogen fertilizer and full dose of all other fertilizers were applied basal in all the treatments and the remaining N fertilizer was applied as top dress. Cowdung was also applied in each plot equally at the rate of 10 tha^{-1} before final land preparation and incorporated in the soil properly. Weeds grown in the plots and visible insects were removed time to time by hands in order to keep the pots neat and clean to avoid competition. The soil was loosened by hand whenever necessary during the period of experiment.

Table 1: Physical properties of the initial soil of the experimental plot at Agricultural Research Station, BARI, Benerpota, Satkhira during 2016-17

Particle size distribution	Value
Sand (%)	45
Silt (%)	27
Clay (%)	28
Textural class	Clay Loam
Bulk density (g/cm^3)	1.35
Particle density (g/cm^3)	2.17
Total porosity (%)	37.79
Field capacity (%)	34.33

Collection of morphological data

Plant samples were collected from plots at 60 and 90 DAS. After harvesting, the plant samples were separated into root, stem, leaf and panicle. The total period from days after emergence of the crop was counted and expressed in days to 80% emergence. The total number of plants was counted in each plot at 15 days after emergence. The total number of plants was counted in each plot at harvest. The total period from days after emergence to first flowering of the crop was counted and expressed in days. The plant height (cm) was measured from the surface to the tip of the longest leaf before harvesting at an interval of 15 days starting from 30 days after sowing to final harvest. Total tillers number $hill^{-1}$ was counted at 100 DAS. Roots collected at 90 DAS and were cleaned carefully with running tap water and finally washed with distilled water. Then the root samples were oven-dried to a constant weight at 70°C. The mean root dry weight $hill^{-1}$ was calculated for each treatment. Root, stem and leaf samples were separated at 90 DAS. Sundried samples were oven-dried to a constant weight at 70 °C. Then the shoot dry weight was calculated from the summation of leaf, stem and panicle. The total dry matter (TDM) was calculated from the summation of root and shoot hill^{-1}.

Biochemical constituents in Sorghum leaf

Sodium, Potassium, Calcium and Magnesium in root, stem and leaf of Sorghum plants were determined (Ashraf and Harris, 2004; Zhu, 2001). At the final harvest, the data on yield components like number of effective tillers hill^{-1}, filled grains panicle^{-1}, unfilled grains panicle^{-1}, 1000-grain weight and grain yield hill^{-1} were recorded. After harvesting, 10 cobs were selected randomly for measuring the length of cob. Length of each cob was measured carefully in cm from the base of the cob to the end with a measuring scale (30 cm). The average number of grains panicles^{-1} was calculated from 5 randomly selected panicles from five hills of the respective treatment plot. Grains of five randomly selected hills were threshed. Then weight of grains was measured by an electrical top balance and yield was calculated in g plant^{-1} at 14% moisture content. After threshing the panicles, the moisture level of grains was measured by moisture meter. Then 1000-grain was counted randomly and weighed by an electric balance. The weight was adjusted at 14% moisture content. After threshing the panicles of whole plot, the moisture level of grains was determined by moisture meter. Then weight of grains was measured by an electrical top balance and yield was calculated in t ha^{-1} at 14% moisture content.

Meseruremnt of EC at Satkhira

With the increase in time EC increased gradually in all the treatments plot (Figure 1). No remarkable differences was observed in EC among the different treatments in all the sampling days.

