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Research Article

Assessment of *Sorghum bicolor* fodder attributes for agroclimatic potential under salt stress

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Abstract
Sorghum (*Sorghum bicolor* L.) is mainly produced as an infallible crop in semi-arid and arid areas. Though the impact of salinity on crop production is extensively documented, very limited studies are available demonstrating the interaction between fodder quality and irradiance use efficiency in sorghum. To study such interactions, the present study aimed to evaluate the resource use efficiency in different sorghum lines for fodder evaluation under a varied salinity regime (60 to 120 mM NaCl), on the 2017-18, 2018-19 and 2019-20 *kharif* seasons. Sorghum grown on June 15, 2018employed higher thermal and heat units than July 2, 2019. Sorghum genotypes' differential quality and yield responses to various temperatures were due to differences in high salinity tolerance during various growth stages. The crop sown on June 15th required the most growing degree days units to reach various phenological stages and physiological maturity. SSG 59-3 maintained higher crude protein, *in vitro* dry matter digestibility (IVDMD), crude protein yield, and digestible dry matter at 120 mM NaCl. SSG 593 exhibited maximum green fodder yield (GFY) and dry matter yield (DMY), while PC-5 had the minimum. SSG 59-3 genotype accumulated high radiation use efficiency (281.23 kgha^{-1} MJ^{1}), heat susceptibility index (0.42%), and yield stability ratio (87.2%) in both control and stressed environments, while PC-5 showed moderate tolerance to temperature stress and thus recorded a lower heat susceptibility index. Since there is no discernible correlation between the agronomic and fodder quality factors, it is possible to breed for desired qualities using independent associations. The results showed that the SSG 59-3 genotype adopted optimum allocation of resources for biomass production, maximized yield potential, and could be utilized in breeding programs as a potential fodder crop in saline regimes.

Keywords: Crude protein, Efficiency, Radiation, Salinity, Sorghum, Sowing dates, Yield

INTRODUCTION

In the current scenario, climate change has become the main restriction in agriculture that harms crop output globally (Punia *et al.,* 2021a; Toka*set al.,* 2021a). Climatic and ecological changes play a significant role in seed germination, subsequent growth and development, and final yield potential (Punia *et al.,* 2021b; Punia *et al.,* 2020a). Salinity has emerged as a major global agricultural concern, posing a significant threat to long-term crop production (Punia *et al.,* 2021c; Punia *et al.,* 2021d). Salinity is a major obstacle to agricultural development in dry and semi-arid tropical regions due to the inconsistent distribution of rainfall, temperature, and underground ions (Afshar *et al.,* 2014). According to the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and the Food and Agriculture Organization (FAO), approximately 20% of the world's cultivated land and 33% of irrigated agricultural land are affected by salinity(Zeeshan *et al.,* 2020; Franzoni *et al.,* 2020).

Due to a lack of feed and competition for resources with other crops, livestock in semi-arid and tropical areas are impoverished and destitute. Although marginal farmers may have few possibilities to cultivate, there is a strong interest in producing dual-purpose cultivars to increase grain output and biomass quality (Somegowda*et al.,* 2021). Sorghum (*Sorghum bicolor*) is one of the important fodder crops that grow well in low-rainfall, high-temperature, and low-fertility conditions (Punia *et al.,* 2021e; Punia *et al.,* 2021f). It is widely cultivated as a dual-purpose cereal crop in arid and semi-arid regions of the world (Tokas *et al.,* 2017). Because there are not enough concentrated animal feeds in India, forage crops make up most of the country's fodder supplies. Ruminants get most of their nutrients from herbs and green forages, which help them maintain moderate growth levels.

Resources are scarce, and improving resource use efficiency for cereal crop systems is indeed an essential aspect. The temperature is the most important factor in determining crop yield (Mohapatra *et al.,* 2021). The appropriate temperature is required for growth and development at different developmental stages. Given sorghum's inherent resilience to various climatic conditions, assessing the radiation use efficiency (RUE) of different genotypes across varying salinity levels becomes imperative (Punia *et al.,* 2020b). This evaluation aims to pinpoint the sorghum genotype that exhibits the highest energy efficiency while facilitating optimal dry matter accumulation. Such identification is crucial for maximizing productivity, especially in Haryana's regions prone to salinity (Rao *et al.*, 2016; Azeem *et al.,* 2023). Further efficiencies of genotypes were assessed in terms of fodder yield, crude protein yield, and digestible dry matter (Punia *et al.,* 2021g; Punia *et al.,* 2020c).

