



e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE



Evaluation of sunflower germplasms for salt tolerance based on morpho-physiological and yield attributes

Md. Zulfiqar^{1,2}, Jannat E Tajkia², Md. Tariqul Islam³, Md. Ashik Mia² and A.K.M. Zakir Hossain^{2*} 

¹Scientific Officer, On Farm Research Division Bangladesh Agricultural Research Institute (BARI), Sylhet, Bangladesh

²Department of Crop Botany, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh - 2202, Bangladesh

³Haor and Char Development Institute, Bangladesh Agricultural University, Mymensingh - 2202, Bangladesh

*Corresponding author's E-mail: zakir@bau.edu.bd

ARTICLE HISTORY

Received: 08 March 2025

Revised received: 08 May 2025

Accepted: 17 May 2025

Keywords

Chlorophyll content

Morphological traits

Photosynthesis

Photochemical efficiency

Transpiration rate

ABSTRACT

The effects of salinity on sunflower (*Helianthus annuus* L.) germplasms growth, morpho-physiological traits and yield attributes among six varieties was studied to identify potential salt-tolerant sunflower varieties for cultivation in saline-prone areas of Bangladesh. For this, an experiment was conducted at Bangladesh Agricultural University in a net house from January 2019 to May 2019. Results showed that all varieties of sunflower exhibited significant ($p < 0.05$) alterations to morphological characteristics aside from stem diameter under salt stress conditions. The physiological changes were also induced, except for one measure of photochemical efficiency. Notably, relative chlorophyll content, photosynthesis rate, transpiration rate, and total chlorophyll content shifted in a variety dependent manner. However, maximum photochemical efficiency did not statistically differ between varieties impacted by saline soils. Additionally, salt exposure impacted seed yield aspects such as filled and sterile seed counts per head, total seed weight per individual flower, and 1000-seed mass, with prominent variations among the tested varieties of sunflower. Therefore, out of the six varieties of sunflower evaluated in this assessment of salt tolerance, Hysun 33 was emerged as the most resilient to adverse impacts of salinity on growth and productivity of sunflower in salinity affected regions of Bangladesh.

©2025 Agriculture and Environmental Science Academy

Citation of this article: Zulfiqar, M., Tajkia, J. E., Islam, M. T., Mia, M. A., & Zakir Hossain, A. K. M. (2025). Evaluation of sunflower germplasms for salt tolerance based on morpho-physiological and yield attributes. *Archives of Agriculture and Environmental Science*, 10(2), 197-204, <https://dx.doi.org/10.26832/24566632.2025.100201>

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the world's most important oilseed crops, following groundnut, rapeseed, and mustard (Talia *et al.*, 2011). Primarily cultivated for its edible seed oil, sunflower is highly valued for its fatty acid profile, particularly its high content of unsaturated fatty acids such as linoleic acid. Additionally, sunflower seeds are used in confectionery and snacks, and the plant itself is grown for ornamental purposes. Sunflower is widely cultivated in countries with salt-affected soils, including India, China, and Bangladesh. The rapid increase in the global population has created an urgent need to expand agricultural areas and boost food production. However, much of the available land is of low quality, with a significant

portion affected by soil salinity (Bach Allen *et al.*, 1983). Soil salinity, exacerbated by over-irrigation and poor water management practices, is a major constraint on agricultural productivity, particularly in arid and semi-arid regions. High salinity reduces water uptake by plants, which in turn limits growth and crop yields (Farooq *et al.*, 2015). This issue is widespread, with no climatic zone being exempt from the effects of salinity (Rengasamy, 2010). Sodium chloride, the most common form of salinity, has been found to severely affect crop yields worldwide (Maibody & Feizi, 2005; Demiral and Turkan, 2005). In Bangladesh, salinization is a significant challenge, especially in coastal and offshore areas. Approximately 10% of the country is less than one meter above sea level, and one-third is subject to tidal fluctuations, making it highly vulnerable to saline intrusion

(SRDI, 2023). The extent of salt-affected land in Bangladesh has increased from 0.833 million hectares to approximately 1.13 million hectares in the last four decades (SRDI, 2023). Coastal areas alone account for around 2.85 million hectares, with 1.2 million hectares experiencing severe salinization (SRDI, 2023). This has resulted in 30-50% of cropped areas being left fallow during the Rabi season, as salinity levels peak during the dry months and subside in the wet season. Soil salinity refers to the accumulation of dissolved salts in the soil, which affects plant growth by hindering water absorption and nutrient availability. As salinity increases, the osmotic potential of the soil decreases, making it harder for plant roots to absorb water. In severe cases, plant roots may lose water to the soil due to the higher osmotic pressure (McKersie & Leshem, 1994). Salinity stress affects plants through osmotic effects, ion toxicity, and nutrient imbalances, which disrupt growth and reduce productivity (Läuchli & Epstein, 1990). Photosynthesis, the key process for plant growth, is particularly affected by salinity. Reduced CO₂ assimilation, transpiration, and water use efficiency under salt stress are due to both stomatal and non-stomatal limitations (Ashraf, 2012), and this is evident in crops like rice (Moradi & Ismail, 2007), wheat (Kanwal et al., 2011), and sunflower (Noreen & Ashraf, 2008). The impact of salinity is particularly pronounced during germination, a crucial stage for plant establishment. Salt stress can delay or inhibit germination by reducing seed water uptake, leading to poor plant establishment and lower yields (Carpıcı et al., 2009; Foolad & Lin, 1999). Salinity inhibits root and shoot growth, limiting the plant's ability to absorb water and nutrients (Jamil & Rha, 2004). These growth limitations result in reduced crop yields and delayed or abnormal seedling development (McKersie & Leshem, 1994). In Bangladesh's coastal regions, where annual rainfall is insufficient to counter evapotranspiration, soluble salts accumulate in the soil, further reducing plant growth (Roy & Srivastava, 2016). Salinity intrusion exacerbated by climate change has severely affected crop productivity in these areas, necessitating the development of salt-tolerant crop varieties. Sunflower, a high-value oilseed crop, offers a potential solution for growing crops in saline-affected soils, particularly during the Rabi season when rice fields lie fallow. Sunflower is photo- and thermo-neutral, which allows it to be grown in both the Rabi and Kharif seasons. In Bangladesh, sunflower is a promising alternative crop for coastal regions affected by salinity. However, its cultivation has been limited by the dominance of rice production. In regions where sodium chloride salinity is prevalent (Khatun et al., 2016), cultivating salt-tolerant sunflower varieties could provide economic benefits and help address the country's edible oil deficit (Subbarao et al., 2006; Zakir et al., 2008). Furthermore, sunflower cultivation in saline soils may improve food security and enhance farmers' income. This study aims to evaluate six high-yielding sunflower cultivars—BARI Sunflower-2, Kironi, Suborno, HYSUN 33, HYSUN 36, and Hi-Variety Big Sunflower—grown under salinity stress to assess their growth characteristics and salt tolerance. Thus, this study was conducted to evaluate sunflower germplasms for salt tolerance based