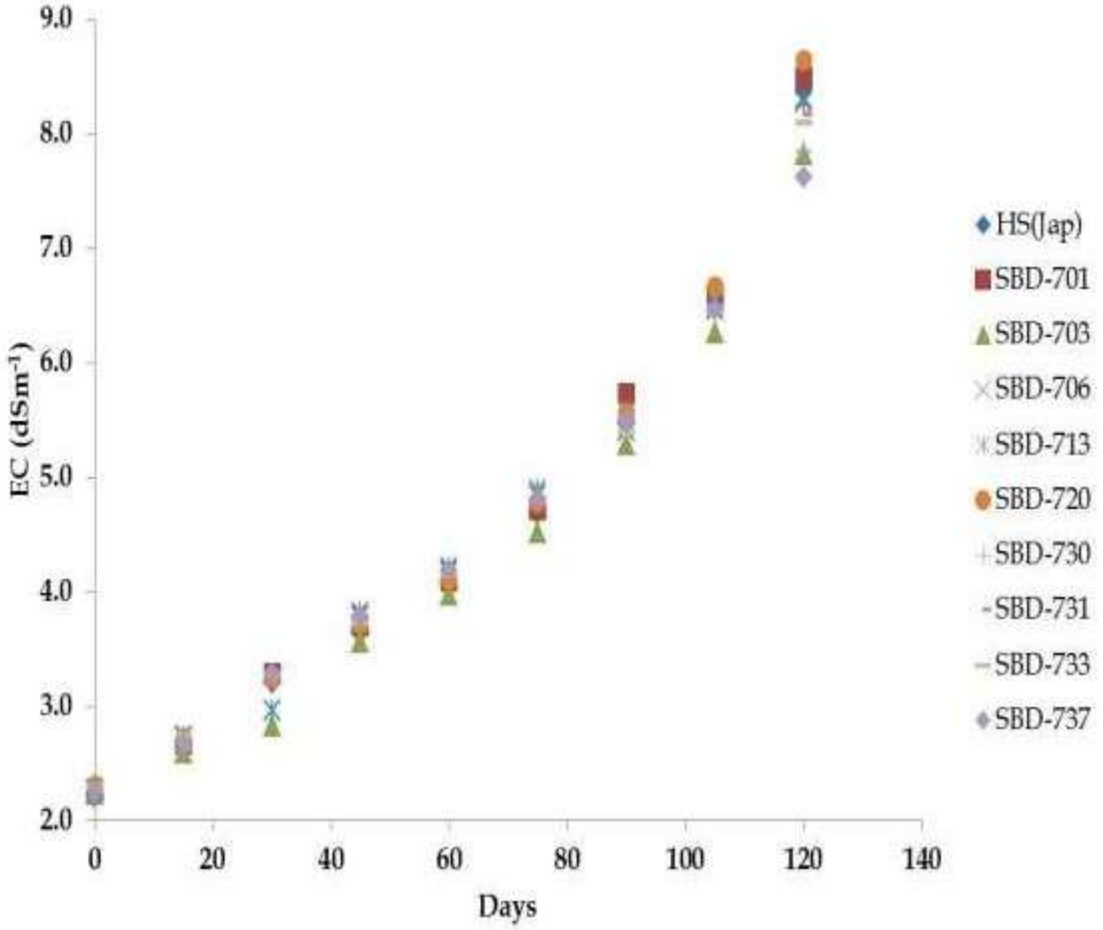

Figure 1: Gradual electrical conductivity (EC) in the plots allocated for 10 Sorghum germplasm at ARS, Benarpota, Satkhira during rabi season of 2016-17.

Table 2: Chemical properties of the soil at the ARS, BARI, Benarpota, Satkhira during the *rabi* season of 2016-2017.

Soil characteristics	Analytical value (Initial soil)		Analytical value (Soil after harvest)		Critical levels
	Value	Interpretation	Value	Interpretation	
Soil p^H	8.11	Moderately alkaline	7.80	Slightly alkaline	-
Organic matter (%)	1.39	Low	2.01	Medium	C:N= 10:1
Total N (%)	0.151	Low	0.161	Low	0.12
Available P (ppm)	13.14	Medium	16.33	High	10.0
Exchangeable K (meq/100g soil)	0.20	Medium	0.17	Low	0.12
Available S (ppm)	15.01	Medium	17.15	Medium	10.0
Available Zn (ppm)	0.653	Low	0.419	Very low	0.6
Available Boron (ppm)	0.27	Low	0.19	Low	0.2
Available Cu (ppm)	1.18	Very high	1.01	Very high	0.2
Available Fe (ppm)	13.00	Very high	4.05	Low	4.0
Available Mn (ppm)	7.68	Very high	5.91	Very high	1.0
Exchangeable Ca (meq/100g soil)	1.69	Low	1.05	Very low	2.0
Exchangeable Mg (meq/100g soil)	1.118	Medium	0.95	Medium	0.5
Exchangeable Na (meq/100g soil)	8.015	-	7.861	-	-
SAR	21.48	Sodic soil	24.86	Sodic soil	13.00

Data analysis

The collected data were analyzed statistically following Randomized Complete Block Design by Statistix-10 computer package programme. Data analysis was done using analysis of variance (ANOVA) technique. The multiple comparisons of treatment means were done by Tukey's HSD t-test. All graphs were done with the help of Microsoft Excel worksheet 2010.

RESULTS

Plant Height (cm)

The results of Figure 2 revealed that Plant height of ten Sorghum cultivars varied significantly at different crop ages. Plant height increased gradually according to age of the plant. The taller plants were observed in the germplasm Sorghum BD-701, HS (Jap), Sorghum BD-703 both at 30 and 60 DAS but Sorghum BD-731 showed the highest plant height at later stage of crop life. At harvest, the highest plant height was observed in the genotype Sorghum BD-731 (208.07) and the shortest plant was recorded in Sorghum BD-713 (115.73 cm).

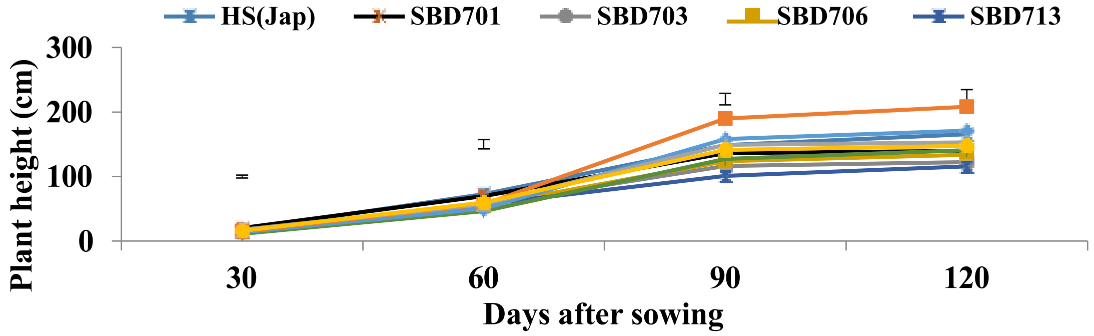

Figure 2: Plant height (cm) of 10 Sorghum germplasm over time grown in natural saline areas at Benerpota, Satkhira.

Number of Leaves per Plant

There was a significant difference in leaf number per plant among the Sorghum cultivars at different plant ages (Figure 3). Leaf numbers increased gradually according to the duration of the plant. At 30 and 60 DAS Sorghum BD-703 produced more leaf compared to other germplasm. At 90 DAS, more leaves per plant were recorded in four germplasm *viz.* Sorghum BD-720, Sorghum BD-730, Sorghum BD-733 and Sorghum BD-737. But at harvest *i.e.,* 120 DAS, the highest leaf number (39.33) was counted in the genotype Sorghum BD-701 and the lowest (25.33) was recorded in Sorghum BD-706 (Figure 3).

