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Investigation of Natural Variation in Gas Exchange, Water Relations, and Quantum Yield among Sweet Gourd Hybrids

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ABSTRACT

Sweet gourd (*Cucurbita moschata* Duch ex Poir) has a high production volume in Bangladesh and holds third rank next to eggplant and radish. Salinity affects almost all growth and physiological aspects of the plant development and eventually reduces yield. Identifying salt tolerance among genetic resources and breeding populations is a valuable study for solving salinity problems. This research aimed to find sweet gourd hybrids tolerant to salinity. Sixteen sweet gourd hybrids (F1) were used for testing salt stress tolerance levels. Salinity stress was induced in pot soil by adding NaCl solutions (4, 8, 12, 16, and control 0.35 dS m^{-1}). The experiment was conducted from October 2019 to March 2020 in a randomized complete block design with three replications. The research was conducted at the Horticulture Research Centre, Bangladesh Agricultural Research Institute (BARI), Gazipur. The measurements included changes in gas exchange parameters against photosynthetic rate (Pn), stomatal conductance (gs), transpiration rate (E), quantum yield (Fv/Fm), and relative water content (RWC). Results showed that the gas exchange traits and RWC in all hybrids decreased under stress compared to the control. Photosynthetic parameters in sweet gourd hybrids responded susceptibly to salt stress, thus suppressing overall growth under salinity stress. The reduction of gaseous exchange traits and RWC were minimal in $P_{11} \times P_{12}$ and $P_6 \times P_{14}$. The highest Fv/Fm and RWC occurred in $P_{11} \times P_{12}$ at 8 dS m^{-1} salinity stress. The highest Fv/Fm and RWC appeared in $P_6 \times P_{14}$ and $P_{11} \times P_{12}$ hybrids at 12 and 16 dS m^{-1} salinity stress, so the hybrid $P_{11} \times P_{12}$ appeared salt tolerant.

Introduction

Salinity is one of the most deleterious factors limiting the productivity of crops, with adverse effects on germination, plant vigor, and crop yield (Munns and Tester, 2008). Soil salinization is a widespread problem affecting almost 20% of irrigated lands worldwide, posing a threat to crop production (Munns et al., 2020). Salinity stress significantly reduces plant growth and productivity. It can result in various physiological disturbances, such as osmotic effects, ion-specific damage, ionic imbalance, and oxidative stress (Tabatabaei and Ehsanzadeh, 2016). Soil salinity has adverse effects. Sodicity can significantly inhibit crop growth rates and cause waterlogging issues with concomitant soil fertility loss (Mohanavelu et al., 2021). High salinity affects plants in several ways, such as drought stress, ion

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toxicity, nutritional disorders, oxidative stress, alteration of metabolic processes, membrane disorganization, and suppression of cell division and expansion (Munns, 2002). Reduction in crop growth is generally a consequence of growth-related physiological responses, such as reduced photosynthetic performance, mineral imbalance, alterations in water relations, and carbon allocation and utilization (Negrao et al., 2017). Leaf photosynthetic carbon assimilation directly determines plant carbon gain or growth. Thus, it primarily focuses on understanding physiological mechanisms and improving crop salt tolerance (Chaves et al., 2009). Various crop species show decreased growth because of lowered leaf carbon assimilation and salt stress (Rouphael et al., 2017; Stoeva and Kaymakanova, 2008). Leaf photosynthesis is reportedly a physiological process that manages plant growth when facing salt stress (Liu and Suarez, 2021).

In Bangladesh, about one million hectares of arable land in coastal and off-shore areas are affected by varying salinity levels (Shammi et al., 2016). Salinity is becoming a bold problem in the southwest coastal region of Bangladesh, where salinity affects irrigation water quality. Each year, about 200 ha of fodder crop area becomes affected by salinity (Alam et al., 2017). Increased soil salinity limits crop growth, affecting overall crop production. It damages soil properties that many potential crops require (Mahmuduzzaman et al., 2014). Salt stress changes morphological, physiological, and biochemical activities where cells and tissues exist (Amirjani, 2010; Siringam et al., 2011). Shoot dehydration is a primary response whereby plants encounter osmotic stress at low salt concentrations. At moderate to high salt concentrations, nutritional imbalances become prevalent because of interferences in saline ions. Their toxicity emanates from ion accumulation, especially Na^+ and Cl^-, as the primary effects of salinity on physiological and biochemical activities in plants (De-Pascale et al., 2003a; De-Pascale et al., 2003b). Considerable attention has gone to the study of salt stress effects on the physiological symptoms in various types of plants (Munns and Gilliham, 2015; Negrao et al., 2017). Reduction of plant growth by salinity differs between species and even between varieties and cultivars due to the variability of salt tolerance among domestic and wild germplasms (Ghoulam et al., 2002). Rapid population growth and subsequent food shortage, especially in Asia and Africa, and exacerbations in salinity among arable land have increased the importance of salt-tolerant genotypes (Blumwald, 2004). Efforts to release salt-tolerant cultivars require a proper understanding of the effects of salinity on plants, responses of plants in terms of physiological, biochemical, and molecular activities to salinity, and recognition of complex mechanisms of salt tolerance in plants (Apse and Blumwald, 2002). Identifying tolerant genotypes would be an effective strategy to overcome the saline stress (Collado et al., 2016).

Sweet gourd (*Cucurbita moschata* Duch. ex Poir.) belongs to the family Cucurbitaceae and is a popular vegetable due to its delicious young leaves, flowers, immature and mature fruits. A delicious pulp, high productivity, long storability, and better transportability of mature pumpkin fruits have caused the widespread cultivation of sweet gourd throughout Bangladesh. Though soil salinity is the most dominant factor that limits crop production in saline areas in Bangladesh during the dry season, salt-tolerant sweet gourd variety can significantly improve farmer success in cultivation. Salt-tolerant plants can minimize these detrimental effects by producing a series of morphological, physiological, and biochemical processes (Gupta and Huang, 2014). The focus on screening germplasms in recent years has shifted towards examining specific physiological traits involved in salt tolerance (Ashrafi et al., 2014). It is essential to understand the mechanism of physiological adaptation and changes in anatomical structure under salinity that may help a plant breeder to evolve a salt-tolerant variety. Therefore, introducing reliable physiological markers can facilitate the selection of salt-tolerant genotypes for direct cultivation or use in breeding programs. The present investigation was essential to study the physiological basis of salt tolerance in select sweet gourd hybrids.

Materials and Methods

Experimental site

The study was carried out in the Plant Physiology Section, Horticulture Research Centre, Bangladesh Agricultural Research Institute, Gazipur, from October 2019 to March 2020. The experiment was in semi-controlled conditions (natural light conditions, average air temperature was 26.09 ºC, relative air humidity minimum 75.73% and maximum 94.04%, and soil pH ranged from 6.2 to 6.7 (Fig. 1).

Planting materials

Fourteen sweet gourd inbred, namely BARI Mistikumra-1 (P_1), CM-31-2-4-5-1 (P_2), CM-31-1-1-12-1 (P_3), CM-75-5-4-2-5 (P_4), CM-31-5-4-2-4 (P_5), CM-34-4-12-9 (P_6), CM-5-4-12-6 (P_7), CM-3-5-4-2-1 (P_8), CM-31-5-4-2-1 (P_9), CM-3-5-4-2-1-5 (P_{10}), BARI Mistikumra-2 (P_{11}), CM-75-4-2-1 (P_{12}), CM-71-9-B-1 (P_{13}) and CM-35-4-2-1-5 (P_{14})

were collected from the Olericulture Division of the Horticulture Research Centre in the Bangladesh Agricultural Research Institute (BARI). From these lines, six lines viz. P_6 = CM-34-4-12-9, P_8 = CM-3-5-4-2-1, P_9 = CM-31-5-4-2-1, P_{11} = BARI Mistikumra-2, P_{12} = CM-75-4-2-1 and P_{14} = CM-35-4-2-1-5 were screened out as medium salt-tolerant to develop salt tolerant hybrids (F1). Finally, 15 hybrids were generated from these six inbred viz. F_1 ($P_6 \times P_8$), F_1 ($P_6 \times P_9$), F_1 ($P_6 \times P_{11}$), F_1 ($P_6 \times P_{12}$), F_1 ($P_6 \times P_{14}$), F_1 ($P_8 \times P_9$), F_1 ($P_8 \times P_{11}$), F_1 ($P_8 \times P_{12}$), F_1 ($P_8 \times P_{14}$), F_1 ($P_9 \times P_{11}$), F_1 ($P_9 \times P_{12}$), F_1 ($P_9 \times P_{14}$), F_1 ($P_{11} \times P_{12}$), F_1 ($P_{11} \times P_{14}$) and F_1 ($P_{12} \times P_{14}$) through half diallel crossing. In this experiment, these 15 F_1 and BARI Hybrid Mistikumra-1 (CK) were used in selecting suitable salt-tolerant sweet gourd hybrid(s).