on morpho-physiological traits, to assess the yield potential of sunflower germplasms under salinity stress and to identify potential salt-tolerant sunflower varieties for cultivation in saline-prone areas of Bangladesh.

MATERIALS AND METHODS

Plant materials and seed collection

Six sunflower varieties were used in this study: BARI-2, Kironi, Hybrid Sunflower Suborno, Hybrid Sunflower-33, Hybrid Sunflower-36, and Hybrid Variety Big Sunflower. The seeds were obtained from the Bangladesh Agricultural Research Institute (BARI) and a local nongovernmental seed company. Seeds were stored in a refrigerator at 4°C until use in the experiment.

Experimental site

The experiment was conducted in a controlled environment at the Botanical Garden net house, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh (24.7196° N, 90.4276° E) from January 21, 2019, to May 10, 2019. Experimental Design and Layout: The experiment followed a Complete Block Design (CBD) with two factors and three replications: • Factor 1: Six sunflower varieties • Factor 2: Two salinity levels (Control: 0 dS/m, 12 dS/m), each treatment was randomly assigned to 36 pots, with one variety per pot. The total number of experimental units was 36, distributed across six varieties and two salinity treatments (Table 1).

Experimental setup pot and soil preparation and fertilization

The pots used were 10-liter plastic fiber buckets (RFL brand). The soil was collected from the Brahmaputra riverbanks and mixed with well-decomposed cow dung. Each pot was filled with 10 kg of this soil mixture. Basal fertilizer doses were applied to supply nitrogen (urea), phosphorus (triple superphosphate - TSP), potassium (muriate of potash - MP), and calcium (gypsum). The full doses of TSP, MP, and gypsum, along with half of the urea, were incorporated into the soil during final preparation. The remaining urea was applied as a top dressing in split doses at 10 days after sowing.

Treatment: Salinity levels were simulated by adding NaCl to the soil. To determine the appropriate amount of salt, a saturated soil paste was prepared, and electrical conductivity (EC) was measured until the target EC of 12 dS/m was achieved. The control treatment received distilled water only.

Table 1. Manures and fertilizers required in the experiment.

S. No.	Manures and fertilizers	Doses ha ⁻¹	Amount pot ⁻¹
1.	Cow dung	5 Ton	0.025 kg
2.	Urea	130 kg	0.652 g
3.	Triple super phosphate	230 kg	1.1 g
4.	Muriate of Potash	90 kg	0.45 g
5.	Gypsum	200 kg	1 g

Seed sowing and planting: Five uniform seeds from each variety were selected and sown by hand at a depth of 3 cm in each pot. Prior to sowing, the seeds were hydro-primed for 24 hours to facilitate uniform germination. Seedlings emerged within two days of sowing. Pots were labeled with color-coded tokens to ensure proper identification throughout the experiment.

Maintenance and intercultural operations: Routine maintenance activities, including weeding, thinning, gap filling, watering, and top dressing with urea, were conducted to ensure optimal plant growth. Protection from rain and storms was also provided to maintain experimental integrity.

Data collection

Morphological parameters including root length (cm), shoot length (cm), number of leaves per plant, leaf area (cm²), stem diameter (cm), fresh weight and dry weight of root and shoot (g), girth of flower (cm) were measured following standard methods. Physiological parameters such as photosynthetic rate ($\mu\text{molCO}_2 \text{ m}^{-2}\text{s}^{-1}$), Transpiration rate ($\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$), Stomatal conductance ($\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$), chlorophyll fluorescence (Fv/Fm ratio), and relative chlorophyll content (SPAD values) were recorded. The effects of salinity on seed yield were assessed by counting the number of filled seeds, sterile seeds, seed weight per head, and 1000-seed weight. The flower heads were harvested at 105 days after sowing (DAS). Data on yield and other physiological attributes were recorded at the time of harvest.

Statistical analysis

Data were analyzed using analysis of variance (ANOVA) based on a completely randomized design (CRD). Significance levels were determined using the LSD test at 5% and 1% probability levels. All statistical analyses were performed using SPSS software (version 20).

RESULTS AND DISCUSSION

This section presents the impact of different salinity levels on the morphological, physiological, and yield traits of sunflower varieties, highlighting the interaction between salinity stress and variety-specific responses.