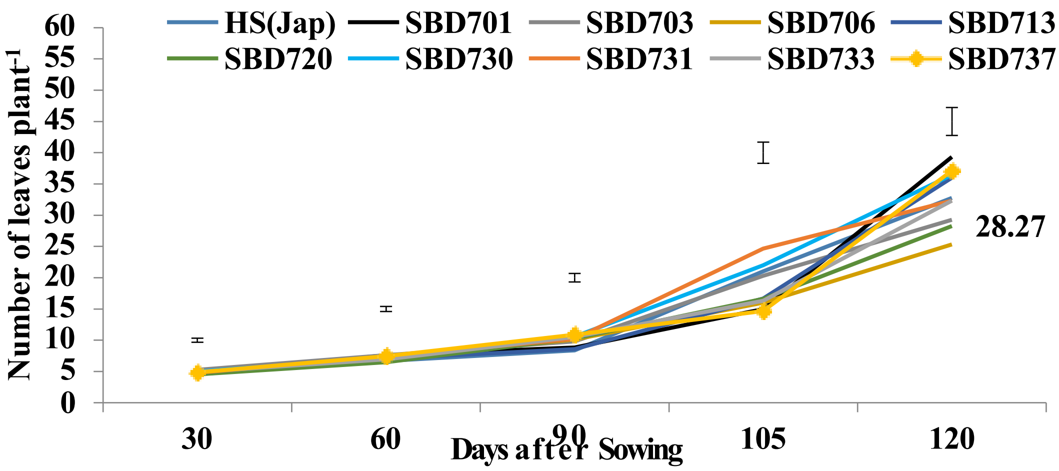

Figure 3: Number of leaves plant^{-1} of 10 Sorghum germplasm over time grown in natural saline areas at Benerpota, Satkhira

Panicle Characteristics

From the results presented in the Table 3, it appears that the features panicle (no. of panicles plant^{-1}, panicle length, no. of grains panicle^{-1}) of different Sorghum germplasm varied significantly in the field under saline condition. The highest number of panicles per plant (4.66) was figured out in the Sorghum genotype Hybrid Sorgo followed by Sorghum BD-720, Sorghum BD-730 and Sorghum BD-706. On the other hand, the lowest panicle number per plant was recorded in Sorghum BD-701 and Sorghum BD-703. In case of panicle length (cm), the longest panicle (29.05) was found in the genotype Hybrid Sorgo and shortest panicle (22.8) was recorded in Sorghum BD-731. Finally, number of grains per panicle varied significantly among different sorghum germplasms. The highest grain per panicle (2658) was recorded from Sorghum BD-720 followed by the germplasm Sorghum BD-730, Sorghum BD-706, Sorghum BD-703 and Sorghum BD-731. The lowest number of grains per panicle (1372) was found in Sorghum BD-733.

Table 3: Number of panicles plant^{-1}, length of panicle (cm), number of grains panicle^{-1} of 10 Sorghum germplasm grown in natural saline areas at Benerpota Satkhira

Germplasm	Panicles/plant (No.)	Length of panicle (cm)	Grains/panicle (No.)
Hybrid Sorgo	4.66^{a}	29.05^{a}	15095^{bc}
Sorghum BD-701	2.66^{b}	23.39^{b}	15585^{bc}
Sorghum BD-703	2.66^{b}	25.27^{ab}	2195^{abc}
Sorghum BD-706	3.66^{ab}	26.60^{ab}	2291^{abc}
Sorghum BD-713	2.66^{b}	25.05^{ab}	1870^{abc}
Sorghum BD-720	4.33^{ab}	23.95^{b}	2658^{a}
Sorghum BD-730	3.66^{ab}	25.70^{ab}	2379^{ab}
Sorghum BD-731	3.33^{ab}	22.80^{b}	2106^{abc}
Sorghum BD-733	3.0^{ab}	22.86^{b}	1372^{c}
Sorghum BD-737	3.0^{ab}	27.02^{ab}	2003^{abc}
LSD	1.89	4.88	962.19
CV (%)	32.74	11.32	28.12

Means bearing the dissimilar letter within the column differ significantly

Fresh weight per plant

Results presented in the Table 4; it revealed that total fresh weight (g) significantly varied among the ten Sorghum germplasms at different crop ages grown in field saline condition at Sathkhira. Fresh weight of plant increased over time. At 2 months (60 DAS) age, the genotype Sorghum BD-737 produced the highest fresh weight (50.0 g) followed by Sorghum BD-703 (48.99 g), and the lowest was in Hybrid Sorgo (Jap) (32.33 g). From the recorded data after three months (90 DAS) of sowing, the highest fresh weight per plant (627.33 g) was found in Sorghum BD-730 and lowest (373.0 g) in HS (Jap).

Dry weight per plant

Dry weight (g) differed significantly among the ten Sorghum germplasm at different crop ages grown in coastal saline region and the results are depicted in Table 4. Dry weight of plant also increased over crop age. At 60 DAS, the highest dry weight (6.79 g) was found in the Sorghum germplasm Sorghum BD-703 followed by Sorghum BD-706 and Sorghum BD-737 and the lowest was in Sorghum BD-713 (4.79 g). At 90 DAS, the highest dry weight per plant (116.72 g) was recorded in Sorghum BD-701 which was at par with the germplasm Sorghum BD-703 and Sorghum BD-730. The lowest dry weight per plant (74.7 g) was found in Sorghum BD-731 (Table 4).

Table 4: Fresh weight and dry weight of ten Sorghum germplasm at 60 and 90 DAS cultivated in natural saline areas at Benerpota, Satkhira during 2016-17

Germplasm	Fresh weight (g) at 60 DAS	Dry weight (g) at 60 DAS	Fresh weight (g) at 90 DAS	Dry weight (g) at 90 DAS
Hybrid Sorgo	32.33^{de}	5.91^{abc}	373.0^{e}	92.15^{bc}
Sorghum BD-701	38.33^{c}	6.05^{abc}	544.0^{b}	116.72^{a}
Sorghum BD-703	48.99^{ab}	6.79^{a}	418.61^{de}	115.74^{a}
Sorghum BD-706	44.33^{b}	6.44^{ab}	472.66^{cd}	93.44^{bc}
Sorghum BD-713	29.76^{e}	4.79^{d}	529.71^{bc}	82.01^{cd}
Sorghum BD-720	35.62^{cd}	5.81^{bc}	310.93^{f}	81.69^{cd}
Sorghum BD-730	35.66^{cd}	6.03^{abc}	627.33^{a}	111.23^{a}
Sorghum BD-731	38.01^{c}	5.53^{cd}	401.37^{e}	74.70^{d}
Sorghum BD-733	33.32^{cde}	4.90^{d}	392.20^{e}	77.25^{d}
Sorghum BD-737	50.0^{a}	6.43^{ab}	557.08^{b}	97.33^{b}
LSD	5.2618	0.8906	59.853	12.748
CV (%)	7.94	8.84	7.54	7.89