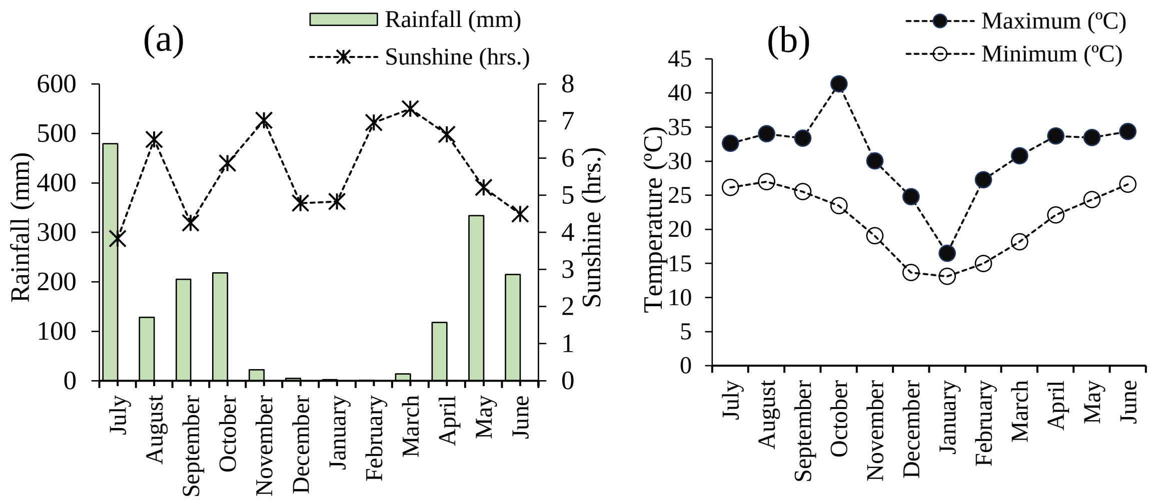

Fig. 1. Monthly average rainfall, sunshine hours (a) and temperature (b) of experimental site during July 2019 to June 2020.

Preparation of pot mixture
Two hundred and forty plastic pots were used in this experiment and each plastic pot (37 cm × 33 cm) contained 22 kg of air-dried clay loam soil (40.22% sand, 29.64% silt, and 3.45% clay) with pH 6.2, 1.60% organic carbon, and a CEC (Cation Exchange Capacity) of 14.60 meq 100 g^{-1} soil. Soil nutrient status was 0.56 mg N 100 g^{-1}, 1.18 mg P 100 g^{-1} dry soil, and 0.25 meq K 100 g^{-1} dry soil). The primary fertilizer was cow dung (25% of the soil volume) and kept beside the net house under natural light. The bottom of each pot was perforated to facilitate drainage.

Seedling raising and transplanting
Seedlings of sweet gourd hybrids were raised in polybags with a mixture of soil and cow dung at a 2:1 ratio. Fifteen-day-old seedlings were transplanted in plastic pots (37 cm × 33 cm) containing 22 kg air-dried clay loam soil mentioned above. One seedling was allowed to grow in each pot. The seedlings were allowed to recover from transplanting shock and finish the complete establishment phase in 20 days before salt application. Through this time, each plant was irrigated with the same quantity (200 mL) of tap water every alternate day for better growth.

Application of salt treatment
A salt solution was prepared by dissolving a calculated amount of laboratory-grade sodium chloride (NaCl) with tap water to make 40 mM (4 dS m^{-1}), 80 mM (8 dS m^{-1}), 120 mM (12 dS m^{-1}) and 160 (16 dS m^{-1}) mM NaCl solution. The experimental treatment consisted of 4, 8, 12, and 16 dS m^{-1}, and tap water (0.35 dS m^{-1}) was used as control. The salt treatment was applied after 20 days of transplanting of seedlings (4-5 leaf stage). On every alternate day, salt solution (NaCl) was applied to the potting soil to attain the required salinity level. In each pot, 200 mL of saline water was applied every other day according to the treatment. The control plants received 200 mL of tap water. The sufficiency of nutrients was ensured by adding the recommended dose of fertilizer (urea-30 g, triple superphosphate (TSP)-90 g, muriate of potash (MoP)-25 g, gypsum-50 g, zinc sulfate-6.5 g, boric acid 6 g, and magnesium sulfate ($MgSO_4$)-30 g. These fertilizers were used as ingredients that supplied N, P, K, and S, Zn, B, and Mg, respectively, during soil preparation for each pot (7 days before

transplanting). After transplanting, 60 g urea and 50 g MoP were applied per plant into two splits.

Physiological/gas exchange data collection

Chlorophyll content index of leaves:
The SPAD meter is a simple diagnostic tool that measures leaf greenness or the relative chlorophyll content index of leaves. Minolta SPAD-502 was used to measure the chlorophyll content index throughout the experiment. SPAD chlorophyll readings were collected from the 4th fully expanded leaf from the plant apex between 10.00 am and 1.00 pm. Leaf chlorophyll content index was measured at 15-day intervals starting from 15 days after induced salinity and continued up to 45 days.

Leaf gas exchange parameters:
A portable LI-6400 (LI-COR, Lincoln, NE) was used to measure the net photosynthetic rate (Pn), stomatal conductance (gs), and transpiration rate (E) of leaves. Young, fully expanded leaves in the third position from the tip of the plant were used for this purpose. Data were collected from 10.30 am to 2.00 pm. These parameters were measured at 15-day intervals, starting from 15 days after induced salinity and continuing up to 45 days.

Determination of leaf relative water content:
Relative water content (RWC) in the leaves was established as 100 × (FM – DM)/(SM –DM), where FM represents the fresh mass of 10 leaf discs (diameter 10 mm), SM is the saturated mass of the same discs after their hydration in the dark for 24 h at room temperature (25 °C) and under the dark conditions of the laboratory and DM is the dry mass of these discs after they were oven-dried at 70 °C for 72 h. WC was established in three repetitions (Chowdhury et al., 2015).

Quantum yield (Fv/Fm):
Quantum yield (Fv/Fm) was measured in situ with the portable Chlorophyll fluorescence measurement meter (ADC Infrared Gas Analysis Plant Efficiency Analyzer, King's Lynn, UK). Young fully expanded leaves were used for this purpose. When using the PEA, the attached leaf was dark-adapted with a leaf clip for 30 min before the measurement. During the measurement, the PEA sensor unit was held over the clip, and the shutter opened. The third or fourth fully expanded leaf from the plant apex was used for this purpose. The data were collected from 10.30 am to 2.00 pm at 15-day intervals starting from 15 days after induced salinity and continued up to 45 days following a method used by Strasser et al. (1995).

Statistical analysis

The experiment was organized in a two-factor (sweet gourd F_1 × salinity) randomized complete block design with three replications. The significance of the difference between the pair of mean values resulted from Duncan's Multiple Range Test. Mean values were compared at 5% significance via MSTATC software.

Results

SPAD value

Salinity significantly influenced SPAD value. Under the conditions where plants grew, the SPAD value increased with the increase in plant growth. At 15 days after induced salinity, the SPAD value slowly decreased with the gradual increase in salinity level. However, 30 days after the induced salt treatment, the SPAD value decreased speedily, and at 45 days after induced salinity, the SPAD value decreased dramatically. The maximum SPAD value occurred in the control treatment (40.99), and a minimum occurred at 16 dS m^{-1} (33.39) after 45 days of induced salinity (Fig. 2A). All sweet gourd F1 individuals varied significantly in the SPAD value. At 15 days after application of NaCl, the highest SPAD value (40.12) occurred in $P_{11} \times P_{14}$ followed by $P_{11} \times P_{12}$, $P_6 \times P_{14}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, and a minimum value (37.04) was recorded in $P_6 \times P_{11}$. At 30 days after application of NaCl, the highest SPAD value (39.65) occurred in $P_{11} \times P_{12}$ followed by $P_{11} \times P_{14}$, $P_9 \times P_{11}$, $P_6 \times P_{12}$, $P_6 \times P_{14}$ and minimum value (36.55) occurred in $P_6 \times P_9$. At 45 days after induced salinity, the highest SPAD value (39.22) was found in $P_6 \times P_{14}$ followed by $P_6 \times P_{12}$, $P_{11} \times P_{12}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$ and the minimum SPAD value (34.66) was in $P_8 \times P_9$ (Fig. 2B).
Salinity in combination with F_1 had a significant effect on the SPAD value. In the control treatment, the SPAD value was increased with the growing period in all F_1 individuals (Table 1). At 15 days after induced salinity, the highest SPAD value (40.65) occurred in $P_{11} \times P_{14}$, and the lowest value (37.18) occurred in $P_8 \times P_9$ in the control treatment. But at 16 dS m^{-1}, the highest SPAD value (39.57) occurred in P6 × P14, followed by $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_{11} \times P_{12}$, $P_{11} \times P_{14}$, and the lowest SPAD value (35.75) occurred in $P_8 \times P_9$. At 30 days after induced salinity, the highest SPAD value (40.30) occurred in P6 × P14, followed by $P_6 \times P_{12}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_9 \times P_{12}$, $P_9 \times P_{14}$, $P_{11} \times P_{12}$, $P_{11} \times P_{14}$, $P_{12} \times P_{14}$ and the lowest value (37.98) occurred in $P_8 \times P_9$ in the control treatment. But at 16 dS m-1, the highest SPAD value (38.56) occurred in $P_6 \times P_{14}$, followed by $P_9 \times P_{11}$, $P_{11} \times P_{12}$, $P_{11} \times P_{14}$, and the lowest SPAD value (34.50) occurred in $P_6 \times P_{11}$. At 45 days

after induced salinity, the highest SPAD value (42.63) occurred in $P_{12} \times P_{14}$, followed by $P_8 \times P_{11}$, and the lowest value (38.88) occurred in $P_6 \times P_9$ in the control treatment. However, at 16 dS m^{-1}, the highest SPAD value (37.25) occurred in $P_{11} \times P_{12}$ followed by $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_{11} \times P_{14}$, and the lowest SPAD value (28.54) occurred in $P_8 \times P_9$, $P_8 \times P_{12}$ and $P_9 \times P_{12}$.