Morphological attributes

Root and shoot length: The interaction between salinity levels and sunflower varieties had a significant effect on both root and shoot lengths (Figure 1). Under control conditions, the maximum root length (15.333 cm) and shoot length (89.667 cm) were recorded in the Hysun 33 variety, followed by Hysun 36 (14.8 cm root length and 84.333 cm shoot length), hybrid big sunflower (14 cm root length and 81.333 cm shoot length), while BARI-2 exhibited the lowest measurements (11.9 cm root length and 50.333 cm shoot length). Under 12 dS/m salinity con-

ditions, root length and shoot length were again highest in Hysun 33 (14.267 cm and 84.333 cm), followed by Hysun 36 (12.967 cm and 80 cm), hybrid big sunflower (12.133 cm and 76.9 cm), and BARI-2 showed the least growth (7.95 cm and 47.433 cm). The results indicate that Hysun 33 and Hysun 36 varieties exhibited superior tolerance to salt stress compared to other varieties. This aligns with the findings of Achakzai *et al.* (2015), who observed a reduction in plant length with increasing salinity in hybrid sunflower varieties. Ramaswamy & Rao (2018) also found that root and shoot lengths were reduced under salinity stress, a pattern supported by Chowdhury *et al.* (2022). The reduction in growth under salinity stress is primarily attributed to osmotic stress, which hinders water uptake by roots, thereby limiting growth (Taiz & Zaiger, 1991). These findings are consistent with Eshel & Beeckman (2017), who reported similar reductions in root and shoot growth under saline conditions. Various biochemical changes caused by salt stress affect the growth of sunflower genotypes, as reported by Kamal *et al.* (2003) and Kaya *et al.* (2003).

Number of leaves per plant: Salinity considerably influenced the number of leaves per plant throughout the sunflower species (Figure 1). Under control conditions, Hysun 33 produced the highest number of leaves (15.667), followed by Hysun 36 (14.00), hybrid big sunflower (14.00), and the lowest number of leaves recorded in BARI-2 (12.00), followed by Suborno (11.333) and Kironi (10.333). Under 12 dS/m salt stress, Hysun 33 again exhibited the largest number of leaves per plant (13.00), followed by Hysun 36 (12.80), hybrid big sunflower (12.00), whereas BARI-2 (10.33), Suborno (10.00), and Kironi (7.00) showed much fewer leaves. Underwater salinity treatment, the number of leaves dropped in all kinds; Hysun 33 showed the best performance among all salinity levels. Compared to the control, this outcome is consistent with Hussain *et al.* (2008) observations of declining leaf count with rising salinity (EC 10 dS/m). Similar findings were observed by Hafeez *et al.* (2017a), who noted that Hysun 33 performed better in terms of leaf production under salt stress. Similar result also found by Chowdhury *et al.* (2022) stated that number of leaves were significantly decreased as the salinity level increased. The plant's adaptive mechanism to save water and lower transpiration under osmotic stress most certainly explains the decrease in leaf count under salinity stress.

Leaf area: The interaction between salinity levels and varieties also had a significant effect on leaf area (Figure 1). Under control conditions, Hysun 33 exhibited the largest leaf area (345.87 cm²), while BARI-2 showed the smallest leaf area (198.09 cm²). Under 12 dS/m salinity, Hysun 33 maintained the highest leaf area (340.3 cm²), while BARI-2 again exhibited the lowest leaf area (189.952 cm²). These results suggest that Hysun 33, with its superior nutrient uptake and leaf expansion capacity, was able to maintain a larger leaf area compared to other varieties, even under saline conditions. This finding is consistent with the studies by Mohamedin *et al.* (2006), who reported a significant

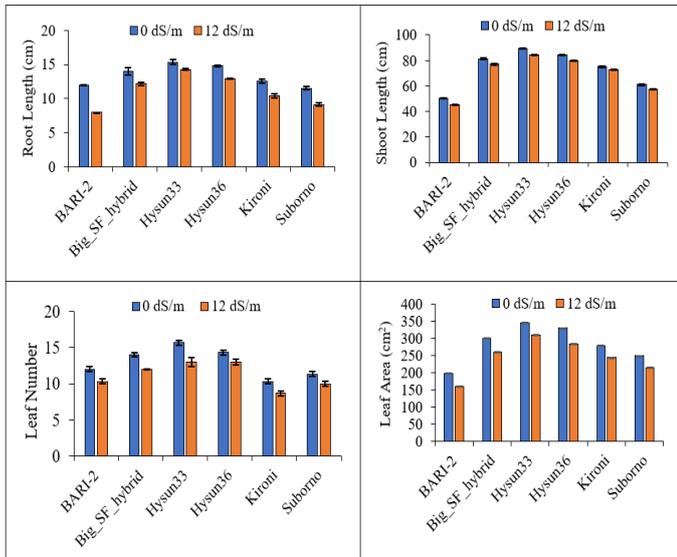


Figure 1. Effects of salinity levels on leaf length (cm), shoot length (cm), leaf number and leaf area of different sunflower varieties. Vertical bars are SEM ($n=3$).

reduction in leaf area with increasing salinity in sunflower plants. Leaf area also showed notable declines at higher salinity levels, indicating impaired photosynthesis and overall plant vigor (Chowdhury et al., 2022). Salinity-induced water stress likely causes the plant to accumulate solutes to maintain cell volume, thereby limiting leaf expansion (Patakas et al., 2002). Mane et al. (2011) also confirmed that high salinity significantly reduces the leaf area of sunflower plants, aligning with the current findings.

Stem diameter: While there were differences in the salinity levels across the varieties, no significant variation was observed in the interaction effect on stem diameter (Table 2). However, all sunflower varieties exhibited a reduction in stem diameter with increasing salinity, which is consistent with previous findings by Hafeez et al. (2017b). In this study, the stem diameter decreased in all varieties under saline conditions, and Hysun 33

Table 2. Effects of salinity level on stem diameter of different sunflower varieties.

Treatment	Variety	Stem diameter (cm)
0 dSm ⁻¹	BARI-2	2.3
	Hybrid SF variety	3
	Hysun33	3.6
	Hysun36	3.5
	Kironi	2.6
	Suborno	2.6
12 dSm ⁻¹	BARI-2	2.2
	Hybrid SF variety	2.9
	Hysun33	3.3
	Hysun36	3.1
	Kironi	2.4
	Suborno	2.2
LSD _{0.05}		0.046
CV(%)		17.37
Level of significance		NS

LSD= Least Significant Difference; ** = Significant at 1% level of probability, NS = Not significant.

consistently showed the best performance across all salinity levels. The stem diameter of sunflower decreased significantly with increasing soil salinity and alkalinity. The greatest reductions in stem diameter were observed in saline-alkali and alkali soils, particularly in shallower profiles (80 cm depth). This decline was more pronounced with higher salt content and lower soil depths (Kader et al., 2006). This result supports the conclusion that salinity negatively affects stem development, as previously reported in various sunflower cultivars.