Means bearing the dissimilar letter within the column differ significantly

Na^+ content in Root, Stem and Leaf at 90 days after sowing

The Na^+ content of Sorghum root, stem and leaf was significantly influenced among different germplasm (Table 5) at 90 days after sowing. The highest Na^+ content in root was determined from the germplasm Sorghum BD-731 (7.67). The lowest Na^+ content was measured from Hybrid Sorgo (5.10) which was statistically identical with germplasm Sorghum BD-703 (5.67). In contrast the highest Na^+ content of stem was found in Sorghum BD-737 (6.32) which was statistically similar to that of Sorghum BD-713 (5.99) and the lowest was determined from Sorghum BD-720 (2.11). Statistically the highest and similar Na^+ content in leaf was recorded in the germplasm Sorghum BD-703 (1.70), Sorghum BD-737 (1.70), Hybrid Sorgo (1.64) Sorghum BD-720 (1.62) whereas the lowest was counted in Sorghum BD-706 (1.22).

K^+ content in Root, Stem and Leaf at 90 days after sowing

Significantly higher amount of K^+ in root (325.97mg) and leaf (282.93mg) was measured from the germplasm Sorghum BD-730 and whereas it was estimated statistically higher both in stem (2657.1 mg) and leaf (271.57 mg) from the germplasm Sorghum BD-703 (Table 5). Also, statistically similar amount of leaf K^+ content was determined from Sorghum BD-701 and Sorghum BD-733. On the other hand, the stem K^+ content of germplasm Sorghum BD-737 showed statistically identical values with all the other germplasm except Sorghum BD-706. The significantly lower amount of root, stem and leaf K^+ content was measured from the germplasm Sorghum BD-731, Sorghum BD-733 and Sorghum BD-706, respectively (Table 5).

Ca^{++} content in Root, Stem and Leaf at 90 days after sowing

The Ca^{++} content of Sorghum root, stem and leaf were significantly influenced among different germplasm (Table 5) at 90 days after sowing. The highest Ca^{++} content in root was determined from the germplasm Sorghum BD-703 (153.45 mg) which was statistically at par with that of Sorghum BD-701 (139.63 mg). The lowest Ca^{++} content was measured from Hybrid Sorgo (56.69 mg). In contrast, the highest Ca^{++} content of stem was found in Sorghum BD-737 (258.96 mg) and the lowest was determined from Sorghum BD-713 (93.70 mg) which was statistically alike with germplasm Sorghum BD-731 (128.91 mg). The statistically higher leaf Ca^{++} content was detected form Sorghum BD-730 (444.87 mg) which was statistically identical to that of Sorghum BD-701(376.68 mg). The lowest leaf Ca^{++} content was measured in Sorghum BD-720 (132.98 mg).

Mg^{++} content in Root, Stem and Leaf at 90 days after sowing

Significantly highest (239.92mg) of Mg^{++} in root was measured from the germplasm Sorghum BD-701 and the lowest was obtained from Sorghum BD-731 (61.17mg) which was statistically alike with germplasm Sorghum BD-733 (66.75 mg) and Sorghum BD-706 (78.77mg) (Table 5). On the other hand, statistically the highest stem Mg^{++} content was calculated from Sorghum BD-703 (345.86mg) and Sorghum BD-737 (340.25mg) whereas the lowest was obtained in Sorghum BD-713 (48.70 mg). The germplasm Sorghum BD-737 (201.03 mg) and Sorghum BD- 703 (190.52mg) gave the statistically highest leaf Mg^{++} content which was statistically at per with that of Sorghum BD-730 (177.40 mg) and Sorghum BD-733 (176.10mg). The lowest leaf Mg^{++} content was obtained in Sorghum BD-713 (64.66 mg).

Total Na^+, K^+, Ca^{++} and Mg^{++} content Leaf at 90 days after sowing

The total plant content of Na^+, K^+, Ca^{++} and Mg^{++} among the Sorghum germplasm varied significantly at 90 days after sowing (Table 6). Significantly the highest total Na^+ uptake was obtained from Sorghum BD-737 (13.78mg) whereas the lowest was calculated from Sorghum BD-720 (8.52 mg). Total K^+ content was found highest in Sorghum BD-703 (3113.30 mg) and the lowest was estimated in Hybrid Sorgo (919.0 mg) which was statistically alike with all the other germplasm except Sorghum BD-706 (2284.80 mg). Statistically the highest Ca^{++} uptake was determined in Sorghum BD-730 (741.67 mg) which was statistically identical Sorghum BD-701 (686.80 mg). The lowest was calculated in Sorghum BD-720 (412.25 mg) which is statistically at par with germplasm Sorghum BD-713 (422.18 mg) and Hybrid Sorgo (425.14 mg). Significantly the highest total Mg^{++} content was counted in Sorghum BD-737 (712.60 mg) which is statistically alike with Sorghum BD-703 (648.05mg) and the lowest Mg^{++} uptake was obtained from Sorghum BD-713 (271.32 mg) (Table 6).