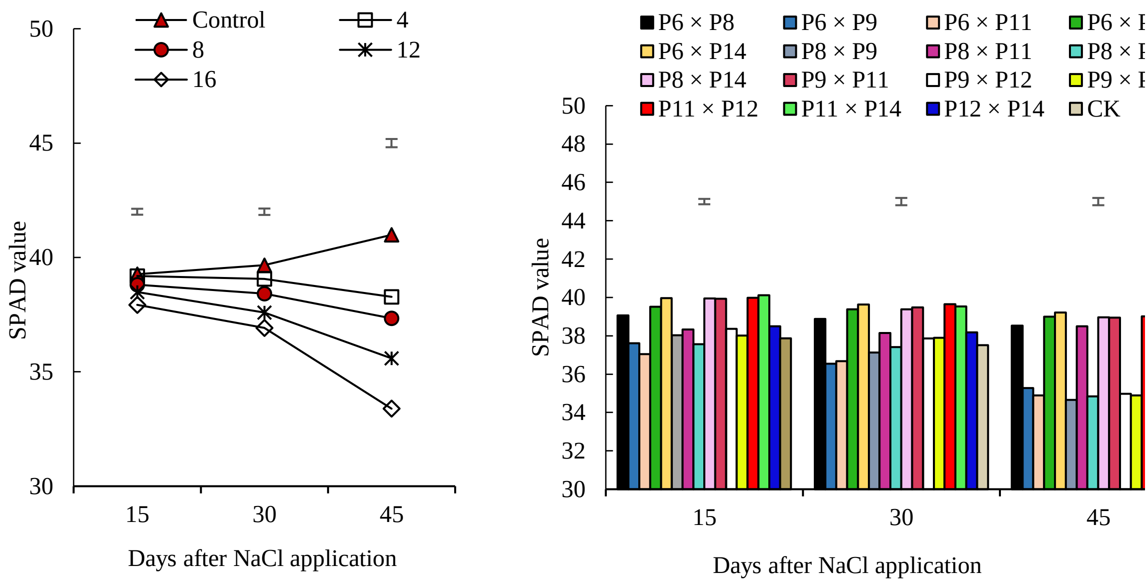

Fig. 2. Effect of salt stress (A) and hybrids (F1) (B) on the SPAD value of sweet gourd at 15, 30 and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

Photosynthetic rate (P_n)

Photosynthesis is the most significant physiological process and during all growth phases, it is affected by stress factors. Salinity had significant effect on photosynthetic rate (P_n). At 15 days after salt application, the highest P_n (18.26 μmol m^{-2} s^{-1}) was recorded in the control treatment followed by 4 dS m^{-1} and the minimum (18.01 μmol m^{-2} s^{-1}) in 16 dS m^{-1} salinity level. At 30 days after application, the highest P_n (18.29 μmol m^{-2} s^{-1}) was recorded in the control treatment which was identical to 4 dS m^{-1} and the minimum (17.69 μmol m^{-2} s^{-1}) in 16 dS m^{-1}. But at 45 days after salt application, the maximum P_n (18.54 μmol m^{-2} s^{-1}) occurred in the control treatment and the minimum (17.39 μmol m^{-2} s^{-1}) occurred in 16 dS m^{-1} NaCl application (Fig. 3A).

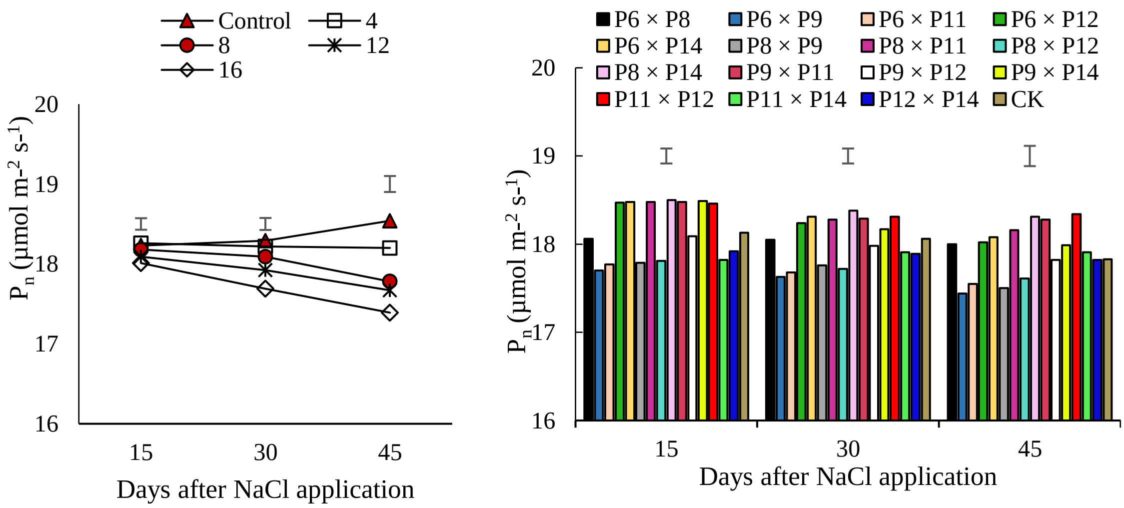

Fig. 3. Effect of salt stress (A) and hybrids (F1 individuals) (B) on Pn of sweet gourd at 15, 30 and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

Table 1. Combined effect of sweet gourd F1 individuals and different concentrations of NaCl on SPAD value.

Crosses (F1 individuals)/ variety	SPAD value														
	15 days after NaCl application					30 days after NaCl application					45 days after NaCl application				
	NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})				
	Control	4	8	12	16	Control	4	8	12	16	Control	4	8	12	16
$P_6 \times P_8$	39.83	39.52	38.76	38.65	38.53	40.00	39.50	38.66	38.24	38.00	40.22	39.39	38.48	38.00	36.58
$P_6 \times P_9$	38.64	38.64	37.08	36.94	36.77	38.75	37.85	36.34	35.26	34.56	38.88	36.24	35.52	34.35	31.34
$P_6 \times P_{11}$	38.58	38.25	36.21	36.13	36.05	39.00	38.24	36.55	35.30	34.25	40.30	37.28	33.50	31.80	31.54
$P_6 \times P_{12}$	40.24	40.12	39.75	39.00	38.50	40.30	40.12	39.28	39.00	38.22	40.60	40.02	39.00	38.77	36.58
$P_6 \times P_{14}$	40.25	40.12	40.00	39.85	39.57	40.30	40.10	40.00	39.25	38.56	40.48	40.00	39.85	38.77	37.00
$P_8 \times P_9$	37.18	36.61	36.60	36.00	35.75	37.98	36.27	35.55	35.35	34.50	38.88	36.05	35.50	31.83	28.54
$P_8 \times P_{11}$	38.73	38.75	38.25	38.16	37.77	38.75	38.18	38.00	38.00	37.77	42.62	38.12	37.74	37.00	37.00
$P_8 \times P_{12}$	38.55	38.16	38.09	37.00	36.04	39.00	38.00	37.57	37.00	35.50	42.25	36.24	35.51	31.80	28.44
$P_8 \times P_{14}$	40.21	40.12	40.00	39.86	39.57	40.27	40.00	39.95	38.25	38.50	40.50	39.55	39.55	38.00	37.25
$P_9 \times P_{11}$	40.22	40.20	40.00	39.66	39.55	40.29	40.00	39.28	39.25	38.56	40.60	39.40	39.00	38.73	37.00
$P_9 \times P_{12}$	38.90	38.76	38.76	38.65	36.75	40.14	38.67	38.66	36.35	35.52	42.28	37.04	35.52	31.80	28.27
$P_9 \times P_{14}$	38.59	38.56	38.56	38.16	36.19	40.20	38.48	37.55	37.25	36.00	42.23	37.07	35.95	31.95	27.25
$P_{11} \times P_{12}$	40.25	40.25	40.21	39.66	39.55	40.29	40.20	40.00	39.22	38.55	40.52	40.18	39.00	38.12	37.25
$P_{11} \times P_{14}$	40.65	40.45	40.10	39.84	39.57	40.00	40.00	39.95	39.22	38.50	40.70	39.40	38.85	38.00	37.22
$P_{12} \times P_{14}$	38.93	38.60	38.60	38.56	37.75	40.32	38.49	38.23	37.35	36.52	42.63	37.25	37.41	34.25	31.52
CK	38.55	38.00	38.00	37.75	37.04	39.00	38.88	37.15	36.25	36.25	40.50	38.12	37.04	36.16	31.50
Level of significance	**					**					**				
LSD (5%)	0.38					0.39					0.39				

** Indicates significance at 1% level of probability.

F_1 individuals had significant effect on photosynthetic rate (P_n). In general, P_n was increased with the increasing growing period. In the control treatment, P_n was increased with the growing period but at saline condition, P_n was decreased. After 15 days of NaCl application, $P_9 \times P_{14}$ showed the highest P_n (18.49 µmol m^{-2} s^{-1}) followed by $P_6 \times P_{12}$, $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_9 \times P_{14}$, $P_{11} \times P_{12}$ and minimum (17.79 µmol m^{-2} s^{-1}) appeared in $P_8 \times P_9$. However, at 30 days after salt application, $P_8 \times P_{14}$ showed the maximum P_n rate (18.38 µmol m^{-2} s^{-1}) than others and a minimum in $P_6 \times P_9$ (17.63 µmol m^{-2} s^{-1}). At 45 days after application of salt, the highest P_n rate occurred in $P_{11} \times P_{12}$ (18.31 µmol m^{-2} s^{-1}) and the minimum P_n (17.44 µmol m^{-2} s^{-1}) in $P_6 \times P_9$ (Fig. 3B).