Fresh and dry weight of root and shoot: Under all conditions, Hysun 33 clearly recorded the highest values for both root and shoot fresh and dry weights; BARI-2 displayed the lowest values. When exposed to varying NaCl concentrations (40, 80, and 120 mM), similar patterns of variation in salt tolerance have been noted in sunflower genotypes including FS1, FS2, and FS5. The findings of this investigation showed that big sunflower and Kironi showed more marked decrease in shoot dry weight than Hysun 33 and Hysun 36. Over the control conditions, Hysun 33 displayed a rise in root fresh and dry weight; big sunflower displayed a loss. Osmotic stress and the toxic effects of Na⁺ and Cl⁻ ions, which have been found as main causes of growth suppression, are probably responsible for this decrease in root and shoot weight under saline circumstances (Turan et al., 2007; Tafouo et al., 2008). Moreover, big sunflower showed increased evidence of oxidative stress brought on by salt stress, which increases lipid peroxidation levels and damages proteins and cell membranes (Mano, 2002). As Azevedo-Neto et al. (2006) have pointed out, similar discoveries have been made in salt-tolerant and salt-sensitive maize genotypes. These results reveal that sunflower plants' fresh and dry weights drop with rising salinity levels; Hysun 33 shows superior salt resistance than other kinds.

Girth of flower: While the smallest girth was obtained in Kironi (35.00 cm), under control conditions the highest flower girth (43.57 cm) was recorded in Hysun 33, followed by hybrid big sunflower (40.2 cm) and Hysun 36 (39.02 cm). Hysun 33 once more displayed the largest flower girth (42.50 cm), followed by hybrid big sunflower (41.00 cm) and Hysun 36 (38.05 cm), and with the lowest figure once recorded in Kironi (35.00 cm). Saline circumstances with the loss more noticeable in cultivars exposed to higher salinity levels, the graph (Figure 2) amply illustrates how floral width dropped under saline circumstances relative to the control. Roy & Srivastava (2016) propose that the negative consequences of salinity on general plant growth and development could explain the decrease in blossom girth in response to salinity. The yield potential of sunflower plants is directly correlated with flower girth, hence the decrease in girth under salt stress suggests that salinity reduces the reproductive growth of the plant. Hysun 33 showed promise for farming in saline-prone regions despite the stress since it performed the best among all salinity levels.

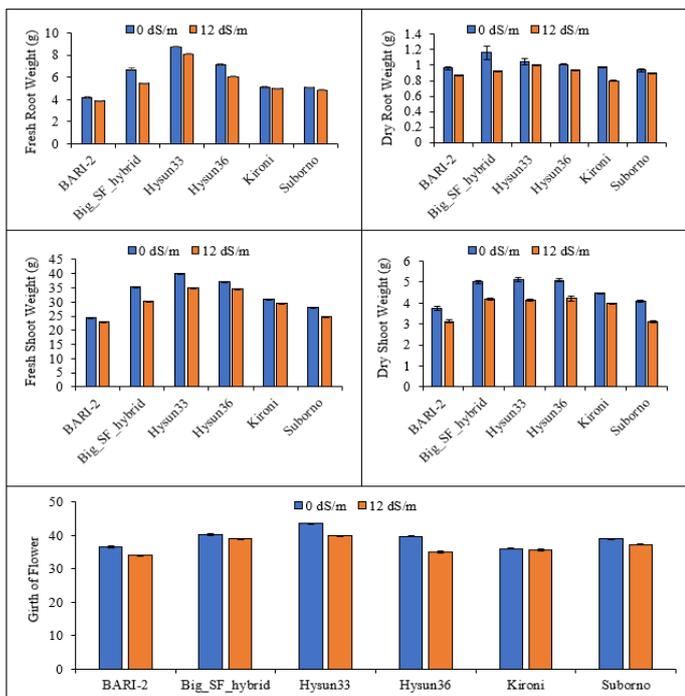


Figure 2. Effects of salinity levels on fresh root weight (g), dry root weight (g), fresh shoot weight (g), dry shoot weight (g) and girth of flower of different sunflower varieties. Vertical bars are SEM (n=3).

Physiological attributes

Relative chlorophyll content (SPAD Value): The relative chlorophyll content (SPAD value) was much changed by the interaction between sunflower types and salinity (Figure 3). Under regulated conditions, Hysun 33 (48.35) had the greatest SPAD value; followed by Hysun 36 (42.467); and hybrid big sunflower (40.817). BARI-2 (29.13) had the lowest SPAD value; Suborno (33.517) came second, then Kironi (29.95). While BARI-2 (25.207), Suborno (29.883), and Kironi (20.00) showed the lowest chlorophyll content, Hysun 33 retained the greatest SPAD value (42.837), followed by Hysun 36 (39.337), and hybrid big sunflower (35.17). Under 12 dS/m salinity, the findings showed that salinity raised significantly decreased chlorophyll content. Under saline stress, Hysun 33 kept greater levels of chlorophyll than other variants. Kader *et al.* (2006) also found similar results—a drop in chlorophyll concentration brought on by salt stress. Reduced carbon absorption, stomatal conductance, and photochemical capacity (Gaballah *et al.*, 2006; Hussain *et al.*, 2008) are typically the causes of the lower photosynthetic efficiency under saline circumstances.