K^+-Na^+, Na^+-Ca^{++} and Na^+-Mg^{++} ratio at 90 days after sowing

The K^+-Na^+ ratio changed significantly among the Sorghum germplasm tested in the experiment at 90 days after sowing (Table 6). The highest K^+-Na^+ ratio was calculated from the germplasm Sorghum BD- 737 which was significantly different from all other germplasm, whereas the lowest K^+-Na^+ ratio was measured from the germplasm Hybrid Sorgo. Significantly lower K^+-Na^+ ratio found in the susceptible germplasm which indicated that higher K^+-Na^+ ratio is a suitable trait for salt tolerance. As regards of Na^+-Ca^{++} ratio at 90 DAS, the highest Na^+-Ca^{++} ratio was estimated in Sorghum BD-713 (0.03) which was statistically similar to that of Sorghum BD-731 (0.026) and 737 (0.026) (Table 6). The lowest identical ratio of was calculated both from Sorghum BD-733 and Sorghum BD-733 (0.013). Significantly higher Na^+-Ca^{++} ratio found in the susceptible germplasm which indicated that lower Na^+-Ca^{++} ratio is a suitable trait for salt tolerance. In case of Na^+-Mg^{++} ratio at 90 DAS, the highest Na^+-Mg^{++} ratio was estimated in Sorghum BD-713 (0.043) (Table 6). The lowest and identical Na^+-Mg^{++} ratio was calculated from Sorghum BD-701 (0.016) and Sorghum BD-720 (0.016) which was statistically similar to that of all germplasm except Sorghum BD-706 (0.033) and 731 (0.033). Total Na^+-Mg^{++} found significantly higher in the susceptible germplasm which indicated that lower Na^+-Mg^{++} ratio is a suitable trait for salt tolerance.

Table 5. Uptake of Na^+, K^+, Ca^{++} and Mg^{++} at harvest by different parts of Sorghum plant at 90 days after sowing grown in the natural saline areas at Benerpota Satkhira, Bangladesh during 2016-17

Germplasm	Na^+ content (mg) at 90 DAS			K^+ content (mg) DAS		
	Root	Stem	Leaf	Root	Stem	Leaf
Hybrid Sorgo	5.10^{e}	3.20^{c}	1.64^{a}	110.87^{d}	664.6^{c}	143.52^{bc}
Sorghum BD-701	5.19^{de}	2.87^{cd}	1.46^{b}	217.73^{b}	882.0^{c}	248.62^{a}
Sorghum BD -703	5.67^{c}	4.27^{b}	1.70^{a}	184.69^{c}	2657.1^{a}	271.57^{a}
Sorghum BD -706	5.99^{b}	3.08^{c}	1.22^{d}	184.17^{c}	1978.6^{b}	122.0^{c}
Sorghum BD -713	4.94^{f}	5.99^{a}	1.35^{c}	164.23^{c}	625.3^{c}	151.30^{bc}
Sorghum BD -720	4.78^{g}	2.11^{d}	1.62^{a}	179.62^{c}	627.4^{c}	137.09^{c}
Sorghum BD -730	5.26^{d}	2.92^{cd}	1.3^{cd}	325.97^{a}	774.8^{c}	282.93^{a}
Sorghum BD -731	7.67^{a}	2.43^{cd}	1.32^{c}	108.63^{d}	841.8^{c}	160.96^{bc}
Sorghum BD -733	4.86^{fg}	2.39^{cd}	1.38^{bc}	110.32^{d}	603.3^{c}	214.86^{ab}
Sorghum BD -737	5.75^{c}	6.32^{a}	1.70^{a}	160.59^{c}	938.1^{c}	167.49^{bc}
LSD	0.09	0.85	0.09	29.41	394.55	77.56
CV (%)	1.05	14.05	3.77	9.82	21.71	23.79

Means bearing the dissimilar letter within the column differ significantly

Table 5 (Continued. ...): Uptake of Na^+, K^+, Ca^{++} and Mg^{++} at harvest by different parts of Sorghum plant at 90 days after sowing grown in the natural saline areas at Benerpota Satkhira, Bangladesh during 2016-17

Germplasm	Ca^{++} content (mg)			Mg^{++} content (mg)		
	Root	Stem	Leaf	Root	Stem	Leaf
Hybrid Sorgo	56.69^{f}	185.83^{bcd}	182.61^{bc}	111.73^{d}	197.21^{cd}	57.28^{d}
Sorghum BD-701	139.63^{a}	170.49^{bcd}	376.68^{ab}	239.92^{a}	206.77^{c}	88.13^{cd}
Sorghum BD -703	153.45^{a}	228.14^{ab}	163.35^{bc}	111.67^{d}	345.86^{a}	190.52^{a}
Sorghum BD -706	86.60^{cd}	160.60^{cd}	272.22^{abc}	78.77^{e}	146.09^{d}	88.95^{cd}
Sorghum BD -713	91.93^{c}	93.70^{e}	236.55^{abc}	157.95^{bc}	48.70^{e}	64.66^{d}
Sorghum BD -720	75.69^{de}	203.58^{abc}	132.98^{c}	128.52^{cd}	267.48^{b}	130.24^{bc}
Sorghum BD -730	118.04^{b}	175.76^{bcd}	447.87^{a}	128.85^{cd}	170.53^{cd}	177.40^{ab}
Sorghum BD -731	110.05^{b}	128.91^{de}	220.72^{bc}	61.17^{e}	175.88^{cd}	90.45^{cd}
Sorghum BD -733	77.05^{cde}	213.23^{abc}	339.50^{abc}	66.75^{e}	166.25^{cd}	176.10^{ab}
Sorghum BD -737	62.78ef	258.96^{a}	233.25^{abc}	171.32^{b}	340.25^{a}	201.03^{a}
LSD	15.90	61.22	226.16	29.67	55.14	52.53

CV (%)	9.54	19.62	50.60	13.77	15.57	24.21

Means bearing the dissimilar letter within the column differ significantly.