The performance of fifteen sweet gourd F_1 individuals with CK in the control and different levels of salinity are shown in Table 2. Control treatment always gave the maximum photosynthetic rate (P_n). Salinity reduced the P_n compared to the control. At 15 days after NaCl application, the maximum P_n was found in $P_6 \times P_{12}$ (18.58 µmol m^{-2} s^{-1}) followed by $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_9 \times P_{14}$, $P_{11} \times P_{12}$ in the control treatment and the minimum P_n in $P_8 \times P_9$ (17.13 µmol m^{-2} s^{-1}). But at 16 dS m^{-1} salinity level, $P_8 \times P_{14}$ performed better (18.47 µmol m^{-2} s^{-1}) with regard to P_n followed by $P_6 \times P_{12}$, $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_9 \times P_{11}$, $P_9 \times P_{14}$, $P_{11} \times P_{12}$ and minimum (17.00 µmol m^{-2} s^{-1}) appeared in $P_8 \times P_9$. At 30 days after induced salinity stress, $P_6 \times P_{12}$ gave the maximum P_n (18.58 µmol m^{-2} s^{-1}) and $P_8 \times P_9$ gave the minimum P_n (17.20 µmol m^{-2} s^{-1}) in the control treatment. But at 16 dS m^{-1} salinity level, $P_8 \times P_{14}$ performed better (18.15 µmol m^{-2} s^{-1}) followed by $P_6 \times P_{14}$, $P_{11} \times P_{12}$ and minimum (17.00 µmol m^{-2} s^{-1}) appeared in $P_8 \times P_9$. At 45 days after induced salinity, $P_9 \times P_{12}$ showed higher P_n (19.14 µmol m^{-2} s^{-1}) and $P_6 \times P_8$ showed lower P_n (17.23 µmol m^{-2} s^{-1}) in the control treatment. At 16 dS m^{-1} NaCl concentration, the highest P_n (18.00 µmol m^{-2} s^{-1}) appeared in $P_6 \times P_{14}$ followed by $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_{11} \times P_{12}$ and the lowest P_n (16.10 µmol m^{-2} s^{-1}) appeared in $P_8 \times P_9$ (Table 2).

Transpiration rate (E)

Salinity had significant effects on transpiration rate (E). Transpiration was decreased with gradual increase of salinity levels. At 15 days after salt application, the highest E (2.56 mol m^{-2} s^{-1}) appeared in the control treatment followed by 4 dS m^{-1} and the minimum E (2.43 mol m^{-2} s^{-1}) in 16 dS m^{-1} salinity level. At 30 days after application of salt, the highest E (2.61 mol m^{-2} s^{-1}) appeared in the control and the minimum E (2.34 mol m^{-2} s^{-1}) in 16 dS m^{-1} salinity level. But at 45 days after induced salinity, the maximum E (2.66 mol m^{-2} s^{-1}) was found in the control treatment and the minimum (2.29 mol m^{-2} s^{-1}) appeared in 16 dS m^{-1} NaCl application (Fig. 4A).

All the sweet gourd F_1 individuals varied significantly in respect of transpiration rate (E). At 15 days after NaCl application, the highest E was found in $P_{11} \times P_{12}$ (2.66 mol m^{-2} s^{-1}) and the lowest E (1.96 mol m^{-2} s^{-1}) occurred in $P_6 \times P_9$. At 30 days after induced salinity, the highest E (2.64 mol m^{-2} s^{-1}) was also occurred in $P_{11} \times P_{12}$ and the lowest in $P_6 \times P_9$ (1.94 mol m^{-2} s^{-1}) which was identical to $P_8 \times P_9$. At 45 days after induced salinity, the highest E was also found in $P_{11} \times P_{12}$ (2.62 mol m^{-2} s^{-1}) and the lowest E (1.39 mol m^{-2} s^{-1}) occurred in $P_8 \times P_9$ (Fig. 4B).

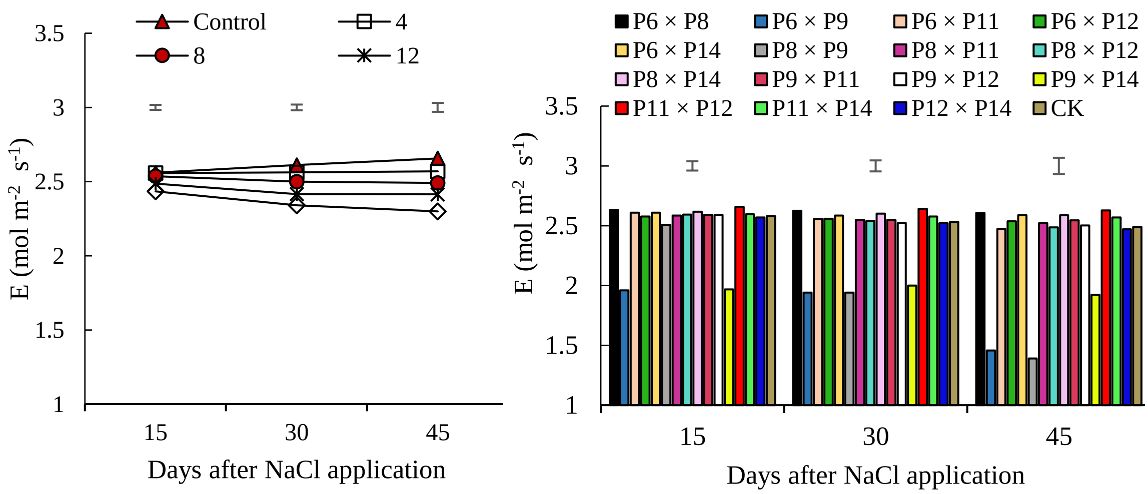

Fig. 4. Effect of salt stress (A) and hybrids (F1 individuals) (B) on E of sweet gourd at 15, 30, and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

The transpiration rate (E) was significantly decreased with the increasing concentration of NaCl in all hybrids. The control treatment always gave the maximum E. At 15 days after induced salinity, the maximum E was found in $P_{11} \times P_{12}$ (2.68, 2.68, 2.68, 2.64 and 2.61 mol m^{-2} s^{-1}) in all salt treatments. At 30 days after induced salinity, $P_{11} \times P_{12}$ showed higher E (2.68, 2.65, 2.61 and 2.58 mol m^{-2} s^{-1}) at all levels of salinity but in the control treatment the highest E (2.70 mol m^{-2} s^{-1}) occurred in $P_6 \times P_{11}$. At high NaCl concentration E was reduced dramatically. However, the results indicate that salinity decreased E in all F1 individuals. At 45 days after induced salinity, all F1 individuals gave identical value of E except $P_8 \times P_9$ in the control treatment. But at 16 dS m^{-1} salinity level, the highest E (2.55 mol m^{-2} s^{-1}) occurred in $P_{11} \times P_{12}$ followed by $P_6 \times P_{14}$ and the lowest E occurred in $P_8 \times P_9$ (1.24 mol m^{-2} s^{-1}) occurred in $P_8 \times P_9$ (Table 3).

Stomatal conductance (gs)

Stomatal conductance (gs) was significantly decreased with the increasing level of salinity. At 15 days after salt application, the highest gs (0.117 mol m^{-2} s^{-1}) was recorded in the control treatment which was identical to 4 dS m^{-1} and the minimum gs (0.088 mol m^{-2} s^{-1}) occurred in 16 dS m^{-1} NaCl application.

At 30 days after salt application, the highest gs (0.125 mol m^{-2} s^{-1}) was recorded in the control treatment and the minimum (0.070 mol m^{-2} s^{-1}) occurred in 16 dS m^{-1} NaCl application. But at 15 days after application, the maximum gs (0.135 mol m^{-2} s^{-1}) occurred in the control treatment and the minimum gs (0.060 mol m^{-2} s^{-1}) occurred in 16 dS m^{-1} NaCl application (Fig. 5A).