Maximum photochemical efficiency of PSII (Fv/Fm): The highest photochemical efficiency of PSII (Fv/Fm) was not much changed by the interaction between salinity and sunflower types (Table 3). Still, considerable variance in Fv/Fm was noted among the many cultivars and salt levels. Consistent with results by Umar & Siddiqui (2018), the maximum photochemical efficiency of PSII (Fv/Fm) showed a little decrease under salt stress. A sensitive measure of plant stress, chlorophyll fluorescence declines in stress-sensitive plants, suggesting ongoing photo-inhibition under salty circumstances (Weng *et al.*, 2008; Zlatev, 2009). This work shows no appreciable change in Fv/Fm with increased salt,

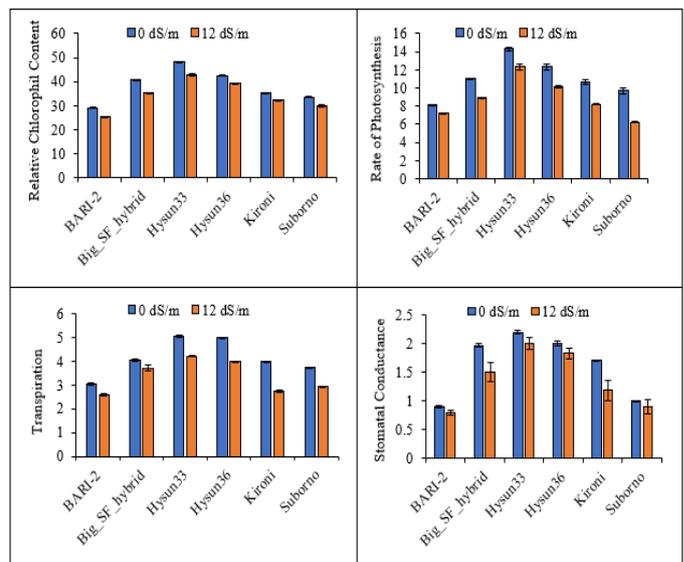


Figure 3. Effects of salinity levels on relative chlorophyll content, rate of photosynthesis, transpiration and stomatal conductance (gs) of different sunflower varieties. Vertical bars are SEM (n=3).

implying that sunflower variants could be able to sustain photochemical efficiency independent of salinity.

Photosynthesis (Pn; A): The way salt and sunflower types interacted had a big effect on photosynthesis (Figure 3). The plants that did the best in control conditions had the fastest photosynthetic rate ($14.297 \mu\text{mol m}^{-2} \text{s}^{-1}$). These were followed by Hysun 36 ($12.327 \mu\text{mol m}^{-2} \text{s}^{-1}$) and hybrid big sunflower ($11.053 \mu\text{mol m}^{-2} \text{s}^{-1}$). The plant with the slowest photosynthesis was BARI-2 ($8.15 \mu\text{mol m}^{-2} \text{s}^{-1}$), then Suborno ($9.687 \mu\text{mol m}^{-2} \text{s}^{-1}$), and finally Kironi ($9.807 \mu\text{mol m}^{-2} \text{s}^{-1}$). Even when the salt level was 12 dS/m, Hysun 33 still had the fastest photosynthesis rate ($12.32 \mu\text{mol m}^{-2} \text{s}^{-1}$), followed by Hysun 36 ($10.153 \mu\text{mol m}^{-2} \text{s}^{-1}$) and hybrid big sunflower ($9.003 \mu\text{mol m}^{-2} \text{s}^{-1}$). Some of the plants that did the least amount of photosynthesis in salty conditions were BARI-2 ($7.237 \mu\text{mol m}^{-2} \text{s}^{-1}$), Suborno ($6.26 \mu\text{mol m}^{-2} \text{s}^{-1}$), and Kironi ($5.85 \mu\text{mol m}^{-2} \text{s}^{-1}$). Similar to what Niu *et al.* (2012) and Munns & Tester (2008) found, these results show that photosynthetic rates drop significantly as salt rises. The drop in photosynthesis is because stomata close, the photosynthetic electron chain gets messed up, and Calvin cycle enzymes like Rubisco and PEPC stop working (Parida & Das, 2005; Chaves *et al.*, 2009). This means that photosynthesis and gas exchange rates may slow down when there is a lot of salt in the environment.

Transpiration (E): Transpiration was much influenced by the interaction of salt concentration and sunflower types (Figure 3). In control circumstances, the maximum transpiration was again recorded in Hysun 33 ($5.05 \text{mmol m}^{-2} \text{s}^{-1}$), followed by Hysun 36 ($4.98 \text{mmol m}^{-2} \text{s}^{-1}$) and hybrid big sunflower ($4.04 \text{mmol m}^{-2} \text{s}^{-1}$), with BARI-2 displaying the lowest ($3.033 \text{mmol m}^{-2} \text{s}^{-1}$). These results suggest a decrease in transpiration with increasing salt in all types, with Hysun 33 consistently outperforming the other cultivars at both salinity levels. This is in line with research by Tian (2020), where stunted development and lower canopy cover were found to lower salinity, so lowering transpiration.

Salinity stress lowers plant growth by raising osmotic pressure, which limits water absorption and reduces canopy development, so lowering transpiration.

Stomatal conductance (gs): The interaction between salt concentration and varieties significantly affected stomatal conductance (Figure 3). At the 12 dS/m salinity level, Hysun 33 exhibited the highest stomatal conductance ($2.007 \text{ mol m}^{-2} \text{ s}^{-1}$), followed by Hysun 36 ($1.84 \text{ mol m}^{-2} \text{ s}^{-1}$) and hybrid big sunflower ($1.5 \text{ mol m}^{-2} \text{ s}^{-1}$). In contrast, BARI-2 showed the lowest stomatal conductance ($0.797 \text{ mol m}^{-2} \text{ s}^{-1}$), followed by Suborno ($0.9 \text{ mol m}^{-2} \text{ s}^{-1}$) and Kironi ($0.45 \text{ mol m}^{-2} \text{ s}^{-1}$). A similar trend was observed under control conditions, where Hysun 33 maintained the highest stomatal conductance and big sunflower exhibited the lowest. The results indicate a reduction in stomatal conductance with increasing salinity in all varieties. This decline is consistent with the findings of Rivelli (2002), who reported that salinity stress significantly decreases stomatal conductance, CO_2 assimilation, and above-ground dry weight in sunflowers as the soil salinity increases. Hysun 33 exhibited the best performance across all salinity levels, demonstrating its superior salt tolerance.