Table 6: Total uptake and ratio of Na^+, K^+, Ca^{++} and Mg^{++} in different Sorghum germplasm grown in the natural saline areas at Benerpota, Satkhira, Bangladesh during 2016-17

Germplasm	Total solute content at 90 Days After Sowing						
	Total content (mg)				Ratios		
	Na^+	K^+	Ca^{++}	Mg^{++}	K^+-Na^+	Na^+-Ca^{++}	Na^+- Mg^{++}
Hybrid Sorgo	9.95^{c}	919.0^{c}	425.14^{c}	366.22^{de}	96.06^{e}	0.023^{abc}	0.026^{bc}
Sorghum BD-701	9.52^{cd}	1348.3^{c}	686.80^{ab}	534.82^{b}	141.16^{cd}	0.013^{c}	0.016^{d}
Sorghum BD-703	11.65^{b}	3113.3^{a}	544.94^{abc}	648.05^{a}	267.80^{a}	0.023^{abc}	0.02^{cd}
Sorghum BD-706	10.29^{c}	2284.8^{b}	519.42^{abc}	313.81^{de}	220.80^{b}	0.02^{abc}	0.033^{b}
Sorghum BD-713	12.29^{b}	940.8^{c}	422.18^{c}	271.32^{e}	78.37^{e}	0.03^{a}	0.043^{a}
Sorghum BD-720	8.52^{e}	944.1^{c}	412.25^{c}	526.25^{b}	110.5^{cde}	0.02^{abc}	0.016^{d}
Sorghum BD-730	9.48^{cd}	1383.7^{c}	741.67^{a}	476.79^{bc}	145.26^{c}	0.016^{bc}	0.02^{cd}
Sorghum BD-731	11.43b	1111.4c	459.67bc	327.51de	96.83de	0.026ab	0.033b
Sorghum BD-733	8.64de	928.4c	629.77abc	409.10cd	107.9cde	0.013c	0.02cd
Sorghum BD-737	13.78a	1266.2c	554.99abc	712.60a	91.61e	0.026ab	0.02cd
LSD	0.962	476.69	230.79	97.382	45.068	0.01	0.01
CV (%)	5.32	19.51	24.93	12.38	19.37	28.81	20.22

Means bearing the dissimilar letter within the column differ significantly

Characteristics of yield attributes

Characteristics of grains (weight of grains per panicle and plant, thousand grain weights) of different Sorghum germplasm differed significantly (Table 7). The maximum weight of grains per panicle (65.56 g) was found in the Sorghum BD-706 which was at par with the genotype Sorghum BD-720. On the other hand, minimum weight of grains per panicle (30.26 g) was measured in the Sorghum germplasm Hybrid Sorgo. Similarly, the maximum weight of grains per plant (254.22 g) was recorded in the Sorghum BD-720 followed by Sorghum BD-706 and minimum weight of grains per plant (98.51 g) was measured in the genotype Sorghum BD-713. In case of 1000 grain weight, the highest weight was recorded from Sorghum BD-733 followed by the Sorghum BD-706 and Sorghum BD-737. The lowest thousand grain weight (20.09 g) was measured in Hybrid Sorgo. As regards of final plant stand, number of final plants varied among the germplasm under the trial in the coastal belt. The highest number of plant stand was counted in the plot allocated for Sorghum BD-737 (37.0) followed by Sorghum BD-701 (31.66) and the lowest was found in the plot of Sorghum BD-720 (9.66) (Table 7). On the contrary, yield performance of different Sorghum germplasm varied significantly when grown at field saline condition (Table 7). The highest yield per plot (3.84 kg) along with total yield (6.41 t/ha) was found in the Sorghum genotype Sorghum BD-737 followed by Hybrid Sorgo, Sorghum BD-701 and Sorghum BD-730. The lowest yield per plot (1.51 kg) as well as total yield (2.52 t/ha) was measured in the Sorghum germplasm Sorghum BD-720 followed by Sorghum BD-706, Sorghum BD-713, Sorghum BD-731 and Sorghum BD-733.

Table 7: Grain characteristics of 10 Sorghum germplasm grown in natural saline areas at Benerpota, Satkhira during 2016-17.

Germplasms	Grain Weight panicle^{-1} (g)	Grain weight plant^{-1} (g)	1000 grain weight (g)	Final plant stand	Plot yield (kg)	Yield (t/ha)
Hybrid Sorgo	30.26^{d}	139.18^{c}	20.09^{e}	23.66^{c}	3.76^{ab}	6.27^{ab}
Sorghum BD-701	39.84^{cd}	108.37^{c}	25.51^{bcd}	31.66^{ab}	2.90^{abc}	4.84^{abc}

Sorghum BD-703	59.85^{ab}	161.92^{bc}	27.52^{abc}	28.33^{bc}	2.40^{bc}	4.0^{bc}
Sorghum BD-706	65.56^{a}	246.27^{ab}	28.50^{ab}	30.33^{abc}	2.18^{c}	3.64^{c}
Sorghum BD-713	40.25^{cd}	98.51^{c}	22.34^{de}	25.33^{bc}	2.06^{c}	3.44^{c}
Sorghum BD-720	62.51^{a}	254.22^{a}	23.34^{cde}	9.66^{d}	1.51^{c}	2.52^{c}
Sorghum BD-730	49.98^{abc}	178.33^{abc}	21.65^{de}	25.0^{bc}	2.52^{abc}	4.20^{abc}
Sorghum BD-731	53.72^{abc}	174.31^{abc}	25.75^{bcd}	26.33^{bc}	2.06^{c}	3.43^{c}
Sorghum BD-733	41.28^{bcd}	124.20^{c}	30.92^{a}	25.0^{bc}	2.23^{c}	3.72^{c}
Sorghum BD-737	52.99^{abc}	163.03^{bc}	26.50^{a-d}	37.0^{a}	3.84^{a}	6.41^{a}
LSD	19.34	90.62	4.86	7.90	1.41	2.35
CV (%)	22.72	32.05	11.24	17.57	32.30	32.30

Means bearing the dissimilar letter within the column differ significantly.