F_1 individuals had a significant effect on stomatal conductance (g_s). The hybrid $P_8 \times P_{14}$ showed maximum g_s (0.117 mol m^{-2} s^{-1}) followed by $P_{11} \times P_{12}$, $P_9 \times P_{11}$, $P_6 \times P_8$, $P_8 \times P_9$, $P_6 \times P_{14}$, at 15 days after NaCl application and the minimum g_s (0.085 mol m^{-2} s^{-1}) appeared in $P_9 \times P_{14}$. At 30 days after induced salinity, the highest g_s (0.114 mol m^{-2} s^{-1}) was also occurred in $P_{11} \times P_{12}$ which was identical to $P_6 \times P_{14}$, $P_8 \times P_{14}$ and the lowest g_s (0.080 mol m^{-2} s^{-1}) occurred in $P_9 \times P_{14}$ which was identical to $P_6 \times P_8$. At 45 days after salt application, the highest g_s (0.10 mol m^{-2} s^{-1}) was also occurred in $P_{11} \times P_{12}$ followed by $P_6 \times P_8$, $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$ and the lowest g_s (0.072 mol m^{-2} s^{-1}) occurred in $P_6 \times P_9$ (Fig. 5B).

All F1 individuals were significantly influence by salinity. At 15 days after induced salinity, the hybrid $P_{11} \times P_{12}$ showed the maximum g_s (0.127 mol m^{-2} s^{-1}) which was identical to $P_8 \times P_{14}$, $P_9 \times P_{11}$ and $P_{11} \times P_{14}$ in the control treatment but at 16 dS m^{-1} salinity stress, $P_{11} \times P_{12}$ showed the highest g_s (0.100 mol m^{-2} s^{-1}) which was identical to $P_6 \times P_{14}$, $P_8 \times P_9$, $P_9 \times P_{11}$ and $P_6 \times P_8$. At 30 days after induced salinity, the highest g_s (0.140 mol m^{-2} s^{-1}) occurred in $P_9 \times P_{12}$ followed by $P_9 \times P_{11}$, $P_8 \times P_{14}$, $P_{11} \times P_{14}$ in the control treatment but at 16 dS m^{-1} salinity stress, the highest g_s (0.090 mol m^{-2} s^{-1}) occurred in $P_6 \times P_8$ followed by $P_6 \times P_{14}$, $P_8 \times P_{14}$, $P_{11} \times P_{12}$ and the lowest g_s (0.040 mol m^{-2} s^{-1}) occurred in $P_6 \times P_9$. At 45 days after induced salinity, the highest g_s was (0.157 mol m^{-2} s^{-1}) occurred in $P_9 \times P_{11}$ followed by $P_6 \times P_{12}$, $P_8 \times P_{12}$, $P_8 \times P_{14}$, $P_9 \times P_{12}$ and the lowest g_s (0.110 mol m^{-2} s^{-1}) occurred in $P_6 \times P_9$ in the control treatment. At 16 dSm^{-1} salinity stress, the highest g_s (0.080 mol m^{-2} s^{-1}) occurred in the hybrid $P_{11} \times P_{12}$ which was identical to $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$ and the lowest g_s (0.030 mol m^{-2} s^{-1}) occurred in the hybrid $P_6 \times P_9$ (Table 4).

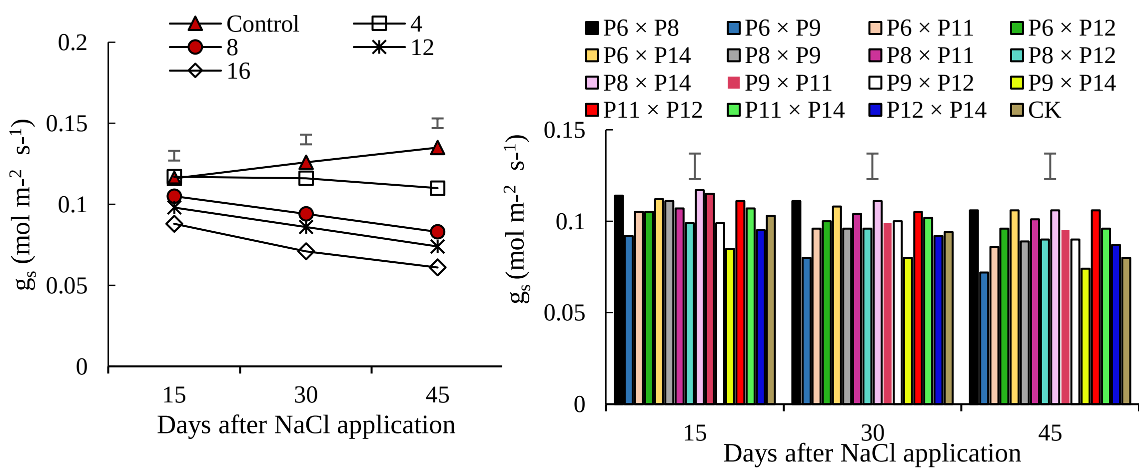

Fig. 5. Effect of salt stress (A) and hybrids (F1 individuals) (B) on gs of sweet gourd at 15, 30, and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

Table 2. Combined effect of sweet gourd F1 individuals and different concentrations of NaCl on photosynthetic rate (Pn).

Crosses (F1 individuals)/ variety	Photosynthetic rate (P_n) (µmol m^{-2} s^{-1})														
	P_n (15 days after NaCl application)					P_n (30 days after NaCl application)					P_n (45 days after NaCl application)				
	NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})				
	Control	4	8	12	16	Control	4	8	12	16	Control	4	8	12	16
$P_6 \times P_8$	18.12	18.12	18.08	18.00	18.00	18.18	18.10	18.08	18.00	17.88	18.44	18.09	18.00	17.85	17.62
$P_6 \times P_9$	17.85	17.85	17.75	17.69	17.37	17.85	17.82	17.72	17.50	17.25	18.10	17.82	17.56	17.05	16.60
$P_6 \times P_{11}$	18.22	18.05	17.82	17.39	17.40	18.22	18.00	17.80	17.24	17.15	18.35	17.95	17.48	17.10	16.85
$P_6 \times P_{12}$	18.58	18.55	18.47	18.40	18.37	18.58	18.55	18.25	18.18	17.64	18.78	18.55	17.18	18.07	17.50
$P_6 \times P_{14}$	18.55	18.55	18.48	18.43	18.37	18.57	18.50	18.37	18.12	18.00	18.66	18.51	17.25	18.00	18.00
$P_8 \times P_9$	17.13	17.12	17.07	17.04	17.00	17.20	17.05	17.05	17.00	17.00	17.23	17.00	16.75	16.50	16.10
$P_8 \times P_{11}$	18.52	18.52	18.46	18.45	18.45	18.55	18.45	18.28	18.25	17.86	18.55	18.40	18.08	18.00	17.70
$P_8 \times P_{12}$	18.20	18.05	17.85	17.50	17.47	18.38	18.00	17.83	17.20	17.15	18.63	18.00	17.75	17.00	16.60
$P_8 \times P_{14}$	18.55	18.52	18.49	18.49	18.47	18.55	18.50	18.35	18.33	18.15	19.06	18.48	18.08	18.08	17.80
$P_9 \times P_{11}$	18.52	18.49	18.47	18.46	18.46	18.56	18.49	18.23	18.22	17.95	19.00	18.45	18.04	18.00	17.90
$P_9 \times P_{12}$	18.18	18.15	18.08	18.05	18.00	18.26	18.05	18.03	18.00	17.56	18.65	18.02	17.77	17.58	17.00
$P_9 \times P_{14}$	18.52	18.51	18.48	18.47	18.45	18.54	18.44	18.09	18.03	17.77	19.14	18.40	17.79	17.50	17.10
$P_{11} \times P_{12}$	18.48	18.47	18.47	18.43	18.43	18.51	18.45	18.45	18.12	18.02	18.66	18.40	18.37	18.20	18.00
$P_{11} \times P_{14}$	17.85	17.85	17.83	17.83	17.75	18.27	17.85	17.82	17.82	17.79	18.33	17.85	17.83	17.78	17.70
$P_{12} \times P_{14}$	18.13	18.12	18.00	17.87	17.50	18.20	18.08	18.00	17.86	17.40	18.65	18.02	17.75	17.55	17.10
CK	18.22	18.18	18.15	18.07	18.05	18.22	18.15	18.09	18.00	17.85	18.65	18.00	17.77	17.50	17.20
Level of significance	*					**					**				
LSD (5%)	0.17					0.17					0.23				

** indicates significance at 1% level of probability, * indicates significance at 5% level of probability.

Table 3. Combined effect of sweet gourd F1 individuals and different concentrations of NaCl on transpiration rate (E).