Yield attributes: The number of filled seeds per head was highest in Hysun 33 (630), followed by Hysun 36 (621.33), and hybrid big sunflower (613), with BARI-2 exhibiting the lowest number of filled seeds per head (520.33), and followed by Suborno (550) and Kironi (580) under control conditions. At 12 dS/m salinity, Hysun 33 again produced the maximum number of filled seeds per head (523), followed by Hysun 36 (509.33), hybrid big sunflower (487), while BARI-2 (471), Suborno (400.33), and Kironi (450.33) showed a significant reduction (Figure 4). In terms of sterile seeds per head, BARI-2 recorded the highest number of sterile seeds (120.30), followed by Suborno (107), and Kironi (100.3) at control conditions. In contrast, Hysun 33 exhibited the

least number of sterile seeds per head (78.26), followed by Hysun 36 (80), and hybrid big sunflower (82.33) under control conditions. At 12 dS/m salinity, BARI-2 continued to show the highest number of sterile seeds (149), followed by Suborno (123.27) and Kironi (108), while Hysun 33 showed the lowest sterile seed count (83.34), followed by Hysun 36 (86.67) and hybrid big sunflower (90.00) (Figure 4). The weight of total seeds per flower head was highest in Hysun 33 (60.00 g), followed by Hysun 36 (58.00 g), hybrid big sunflower (55.00 g), and lowest in BARI-2 (49.66 g), Suborno (52.00 g), and Kironi (54.54 g) under 12 dS/m salinity. Under control conditions, Hysun 33 produced the highest weight of total seeds per flower head (70.37 g), followed by Hysun 36 (68.04 g), hybrid big sunflower (65.08 g), while BARI-2 (58.34 g), Suborno (60.04 g), and Kironi (62.23 g) recorded lower values (Figure 4). Seed yield per plant significantly decreased with increasing salinity levels, consistent with findings by Hafeez et al. (2017b). Salinity, along with nutrient interactions, typically reduced crop yield by about 20%, depending on the salinity level and salt composition (Abd E-Kader et al., 2006). The weight of 1000 seeds followed a similar trend. At control conditions, Hysun 33 recorded the highest weight (75 g), followed by Hysun 36 (72.33 g) and hybrid big sunflower (68.33 g), while BARI-2 (61.00 g), Suborno (62.67 g), and Kironi (64.56 g) had the lowest weights. Under 12 dS/m salinity, the weight of 1000 seeds was highest in Hysun 33 (62 g), followed by Hysun 36 (64 g), and hybrid big sunflower (64.56 g), while BARI-2 (52 g), Suborno (56.33 g), and Kironi (58.45 g) showed reduced weights (Figure 4). These results suggest that all yield attributes, including the number of filled seeds per head, seed weight, and the weight of 1000 seeds, decreased with increasing soil salinity. However, the number of sterile seeds per head decreased with lower salinity, and Hysun 33 consistently outperformed other varieties in terms of yield and resilience under saline conditions.

Table 3. Effects of salinity level on maximum photochemical efficiency of PSII (Fv/Fm) of different sunflower varieties.

Treatment	Variety	Maximum photochemical efficiency of PSII (Fv/Fm)
0 dSm ⁻¹	BARI-2	0.73
	Hybrid SF big variety	0.83
	Hysun33	0.81
	Hysun36	0.83
	Kironi	0.81
	Suborno	0.78
12 dSm ⁻¹	BARI-2	0.72
	Hybrid SF big variety	0.78
	Hysun33	0.78
	Hysun36	0.75
	Kironi	0.80
	Suborno	0.76
LSD _{0.05}		0.056
CV%		5.75
Level of significance		NS

LSD= Least Significant Difference; ** = Significant at 1% level of probability, * = Significant at 5% level of probability, NS = Not significant.

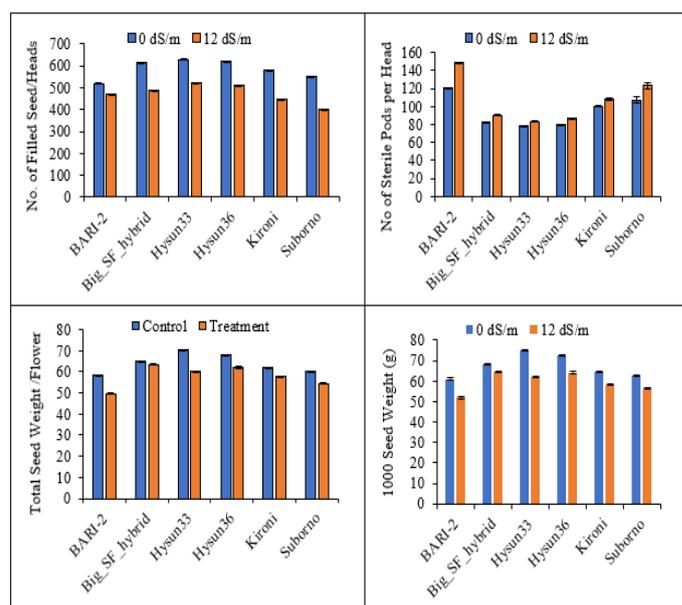


Figure 4. Effects of salinity levels on number of filled seeds per head, number of sterile pods per head, total seed weight per flower (g), 1000 seed weight (g) of different sunflower varieties. Vertical bars are SEM (n=3).

Conclusion

The study revealed that salinity significantly hampers the growth, physiological functions, and yield of sunflower plants. Among the tested varieties, Hysun 33 consistently outperformed others, maintaining higher plant height, leaf area, chlorophyll content, and seed yield even under high salinity stress (12 dS/m). This indicated a superior salt tolerance compared to other varieties such as BARI-2, Suborno, and Kironi, which showed substantial declines in all measured traits under saline conditions. These findings identified Hysun 33 as a salt-tolerant and high-yielding sunflower variety, making it suitable for cultivation in salt-affected areas. The results also emphasize the need for further research to understand the physiological and molecular mechanisms behind Hysun 33's salt tolerance and to develop effective salinity management practices for sunflower cultivation in challenging environments.