DISCUSSION

A significant abiotic barrier to crop productivity is soil salinity, especially in Bangladesh's coastal region, where land degradation from salt intrusion is getting worse. Sorghum (*Sorghum bicolor* L. Moench), a salt-tolerant cereal crop, has potential for growing in these saline conditions. With a view to know to evaluate the ten sorghum germplasm (Hybrid Sorgo, Sorghum BD-701, Sorghum BD-703, Sorghum BD-706, Sorghum BD-713, Sorghum BD-720, Sorghum BD-730, Sorghum BD-731, Sorghum BD-733 and Sorghum BD-737) for growth, physiological adaptation, and yield performance under natural saline field conditions at the Agricultural Research Station, BARI, Satkhira during the 2015–16 and 2016–17 rabi seasons where a Randomized Complete Block Design (RCBD) with three replications was used. Plant height increased gradually according to the age of the plant (Figure 2). There was a significant difference in leaf number per plant among the Sorghum cultivars at different plant ages. The highest number of panicles per plant was observed in Hybrid Leaf numbers increased gradually according to the duration of the plant (Figure 3). From the results presented in Table 3, it appears that the features panicle (no. of panicles plant^{-1}, panicle length, no. of grains panicle^{-1}) of different Sorghum genotypes varied significantly in the field under saline conditions. Several grains per panicle varied significantly among different Sorghum genotypes. This result of the present study agrees with the observation of Begdullayeva, 2005. They said plant height, no. of panicles plant^{-1}, panicle length and no. of grains per panicle increased gradually according to the age of the plant. The total fresh weight of plant increased over time. Dry weight (g) significantly differed among the ten sorghum genotypes grown in the coastal saline region at different crop ages (Table 4). Dry weight of plants also increased over crop age. Francois *et al.* (1984) reported sorghum DM production to be unaffected by low and medium saline conditions, which was much in line with our findings. Conversely, our findings on the DM production are not in line with those of Netondo *et al.* (2004) who reported a linear decrease of both stem and plant dry weight with a soil salinity increase. Yet most studies on salinity resistance and tolerance of Sorghum and its underlying components have usually been conducted under highly controlled and artificial conditions such as growth chambers and greenhouses, often in hydroponic systems or with pot trials and during short periods (Richardson and McCree, 1985; Maas *et al.*, 1986; Amzallag *et al.*, 2000; Bernstein *et al.*, 1995; Netondo *et al.*, 2004). For this reason, Kotuby-Amacher *et al.* (2006) correctly advocate screening for salt sensitivity under local conditions and within field experiments. The yield performance could be explained by the capacity of Sorghum to adapt to salt-affected soils (Begdullayeva, 2005). Maas *et al.* (1986) reported no significant effect of soil salinity level on kernel weight but monitored a reduction in kernel weight when exposed to high soil salinity during the vegetative stage. Also, stover yields were reduced by increased salinity during the vegetative and reproductive phases, but not when the salinity was high during the maturation stage (Maas *et al*., 1986). Given the changing sensitivity to soil salinity during the growth cycle of Sorghum, a differentiation in salt uptake according to growth phases helps identify the optimal use of Sorghum in the amelioration of salt-affected soils. Although differences of Sorghum varieties in their salinity tolerance at different growth stages have been reported in various studies, the findings were inconsistent. At the same time, Maas *et al*. (1986)

concluded for two Sorghum varieties that the highest salt tolerance was at germination and emergence compared to other stages in the growth cycle. Amzallag *et al.* (2000) and El-Hendawy *et al.* (2005) reported that high soil salt concentrations during germination and emergence resulted in a (strongly) reduced stand establishment. Total K^+-Na^+ differed significantly among the tested sorghum germplasm (Table 6). Total K^+-Na^+ ratio found significantly higher in Sorghum BD-703, Sorghum BD-706 Sorghum BD-701, and Sorghum BD-733 and the lowest was estimated from Sorghum BD-713. The higher K^+-Na^+ ratio is a suitable indicator for salt tolerance. For improved tolerance to salinity, it is important to re-establish homeostasis by controlling Na^+, K^+, Cl^- transporters mediating influx and efflux to fine-tune ion concentrations in the cytoplasm (Zhu, 2001). Nonselective cation channels mediate Na^+ entry into the cell and their molecular identity is becoming clear (Munns and Tester, 2008). Anion and cation transporters are a frequent target of genetic engineering to improve crop salt tolerance (Yamaguchi and Blumwald, 2005). Total Na^+-Ca^{++} and Na^+-Mg^{++} were found significantly higher in the susceptible germplasm, indicating that lower Na^+-Ca^{++} and Na^+-Mg^{++} ratio is a suitable trait for salt tolerance. This is in line with the mechanism stated by Rashad and Dultz (2007). Generally, 6-co-ordinated Ca^{++} and Mg^{++} ions have radii of 0.100 and 0.072 nm, respectively, whereas Na^+ is 0.102 nm (Shannon, 1976). Also, single-charged Na^+ has lower clay-binding ability than double-charged Ca^{++} (or Mg^{++}), which in turn is not as strongly hydrated as Na^+ (Rashad and Dultz, 2007). Thus, after $Ca^{++}(Mg^{++})$ replacement by Na^+ and its intrusion into secondary clay minerals (e.g., 1:1 or 2:1 phyllosilicate sheets) and watering (i.e., hydration), interlamellar space increases and may cause decoupling of lamellae (sheets), i.e., clay dispersion. Finally, under alkaline conditions (pH>8) rate of dissolution (dispersion) of silicate minerals increases because excessive OH- interacts with the clay interface and generates a strong negative charge (Rashad and Dultz, 2007). Yield and yield attributes differed significantly among the germplasm (Table 7). Sorghum BD-737 recorded the highest grain yield followed by Hybrid Sorgo. Based on the results, Sorghum BD-737, Hybrid Sorgo, Sorghum BD-701 and Sorghum BD-730. This indicates that these germplasms have production potentials to grow in the natural saline soils. Therefore, these germplasms could be recommended for production in the salinity affected coastal areas of Bangladesh. These germplasms can be used as parents in breeding programs for salt-tolerant offspring.

CONCLUSION

The results of present study revealed that sorghum BD-737 recorded the highest grain yield (6.41 t ha^{-1}), followed by Hybrid Sorgo (6.27 t ha^{-1}), Sorghum BD-701 (4.84 t ha^{-1}), and Sorghum BD-730 (4.20 t ha^{-1}) among all tested germplasm. Superior K^+/Na^+ ratios were noted in Sorghum BD-737 and Sorghum BD-701, indicating strong ionic homeostasis under salt stress. These findings also suggest that the identified genotypes can serve dual purposes: as productive cultivars for saline-prone environments and as valuable parental lines in Sorghum breeding programs targeting salinity resilience. Therefore, based on the result of this study, it may be concluded that Sorghum BD-737, Hybrid sorgo, Sorghum BD 701 and Sorghum BD-730 are suitable as a cultivated genotypes in coastal saline areas and their utility in breeding salt-tolerant Sorghum varieties.