Transpiration rate (E) (mol m^{-2} s^{-1})															
Crosses (F1 individuals)/ variety	E (15 days after NaCl application)					E (30 days after NaCl application)					E (45 days after NaCl application)				
	NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})				
	Control	4	8	12	16	Control	4	8	12	16	Control	4	8	12	16
$P_6 \times P_8$	2.67	2.67	2.65	2.61	2.55	2.67	2.67	2.65	2.60	2.42	2.67	2.66	2.63	1.57	1.50
$P_6 \times P_9$	2.00	2.00	2.00	1.95	1.85	2.12	2.00	2.00	1.85	1.74	2.67	1.57	1.44	1.38	1.25
$P_6 \times P_{11}$	2.67	2.67	2.62	2.58	2.50	2.70	2.65	2.55	2.47	2.41	2.70	2.58	2.47	2.35	2.25
$P_6 \times P_{12}$	2.65	2.60	2.60	2.51	2.40	2.68	2.64	2.57	2.48	2.42	2.68	2.60	2.55	2.42	2.42
$P_6 \times P_{14}$	2.65	2.65	2.62	2.58	2.55	2.65	2.64	2.62	2.52	2.50	2.68	2.60	2.60	2.52	2.50
$P_8 \times P_9$	2.61	2.61	2.58	2.53	2.50	2.68	2.60	2.55	2.45	2.42	2.70	2.15	2.08	1.42	1.24
$P_8 \times P_{11}$	2.65	2.61	2.60	2.55	2.51	2.67	2.60	2.57	2.45	2.45	2.60	2.55	2.55	2.42	2.42
$P_8 \times P_{12}$	2.65	2.63	2.62	2.55	2.51	2.69	2.62	2.58	2.44	2.37	2.70	2.60	2.49	2.40	2.24
$P_8 \times P_{14}$	2.67	2.64	2.62	2.60	2.55	2.69	2.64	2.60	2.57	2.51	2.70	2.63	2.58	2.58	2.45
$P_9 \times P_{11}$	2.65	2.60	2.60	2.55	2.51	2.65	2.64	2.55	2.48	2.42	2.67	2.63	2.55	2.45	2.42
$P_9 \times P_{12}$	2.61	2.61	2.60	2.58	2.55	2.67	2.58	2.55	2.50	2.32	2.70	2.55	2.55	2.47	2.24
$P_9 \times P_{14}$	2.12	2.00	2.00	1.90	1.80	2.55	2.20	1.85	1.78	1.62	2.67	2.00	1.79	1.67	1.48
$P_{11} \times P_{12}$	2.68	2.68	2.68	2.64	2.61	2.68	2.68	2.65	2.61	2.58	2.72	2.68	2.63	2.58	2.55
$P_{11} \times P_{14}$	2.65	2.63	2.61	2.57	2.52	2.68	2.60	2.57	2.55	2.48	2.70	2.60	2.55	2.55	2.45
$P_{12} \times P_{14}$	2.66	2.62	2.58	2.53	2.45	2.67	2.62	2.55	2.45	2.32	2.68	2.60	2.44	2.42	2.21
CK	2.66	2.61	2.60	2.55	2.48	2.67	2.60	2.57	2.45	2.37	2.68	2.60	2.55	2.42	2.19
Level of significance	**					**					**				
LSD (5%)	0.032					0.046					0.068				

** indicates significance at 1% level of probability.

Table 4. Combined effect of sweet gourd F1 individuals and different concentrations of NaCl on stomatal conductance (gs).

Crosses (F1 individuals)/ variety	Stomatal conductance (g_s) (mol m^{-2} s^{-1})														
	g_s (15 days after NaCl application)					g_s (30 days after NaCl application)					g_s (45 days after NaCl application)				
	NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})					NaCl concentrations (dS m^{-1})				
	Control	4	8	12	16	Control	4	8	12	16	Control	4	8	12	16
$P_6 \times P_8$	0.117	0.120	0.110	0.110	0.100	0.117	0.120	0.100	0.100	0.090	0.130	0.120	0.100	0.100	0.070
$P_6 \times P_9$	0.100	0.100	0.090	0.090	0.080	0.110	0.100	0.090	0.060	0.040	0.110	0.100	0.070	0.050	0.030
$P_6 \times P_{11}$	0.117	0.107	0.110	0.100	0.090	0.130	0.120	0.090	0.080	0.060	0.140	0.110	0.070	0.060	0.050
$P_6 \times P_{12}$	0.117	0.117	0.100	0.100	0.090	0.120	0.120	0.090	0.090	0.080	0.150	0.100	0.080	0.080	0.070
$P_6 \times P_{14}$	0.117	0.117	0.117	0.110	0.100	0.120	0.120	0.110	0.100	0.090	0.130	0.120	0.100	0.100	0.080
$P_8 \times P_9$	0.108	0.107	0.100	0.100	0.090	0.112	0.107	0.090	0.090	0.070	0.115	0.100	0.090	0.070	0.050
$P_8 \times P_{11}$	0.117	0.117	0.110	0.100	0.090	0.130	0.110	0.100	0.100	0.080	0.147	0.100	0.090	0.090	0.080
$P_8 \times P_{12}$	0.117	0.120	0.090	0.090	0.080	0.130	0.120	0.090	0.080	0.060	0.150	0.110	0.070	0.060	0.060
$P_8 \times P_{14}$	0.127	0.130	0.120	0.110	0.100	0.136	0.130	0.100	0.100	0.090	0.150	0.120	0.100	0.080	0.080
$P_9 \times P_{11}$	0.127	0.130	0.120	0.100	0.100	0.137	0.110	0.090	0.090	0.070	0.157	0.090	0.080	0.080	0.070
$P_9 \times P_{12}$	0.117	0.120	0.090	0.090	0.080	0.140	0.120	0.090	0.080	0.070	0.150	0.110	0.070	0.070	0.050
$P_9 \times P_{14}$	0.096	0.097	0.090	0.080	0.060	0.100	0.100	0.080	0.070	0.050	0.100	0.100	0.070	0.060	0.040
$P_{11} \times P_{12}$	0.127	0.127	0.117	0.100	0.100	0.127	0.130	0.110	0.100	0.090	0.130	0.130	0.100	0.100	0.080
$P_{11} \times P_{14}$	0.127	0.120	0.100	0.100	0.090	0.140	0.110	0.090	0.090	0.080	0.140	0.110	0.090	0.070	0.070
$P_{12} \times P_{14}$	0.117	0.120	0.090	0.080	0.070	0.130	0.120	0.090	0.070	0.050	0.137	0.120	0.080	0.060	0.040
CK	0.117	0.120	0.100	0.100	0.080	0.130	0.110	0.090	0.080	0.060	0.130 e	0.100	0.070	0.060	0.040
Level of significance	**					**					**				
LSD (5%)	0.007					0.007					0.007				

** indicates significance at 1% level of probability.

Quantum yield (Fv/Fm)

F_v/F_m indicates the quantum yield of photosystem II. F_v/F_m estimated the efficiency of excitation energy transfer to open PSII centers. Salinity had a significant effect on quantum yield (F_v/F_m). Increasing salinity levels antagonistically affected F_v/F_m. At 15 and 30 days after induced salinity, F_v/F_m was decreased slowly but at 45 days after induced salinity F_v/F_m decreased dramatically. The maximum F_v/F_m (0.794) occurred in the control treatment followed by 4 dS m^{-1} salinity stress at 15 days after induced salinity and the minimum F_v/F_m (0.783) occurred in 16 dS m^{-1} salinity level. The maximum F_v/F_m (0.794) occurred in the control treatment followed by 4 dS m^{-1} salinity stress at 30 days after induced salinity and the minimum F_v/F_m (0.772) occurred in 16 dS m^{-1} salinity level. The maximum F_v/F_m (0.802) occurred in the control treatment at 45 days after induced salinity and the minimum F_v/F_m (0.726) occurred in 16 dS m^{-1} salinity level (Fig. 6A).

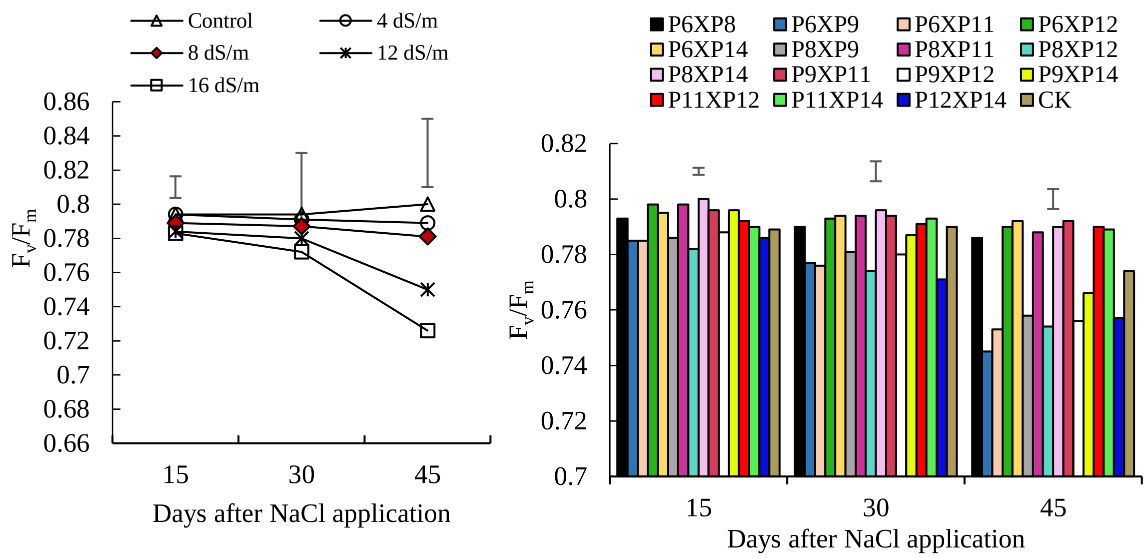

Fig. 6. Effect of salt stress (A) and hybrids (F_1 individuals) (B) on Fv/Fm of sweet gourd at 15, 30 and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

F1 individuals had a significant effect on quantum yield (F_v/F_m). At 15 days after induced salinity, a similar result was found in all F1 individuals (Fig. 6B). At 30 days after induced salinity, the highest F_v/F_m (0.808) occurred in $P_8 \times P_{14}$ followed by $P_6 \times P_8$, $P_6 \times P_{12}$, $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_{11} \times P_{12}$, $P_{11} \times P_{14}$, BARI Hybrid Mistikumra-1 (CK) and minimum F_v/F_m (0.772) occurred in $P_{12} \times P_{14}$. But at 45 days after induced salinity, F_v/F_m was dramatically decreased. In the control treatment, the highest F_v/F_m (0.790) occurred in $P_{11} \times P_{12}$ which was identical to $P_6 \times P_8$, $P_6 \times P_{12}$, $P_6 \times P_{14}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_9 \times P_{11}$, $P_{11} \times P_{14}$ in the control treatment and minimum (0.753) occurred in $P_6 \times P_{14}$ and $P_{11} \times P_{12}$ showed higher F_v/F_m in all growing periods (Fig. 6B).