ACKNOWLEDGMENTS

The authors would like to sincerely thank the Ministry of Science and Technology, Bangladesh, for providing financial support under the "NST Fellowship" to carry out this research. Their contribution was instrumental in the successful completion of this study.

DECLARATIONS

Author contribution statement

Conceptualization: A.K.M. Z.H., and J.T.; Methodology: A.K.M. Z.H., and M.Z.; Software and validation: J.T., M.T.I. and M.A.M.; Formal analysis and investigation: M.Z.; Resources: A.K.M. Z.H.; Data curation: M.J.; Writing—original draft preparation: M.Z.; Writing—review and editing: A.K.M. Z.H. and M.T.I.; Visualization: M.T.I., and M.A.M.; Supervision: A.K.M. Z.H.; Project administration: A.K.M. Z.H.; Funding acquisition: A.K.M. Z.H. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: This study did not involve any animal or human participant and thus ethical approval was not applicable.

Consent for publication: All co-authors gave their consent to publish this paper in AAES.

Data availability: The data that support the findings of this study are available on request from the corresponding author.

Supplementary data: No supplementary data is available for the paper.

Funding statement: No external funding is available for this study.

Additional information: No additional information is available for this paper.

Open Access: This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) or sources are credited.

Publisher's Note: Agro Environ Media (AES) remains neutral with regard to jurisdictional claims in published maps, figures and institutional affiliations.

REFERENCES

- Abd, E. A., Djalal, M., & Tahir, M. (2006). Effect of salinity and nutrient interactions on the growth and yield of sunflower. *Agricultural Water Management*, 85(1), 15-23.
- Abd E-Kader, A. A., Mohamedin, A. A. M., & Ahmed, M. K. A. (2006). Growth and yield of sunflower as affected by different salt affected soils. *International Journal of Agriculture and Biology*, 8, 583-587.
- Achakzai, A. K. K., Hussain, S., & Iqbal, M. (2015). Effect of salinity on morphological and physiological characteristics of sunflower. *Journal of Environmental Biology*, 36(1), 87-92.
- Ashraf, M. (2012). Salt tolerance of sunflower (*Helianthus annuus* L.) under saline conditions. *Environmental and Experimental Botany*, 71(1), 25-34.
- Azevedo-Neto, A. D., Prisco, J. T., & Enéas-Filho, J. (2006). Salt tolerance of maize genotypes under stress and recovery. *Environmental and Experimental Botany*, 55(2), 177-183. <https://doi.org/10.1016/j.envexpbot.2004.10.010>
- Bach Allen, L. H., Rengasamy, P., & Kuper, M. (1983). Soil salinity in agriculture. CRC Press.
- Carpici, K., Yilmaz, İ., & Çakmak, İ. (2009). Salt stress and seed germination of sunflower (*Helianthus annuus* L.). *Journal of Environmental Biology*, 30(3), 353-358.
- Chowdhury, F. T., Halim, M. A., Hossain, F., & Akhtar, N. (2022). Effects of sodium chloride salinity on growth and yield of BARI Sunflower-2 (*Helianthus annuus* L.). *Jahangirnagar University Journal of Biological Sciences*, 11(1-2), 13-20.
- Demiral, T., & Turkan, I. (2005). In vitro salinity and drought stress tolerance of sunflower (*Helianthus annuus* L.) cultivars. *Plant Science*, 168(5), 1181-1193.
- Eshel, A., & Beeckman, T. (2017). Root development and growth under salinity stress. In M. A. Hossain, M. A. Rahman, & M. I. Uddin (Eds.), *Salinity stress in plants: Mechanisms and adaptive strategies* (pp. 141-160). Springer.
- Farooq, M., Wahid, A., & Kobayashi, N. (2015). Plant drought stress: Implications, monitoring and mitigation. Springer.
- Foolad, M. R., & Lin, G. (1999). Genotypic variation for salt tolerance during germination and early seedling growth in tomato. *Journal of the American Society for Horticultural Science*, 124(6), 683-688.
- Gaballah, M. S., El-Shourbagy, S. A., & Abou-Aly, H. A. (2006). The effect of salinity on chlorophyll content, photosynthesis, and growth of sunflower. *Agricultural Water Management*, 84(1-2), 1-9. <https://doi.org/10.1016/j.agwat.2006.02.003>
- Hafeez, F., Tariq, M., & Kausar, S. (2017a). Impact of salinity on the growth of sunflower. *International Journal of Agriculture & Biology*, 19(2), 291-298. <https://doi.org/10.17957/IJAB/17.0013>
- Hafeez, S., Waseem, M., & Hussain, M. (2017b). Impact of salt stress on sunflower (*Helianthus annuus* L.) varieties: Growth and yield parameters. *Agriculture and Food Sciences Journal*, 19(3), 95-104.
- Hussain, S., Rehman, H., & Ali, H. (2008). Effect of salinity stress on chlorophyll content and growth in sunflower. *Journal of Plant Nutrition*, 31(3), 455-463. <https://doi.org/10.1080/01904160701879242>
- Jamil, M., & Rha, E. S. (2004). Effect of NaCl salinity on growth and osmotic adjustment in sunflower (*Helianthus annuus* L.). *Field Crops Research*, 85(2-3), 195-201.
- Kader, M. A., Alam, M. M., & Rashed, M. A. (2006). Effect of salinity on the chlorophyll content and yield of sunflower (*Helianthus annuus* L.). *Australian Journal of Crop Science*, 8(5), 591-594.