REFERENCES

[1] Rutto, L. K., Xu, Y., Brandt, M., Ren, S., and Kering, M. K., 2013, "Juice, Ethanol and Grain Yield Potential of Five Sweet Sorghum Cultivars," *J. Sustain. Bioenerg. Syst.*, **3**, pp. 113–118.

[2] Food and Agriculture Organization (FAO), 2021, *FAO Statistical Yearbook 2021*, Food and Agriculture Organization of the United Nations, Rome.

[3] Rakshit, S., Tonapi, V. A., Elangovan, M., and Kholová, J., 2023, "Recent Advances in Sorghum Genetics and Breeding for Abiotic Stress Resilience," *Front. Plant Sci.*, **13**, Article 1072523. https://doi.org/10.3389/fpls.2022.1072523

[4] Rooney, W. L., 2016, "Sorghum," in *Encyclopedia of Food Grains* (2nd ed.), Wrigley, C., Corke, H., Seetharaman, K., Faubion, J., eds., Academic Press, Oxford, pp. 222–229.

[5] Ashraf, M., and Harris, P. J. C., 2005, "Abiotic Stresses: Plant Resistance Through Breeding and Molecular Approaches," *Haworth Press*, Binghamton, NY, pp. 201–255.

[6] Mansour, M. M. F., 2021, "Salinity Tolerance Mechanisms in Sorghum," *Physiol. Mol. Biol. Plants*, **27**(3), pp. 501–511.

[7] Munns, R., and Tester, M., 2008, "Mechanisms of Salinity Tolerance," *Annu. Rev. Plant Biol.*, **59**, pp. 651–681.

[8] Zörb, C., Geilfus, C. M., and Dietz, K. J., 2019, "Salinity and Crop Yield," *Plant Biol.*, **21**(s1), pp. 31–38.

[9] Mahmuduzzaman, M., Ahmed, Z. U., Nuruzzaman, A. K. M., and Rahman, M. S., 2014, "Causes of Salinity Intrusion in Coastal Bangladesh," *J. Environ. Manage.*, **144**, pp. 571–578.

[10] Soil Resources Development Institute (SRDI), 2010, *Saline Soils of Bangladesh*, SRDI, Ministry of Agriculture, Dhaka, Bangladesh.

[11] Haque, S. A., 2006, "Salinity Problems and Crop Production in Coastal Regions of Bangladesh," *Pak. J. Bot.*, **38**(5), pp. 1359–1365.

[12] Islam, M. S., Hossain, M. A., and Miah, M. G., 2020, "Crop Diversification in the Coastal Area of Bangladesh: Constraints and Policy Options," *Bangladesh J. Agric. Econ.*, **41**(1), pp. 55–73.

[13] Netondo, G. W., Onyango, J. C., and Beck, E., 2004, "Sorghum and Salinity: II. Gas Exchange and Chlorophyll Fluorescence of Sorghum under Salt Stress," *Crop Sci.*, **44**, pp. 806–811.

[14] Gupta, B., and Huang, B., 2014, "Mechanism of Salinity Tolerance in Plants: Physiological, Biochemical, and Molecular Characterization," *Int. J. Genomics*, Article ID 701596. https://doi.org/10.1155/2014/701596

[15] Begdullayeva, T., 2005, "The Crop of Multipurpose Use," *Agric. Uzbekistan*, **4**, pp. 28–29.

[16] Francois, L. E., Donovan, T. J., and Maas, E. V., 1984, "Salinity Effects on Seed Yield, Growth, and Germination of Grain Sorghum," *Agron. J.*, **76**, pp. 741–744.

[17] Richardson, S. G., and McCree, K. J., 1985, "Carbon Balance and Water Relations of Sorghum Exposed to Salt and Water Stress," *Plant Physiol.*, **79**, pp. 1015–1020.

[18] Maas, E. V., Poss, J. A., and Hoffman, G. J., 1986, "Salinity Sensitivity on Sorghum at Three Growth Stages," *Irrig. Sci.*, **7**, pp. 1–11.

[19] Amzallag, G. N., 2000, "Maternal Transmission of Adaptive Modifications in Salt Treated *Sorghum bicolor*: A Rest Stage in Ecotypic Differentiation?" *New Phytol.*, **146**, pp. 483–492.

[20] El-Hendawy, S. E., Hu, Y., Yakout, G. M., Awad, A. M., Hafiz, S. E., and Schmidhalter, U., 2005, "Evaluating Salt Tolerance of Wheat Genotypes Using Multiple Parameters," *Eur. J. Agron.*, **22**(3), pp. 243–253.

[21] Kotuby-Amacher, J., Koenig, R., and Kitchen, B., 2006, "Salinity and Plant Tolerance," Utah State University Extension. Available at: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1092&context=extension_curall [Accessed 3 July 2006].

[22] Zhu, J. K., 2001, "Plant Salt Tolerance," *Trends Plant Sci.*, **6**(2), pp. 66–71.

[23] Yamaguchi, T., and Blumwald, E., 2005, "Developing Salt-Tolerant Crop Plants: Challenges and Opportunities," *Trends Plant Sci.*, **10**(12), pp. 615–620.

[24] Rashad, M., and Dultz, S., 2007, "Decision Factors of Clay Dispersion in Alluvial Soils of the Nile River Delta – A Study on Surface Charge Properties," *Am.-Eurasian J. Agric. Environ. Sci.*, **2**(3), pp. 213–219.

[25] Bernstein, N., Silk, W. K., and Läuchli, A., 1995, "Growth and Development of Sorghum Leaves under Conditions of NaCl Stress: Possible Role of Some Mineral Elements in Growth Inhibition," *Planta*, **196**, pp. 699–705.