Salinity stress on F1 individuals had significant effects on F_v/F_m at 45 days after induced salinity. The combined effect of F1 individuals and salinity on F_v/F_m are shown in Table 5. The F_v/F_m ratio decreased under stress conditions as compared to the control. At 15 and 30 days after induced salinity, there was no significant effect on F_v/F_m. At 45 days after induced salinity, most of the F1 individuals showed maximum F_v/F_m in the control treatment, but at 4 dS m^{-1} salinity stress, the highest F_v/F_m (0.800) occurred in $P_8 \times P_{14}$ followed $P_6 \times P_8$, $P_6 \times P_{11}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$ $P_9 \times P_{11}$, $P_{11} \times P_{12}$, $P_{11} \times P_{14}$, CK and the lowest F_v/F_m (0.778) occurred in $P_6 \times P_9$. At 8 dS m^{-1} salinity stress, the highest F_v/F_m (0.795) occurred in $P_{11} \times P_{12}$ followed by $P_6 \times P_{12}$, $P_6 \times P_{14}$, $P_9 \times P_{11}$, $P_9 \times P_{14}$, $P_8 \times P_{14}$ and the lowest value (0.765) occurred in $P_8 \times P_9$. At 12 dS m^{-1}, the highest F_v/F_m (0.788) occurred in $P_6 \times P_{14}$ followed by $P_{11} \times P_{12}$ and the lowest F_v/F_m (0.749) occurred in $P_6 \times P_9$. At 16 dS m^{-1} salinity stress, the maximum F_v/F_m (0.777) occurred in $P_6 \times P_{14}$ which was statistically identical to $P_{11} \times P_{12}$, $P_8 \times P_{11}$, $P_8 \times P_{14}$, $P_6 \times P_8$, $P_9 \times P_{11}$ and the lowest F_v/F_m (0.661) occurred in $P_6 \times P_9$ (Table 5).

Table 5. Combined effect of sweet gourd F1 individuals and different concentrations of NaCl on quantum yield (Fv/Fm).

Cross (F_1s)/ variety	Quantum yield (F_v/F_m) (15 days after NaCl application) NaCl concentration (dS m^{-1})					(30 days after NaCl application) NaCl concentration (dS m^{-1})					(45 days after NaCl application) NaCl concentration (dS m^{-1})				
	Control	4	8	12	16	Control	4	8	12	16	Con-trol	4	8	12	16
$P_6 \times P_8$	0.800	0.800	0.794	0.789	0.784	0.800	0.798	0.788	0.787	0.780	0.802	0.793	0.785	0.779	0.775
$P_6 \times P_9$	0.800	0.792	0.792	0.781	0.778	0.800	0.780	0.777	0.772	0.761	0.800	0.778	0.765	0.749	0.661
$P_6 \times P_{11}$	0.804	0.789	0.782	0.781	0.781	0.802	0.777	0.773	0.768	0.762	0.800	0.793	0.765	0.760	0.672
$P_6 \times P_{12}$	0.804	0.804	0.797	0.797	0.788	0.804	0.798	0.793	0.790	0.780	0.807	0.797	0.790	0.782	0.774
$P_6 \times P_{14}$	0.800	0.800	0.800	0.795	0.795	0.802	0.800	0.800	0.795	0.786	0.802	0.800	0.794	0.788	0.777
$P_8 \times P_9$	0.802	0.798	0.788	0.785	0.781	0.800	0.798	0.775	0.768	0.754	0.808	0.791	0.767	0.753	0.675
$P_8 \times P_{11}$	0.806	0.804	0.800	0.792	0.790	0.807	0.800	0.792	0.788	0.784	0.812	0.792	0.785	0.779	0.775
$P_8 \times P_{12}$	0.803	0.794	0.780	0.778	0.775	0.800	0.788	0.778	0.765	0.755	0.800	0.793	0.775	0.755	0.672
$P_8 \times P_{14}$	0.806	0.804	0.800	0.798	0.792	0.808	0.800	0.795	0.792	0.788	0.808	0.794	0.794	0.780	0.775
$P_9 \times P_{11}$	0.804	0.800	0.794	0.793	0.790	0.804	0.800	0.794	0.790	0.785	0.808	0.798	0.791	0.789	0.777
$P_9 \times P_{12}$	0.804	0.800	0.798	0.798	0.794	0.804	0.798	0.785	0.779	0.762	0.804	0.795	0.775	0.761	0.672
$P_9 \times P_{14}$	0.805	0.805	0.800	0.795	0.774	0.807	0.795	0.795	0.778	0.763	0.810	0.794	0.788	0.765	0.673
$P_{11} \times P_{12}$	0.800	0.800	0.800	0.795	0.795	0.802	0.800	0.800	0.795	0.785	0.808	0.800	0.795	0.788	0.777
$P_{11} \times P_{14}$	0.802	0.799	0.794	0.794	0.789	0.802	0.800	0.792	0.788	0.784	0.808	0.795	0.785	0.782	0.774
$P_{12} \times P_{14}$	0.800	0.788	0.788	0.785	0.781	0.802	0.788	0.775	0.765	0.758	0.808	0.781	0.771	0.753	0.675
CK	0.800	0.800	0.794	0.792	0.790	0.800	0.795	0.792	0.788	0.775	0.812	0.792	0.785	0.769	0.715
Level of significance			NS					NS					**		
LSD (5%)			-					-					0.003		

** indicates significance at 1% level of probability, NS = Not significant.

Relative water content (RWC)

Salinity had a significant effect on the relative water content (RWC) in sweet gourd. In comparison to the control treatment, the RWC was significantly reduced by the salt treatments. The highest RWC occurred in the control treatment (87.47%), whereas the minimum RWC (60.80%) occurred in 16 dS m^{-1} (Fig. 7A).

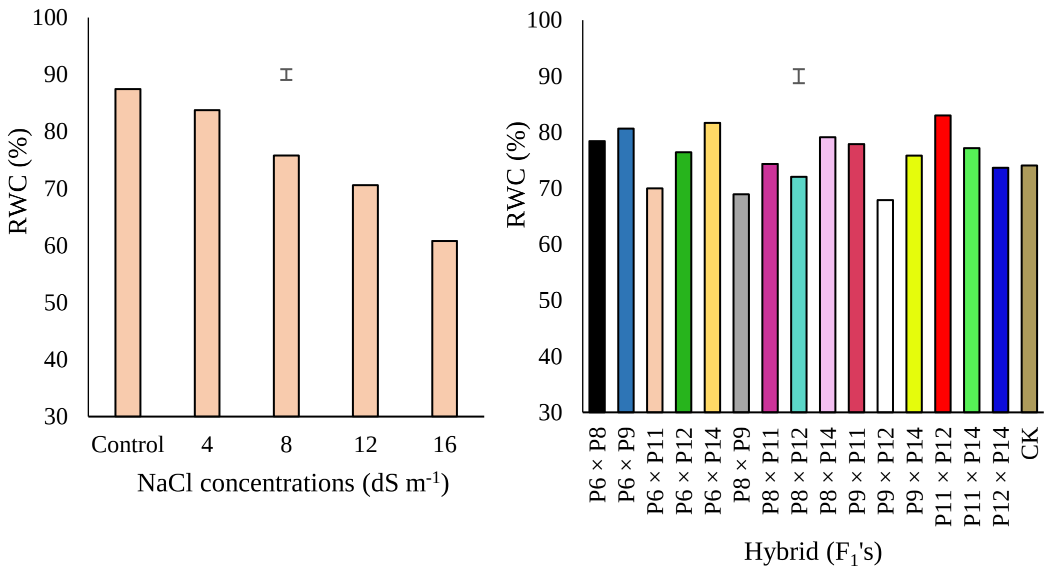

Fig. 7. Effect of salt stress (A) and hybrids (F1 individuals) (B) on Fv/Fm of sweet gourd at 15, 30, and 45 days after application. Vertical bars indicate LSD at 5% level of significance.

The F1 individuals had a significant effect on RWC of sweet gourd hybrids. The maximum RWC (82.98%) appeared in the sweet gourd hybrid $P_{11} \times P_{12}$ whereas the minimum RWC (67.87%) appeared in the hybrid $P_9 \times P_{12}$ (Fig. 7B).