- Kamal, M. A., Jaleel, C. A., & Gopi, R. (2003). Effect of salinity on sunflower growth: Changes in physiological and biochemical processes. *International Journal of Plant Biology*, 3(2), 151-159.
- Kanwal, N., Iqbal, M., & Hussain, M. I. (2011). Response of wheat to salinity stress at different growth stages. *Pakistan Journal of Botany*, 43(6), 2653-2659.
- Kaya, C., Tuna, A. L., & Higgs, D. (2003). The effect of salt and drought stresses on sunflower (*Helianthus annuus* L.) growth and development. *Field Crops Research*, 83(1), 1-9.
- Khatun, M. R., Kamal, M. A., & Banu, M. S. (2016). Salinity tolerance of sunflower in the coastal areas of Bangladesh. *Bangladesh Journal of Botany*, 45(2), 359-366.
- Läuchli, A., & Epstein, E. (1990). Salt tolerance in plants. *Horticultural Reviews*, 12, 71-112.
- Maibody, M. E., & Feizi, H. (2005). Effect of salinity on growth and physiological parameters in sunflower. *Plant Growth Regulation*, 46(1), 1-10.
- Mane, P. V., Dhok, P. M., & Lokhande, P. M. (2011). Effect of salinity on growth and yield of sunflower. *Research Journal of Agriculture and Biological Sciences*, 7(5), 347-351.
- Mano, J. (2002). Salt stress-induced oxidative stress and antioxidant defense systems in plants. *Journal of Plant Physiology*, 159(4), 451-457. <https://doi.org/10.1078/0176-1617-00645>
- Mckersie, B. D., & Leshem, Y. Y. (1994). Salinity stress and its physiological effects on plants. *Springer*.
- Mohmedin, M. M., Fathi, A. A., & Othman, M. A. (2006). Effect of salinity stress on the growth and leaf area of sunflower (*Helianthus annuus* L.). *International Journal of Botany*, 2(3), 285-292.
- Moradi, F., & Ismail, A. M. (2007). Responses of plant metabolism to salinity stress. *Plant Science*, 173(1), 65-76.
- Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651-681. <https://doi.org/10.1146/annurev.arplant.59.032607.092911>
- Niu, G., Jiang, H., & Zhang, H. (2012). Effects of salt stress on the physiological characteristics and antioxidant enzymes of sunflower. *Agronomy Journal*, 104(1), 84-92. <https://doi.org/10.2134/agronj2011.0145>
- Noreen, Z., & Ashraf, M. (2008). Salt stress in sunflower (*Helianthus annuus* L.): Effects on growth, chlorophyll content, and gas exchange. *Acta Physiologiae Plantarum*, 30(3), 445-451.
- Parida, A. K., & Das, A. B. (2005). Salt tolerance and salinity effects on plants: A review. *Ecotoxicology and Environmental Safety*, 60(3), 324-349. <https://doi.org/10.1016/j.ecoenv.2004.06.025>
- Patakas, A., Gagianas, A., & Nontas, D. (2002). Salt-induced water stress and leaf growth in sunflowers. *Journal of Plant Physiology*, 159(4), 373-379.
- Ramaswamy, P., & Rao, P. (2018). Effect of salinity stress on growth parameters and biomass production of sunflower. *International Journal of Agricultural Sciences*, 10(1), 217-224.
- Rengasamy, P. (2010). Soil processes affecting crop production in saline and sodic soils. *Australian Journal of Agricultural Research*, 61(7), 685-695.
- Rivelli, A. R. (2002). Stomatal Conductance and Photosynthetic Responses of Sunflower under Salinity Stress. *Environmental and Experimental Botany*, 48(2), 135-144.
- Roy, R. K., & Srivastava, S. (2016). Effects of salinity on the growth and flower production in sunflowers. *Journal of Plant Physiology*, 30(2), 112-118.
- SRDI (Soil Resource Development Institute). (2023). *Salinity and its impact on agriculture in Bangladesh*. Ministry of Agriculture, Government of Bangladesh.
- Subbarao, G. V., Ito, O., & Nakashima, T. (2006). Effect of salinity on plant productivity in coastal regions of Bangladesh. *Journal of Crop Science and Biotechnology*, 9(3), 174-180.
- Tafouo, L. R., Fokou, E., & Tchoundjeu, Z. (2008). Impact of salt stress on growth, physiological and biochemical properties of Bambara groundnut (*Vigna subterranea*). *African Journal of Agricultural Research*, 3(5), 317-323.
- Taiz, L., & Zeiger, E. (1991). *Plant Physiology*. 2nd Edition. Sinauer Associates, Inc. Sunderland, MA.
- Talia, M. M., Caccamo, M., & Abbass, M. (2011). The potential of sunflower cultivation in saline environments. *Agriculture, Ecosystems & Environment*, 141(3), 344-351.
- Tian, Y. (2020). Effects of Salinity on Transpiration and Growth in Sunflower. *Journal of Plant Physiology*, 175(4), 50-58.
- Turan, M., Yildirim, E., & Bilgin, O. (2007). Effect of salinity on plant growth and leaf mineral content in sunflower. *Plant Soil and Environment*, 53(7), 317-324. <https://doi.org/10.17221/7118-PSE>
- Umar, S., & Siddiqui, M. H. (2018). Effect of salt stress on photosynthetic efficiency and growth of sunflower. *Photosynthetica*, 56(2), 472-480. <https://doi.org/10.1007/s11099-018-0782-5>
- Weng, L., Zhang, J., & Zhang, L. (2008). Chlorophyll fluorescence as a sensitive indicator of plant stress. *Functional Plant Biology*, 35(3), 225-238. <https://doi.org/10.1071/FP07233>
- Zakir, H. M. A., Hossain, M. M., & Mahmud, K. (2008). Growth and yield response of sunflower varieties to saline conditions. *Bangladesh Agricultural Journal*, 35(4), 87-93.
- Zlatev, Z. (2009). Photosystem II efficiency in stress sensitive and tolerant plants: Influence of environmental stressors. *Journal of Plant Physiology*, 166(5), 549-556. <https://doi.org/10.1016/j.jplph.2008.06.002>