Salinity in combination with F_1 individuals had a significant effect on RWC. The control treatment showed significantly better results compared to all salinity levels. In the control treatment, the highest RWC (95.53%) occurred in $P_9 \times P_{14}$ followed by $P_6 \times P_{14}$ whereas the minimum RWC (82.83%) occurred in $P_8 \times P_9$. At 4 dS m^{-1} salinity stress. The highest RWC (91.06%) occurred in $P_6 \times P_9$ followed by $P_6 \times P_8$ and the minimum (72.65%) in $P_8 \times P_9$.

At 8 dS m^{-1} salinity stress, the highest RWC (84.00%) occurred in $P_{11} \times P_{12}$ and the minimum RWC (67.50%) in $P_9 \times P_{12}$. At 12 dS m^{-1} salinity stress, the highest RWC (72.50%) occurred in the hybrid $P_{11} \times P_{12}$ and the minimum RWC (62.40%) appeared in $P_9 \times P_{12}$. However, at 16 dS m^{-1} salinity stress, the maximum RWC (72.80%) occurred in $P_6 \times P_{14}$ which was identical to $P_{11} \times P_{12}$ whereas the least RWC (48.52%) occurred in $P_9 \times P_{12}$ (Table 6).

Discussion

Chlorophyll content (SPAD value)

A significant difference occurred between salt stress and hybrids (F_1 individuals). The chlorophyll content (SPAD value) decreased in sweet gourd under salt stress but increased in the control. The higher SPAD value may be related to the repair of the cell injury or an efficient mechanism for the uptake of necessary elements for chlorophyll in saline soils. These results were generally consistent with the findings of Ghogdi et al. (2012). Thus, selecting cultivars based on increased or stable Chlorophyll content may prevent yield losses under salt-stress conditions. Genotypes with a higher SPAD value under a salt environment should produce a higher grain yield than those having a lower chlorophyll content (Abu Hasan et al., 2016; James et al., 2002). Many researchers have suggested that the SPAD measurement could be a handy selection criterion to screen a large set of genotypes for salt tolerance (Cuin et al., 2010; Pak et al., 2009). Different opinions exist about the salinity effect on chlorophyll content, and among these, many studies have reported a significant decrease in chlorophyll content under salt stress (Kumar et al., 2021; Sharif et al., 2017).

Table 6. Combined effect of F1 individuals and different NaCl levels on relative water content (RWC).

Cross (F_1s)/ variety	Relative water content (RWC) (%)				
	NaCl concentration (dS m^{-1})				
	Control	4	8	12	16
$P_6 \times P_8$	91.07	90.55	72.13	72.13	66.11
$P_6 \times P_9$	92.20	91.06	80.55	74.50	64.88
$P_6 \times P_{11}$	80.55	80.00	68.21	68.50	52.55
$P_6 \times P_{12}$	83.54	80.00	81.05	75.00	62.40
$P_6 \times P_{14}$	95.20	87.52	80.55	72.30	72.80
$P_8 \times P_9$	74.32	72.65	72.00	68.50	52.72
$P_8 \times P_{11}$	83.55	85.25	80.55	68.50	53.91
$P_8 \times P_{12}$	84.54	82.00	77.33	66.11	50.28
$P_8 \times P_{14}$	84.45	85.50	82.17	72.50	70.85
$P_{11} \times P_{12}$	87.23	85.52	78.50	72.00	66.11
$P_9 \times P_{12}$	85.26	75.65	67.50	62.40	48.52
$P_9 \times P_{14}$	95.53	87.82	72.00	68.50	55.25
$P_9 \times P_{11}$	88.25	87.76	84.00	82.40	72.50
$P_{11} \times P_{14}$	88.75	83.65	75.25	72.00	66.11
$P_{12} \times P_{14}$	91.60	85.53	70.25	67.00	53.91
CK	93.56	75.80	70.00	67.00	63.91
Level of significance		**			
LSD (5%)		1.25			

** indicates significance at 1% level of probability.

Gas exchange parameter

Photosynthetic pigments are essential regulators of photosynthesis (Ashraf, 2004; Parida and Das, 2005). However, these pigments are degraded in plants when exposed to salt stress. Traditional screening techniques for salt tolerance are usually based on grain yield and are expensive and time-consuming (Kiani-Pouya and Rasouli, 2014). The focus on screening salt-tolerant genotypes has shifted towards examining specific physiological traits involved in salt tolerance in recent years (Ashrafi et al., 2014). Water deficit causes a decrease in leaf turgor, resulting in stomatal closure and stomatal conductance (gs) that limits photosynthetic rates (Pn) (Chaves et al., 2009). Photosynthesis is the most significant physiological process in plants and is affected by stress factors, including salt stress. Ashraf and Harris (2013) stated that the mechanism of photosynthesis involves various components, including photosynthetic pigments and photosystems, the electron transport system, and CO_2 reduction pathways, and any level caused by a stress factor may reduce the overall photosynthetic capacity of a green plant. Researchers proved that gs, sub-stomatal concentration of CO_2, E, and Pn are all parameters affected by salt stress (Dikobe et al., 2021; Sudhir and Murthy, 2004).

Similar to drought stress, under salt stress, a reduction in gs was also reported (Chaves et al., 2009; Rouphael et al., 2017). Salinity affects stomatal conductance immediately, firstly, and transiently owing to perturbed water relations and shortly afterward owing to the local synthesis of ABA (Munns and Tester, 2008). A decreased stomatal conductance lowers CO_2 assimilation and respiration rate in various species and salinity levels (Ashraf, 2004). The previous research showed that the reduction rate in photosynthesis and translocation of assimilates under saline conditions depends on species and salt concentrations (Parida et al., 2005). Agastian et al. (2012) showed that in mulberry, stomatal conductance, CO_2 assimilation, and respiration rate were decreased in response to salinity, while the concentration of intercellular CO_2 increased with salinity. High osmotic potential and reduced water availability to plants usually result in cell membrane dehydration and reduction of the permeability of CO_2. Thus, it decreases the photosynthetic electron transport via the shrinkage of intercellular spaces.

Quantum yield (Fv/Fm)

The maximum quantum efficiency of photosystem II (Fv/Fm) is a widely used indicator of photosynthetic health in plants (Wu et al., 2023). Chlorophyll fluorescence is a non-destructive screening method to discriminate susceptible and resistant genotypes to salt stress (Najar et al., 2018). These chlorophyll fluorescence attributes are excellent measures of stress-induced damage to photosystem II. The significant decrease of Fv/Fm in comparison with the control took place at 4, 8, 12, and 16 dS m^{-1} NaCl. These results are in agreement with the results of Al Gehani and Ismail (2016), who stated that chlorophyll fluorescence (Fv/Fm) decreased with the increasing level of salinity. The quantum yield of PSII decreased significantly in ‘Adriatica’ and ‘Black Beauty’ eggplants under salt stress (Hanachi et al., 2014). Jhong et al. (2019) found that the chlorophyll fluorescence of cucumber plants significantly decreased after treatment with high NaCl concentrations. Lower values indicated that a proportion of the PSII reaction center is damaged or inactivated, a phenomenon commonly observed in plants under stress (Baker and Rosenqvist, 2004). High salinity decreased Pn, E, and gs and grain yield but increased electrolyte leakage and Na+ content (Mahlooji, 2018). Zhao et al. (2007) reported that in naked oats at salinity stress up to 150 mM NaCl, the Fv/Fm ratio did not change, but when salinity concentration increased to 200 mM or higher, a sharp reduction in Fv/Fm ratio occurred. In addition, salt-induced increase in photorespiration in C_3 plants like wheat is the main reason for the increase in electron transport rates (Megdiche et al., 2008).

Relative water content (RWC%)

Relative water content (RWC) decreased with the increase in salinity. The tolerant genotype showed a higher RWC under salinity stress rather than the sensitive genotype. This finding agrees with the results of Geravandi et al. (2011). Reduction in RWC may be due to the reduction in water content, leaf area, transpiration rate (E), stomatal conductance (gs), absorption of radiation under leaf rolling, production of leaves, and yield, or increase in leaf senescence and abscission. Similar results were observed by Bybordi and Ebrahimian (2011) and Munns and Tester (2008) that the ability to maintain osmotic potential for higher RWC in saline soil and water at various stages is an effective mechanism staged by salt-tolerant genotypes (Kafi and Rahimi, 2011).

Conclusion

It can be concluded from the results that sweet gourd was more sensitive to salinity-induced damage at growth stages, as evidenced by the increased chlorophyll degradation, marked reduction in various gas exchange attributes, and chlorophyll fluorescence attributes at the growth stages. Furthermore, $P_6 \times P_{14}$ and $P_{11} \times P_{12}$ were higher in salinity tolerance by maintaining relatively higher photosynthetic rates, relative water content, and less salinity-induced damage done to photosystem-II than the other hybrids.

Author contributions

RK conducted the experiment, carried out laboratory analysis, collected and compiled data, analyzed the data, and wrote the manuscript draft. MH directed and designed the experiment, monitored the data analysis and the experiment, and guided manuscript preparation for submitting to the journal. LA assisted in field work and laboratory analysis, verified the data, and contributed to manuscript preparation.

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Conflict of Interest

The authors indicate no conflict of interest in this work.

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