Quality is critical in developing and breeding new varieties (Tokas*et al.,* 2021b). Plant breeders' primary criterion for selecting sorghum lines is the utilization of agronomically important aspects with improved grain and fodder content. Plant breeders must closely study and assess Sorghum to help growers find certain varieties with a valuable agronomic trait. Studies on the relationship between fodder quantity and quality may help breed for traits without forfeiture. Very little information is available on how salt affects the nutritional value of forage plants. Furthermore, as diverse lines provide resilience in the crop development program, a robust genetic foundation for effective radiation usage can sustain sorghum production. Hence, the present study aimed to evaluate the efficiency of resource use and its effect on the fodder quality of sorghum under saline conditions.

MATERIALS AND METHODS

Plant material and growth conditions

The seeds of four sorghum (*Sorghum bicolor* L.) genotypes, SSG 59-3 (sweet sorghum), G-46, CSV 44F, and PC-5 were obtained from the Forage Section, Department of Genetics & Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, India. A screen house experiment was conducted at the Department of Biochemistry, CCS HAU, Hisar (29° 10' N of 75° 46'E, 216 m above sea level) during the *kharif* seasons of 2017-18, 2018-19 and 2019-20. The four sorghum genotypes were exposed to different salt concentrations (60- 120 mM of NaCl) using distilled water as a control.Four concentrations were selected after sorghum germplasm was screened. The concentrations were chosen following accepted practices in the industry and earlier research that showed how salt stress affected the physiology and growth of sorghum. Because the concentrations chosen constitute a spectrum of stress intensities that can capture both moderate and severe stress conditions without adding too many variables to the experimental design (Dehnavi *et al*., 2024).The physicochemical properties of the collected soil samples are shown in Table 1. The genotypes were sown manually on 15^{th} May 2017-18, 15^{th} June 2018-19 and 2^{nd} July 2019-20 (rainy season). Sampling was done at the vegetative stage and physiological maturity. The first sampling was taken 35 days after sowing, and the second was taken 95 days after sowing (post-rainy season), when 95% of panicles had turned yellow. The fresh weights of the samples were air-dried in an oven at 65 °C for 72 h. The dried fodder samples were then grounded in a Willey mill using a 2 mm sieve. The standard agronomic packaging and practices were used for sorghum in all treatments(Hossain *et al*., 2022). Conventional breeding works by identifying plants with desirable qualities and then using them to create the next generation. These methods are ancient and the foundation of all agriculture.

Quality traits

Hydrocyanic acid was estimated using the method of Gilchrist *et al.*(1967). The stem was cut, and the innermost collars were collected for HCN estimation.*Invitro* dry matter digestibility (IVDMD) was determined as described (Bornes *et al.,* 1971). 250 mg of dried sample was extracted with McDougall's buffer solution, and rumen liquor (which serves as inoculum) obtained from

Table 1. Properties of the soil used in the pots during the net house experiment

Soil Texture	EC (%)	pH	OC (%)	N (mg/kg)	P (mg/kg)	K (mg/kg)
Sandy-loam	0.09	7.50	0.18	86.33	3.67	165.0

a ruminally fistulated steer was incubated at 40 °C for 48 h. The contents were filtered through Whatman No. 4 filter paper and weighed. The residues were dried on the filter paper in an oven at 100 °C and expressed on a percent dry weight basis (Bornes *et al.,* 1971). Total nitrogen content was estimated by the micro-Kjeldahl method (AOAC, 2000) and crude protein content was calculated using N concentration × 6.25.

Crude protein (%)=$\underline{(X−Y) \times 0.00014 \times D \times 100 \times 6.25/}$ W × A ……………Eq. 1

Where,

X = Volume of blank reading

Y = Volume of 0.01 N HCl used to neutralize NH_3 in boric acid

D = Dilution factor (Volume made in a volumetric flask)

W = Weight of sample taken

A = Aliquot for the sample taken for digestion

Crude protein yield was calculated by multiplying dry matter yield to crude protein content, and all values were given in % on a dry matter basis. The digestible dry matter was calculated by multiplying IVDMD with dry matter yield (q/ha).

Tannin was estimated as described (Burnes,1971). To the 200 mg of ground sample, 25 ml of methanol was added to the test tube, stopped with wax-coated cork, and incubated at 30 °C for 20 h. 5 ml of vanillin (4% w/v) in methanol - HCl (8% v/v) in methanol were added to the reconstituted sorghum extract, followed by an incubation of 20 minutes at 2°C. The optical density of the solution was read at 525 nm.

Agronomic traits

The seed yield per plant (g) was measured for each plant in each treatment. The numbers of leaves per plant were expressed as the mean of counted leaves from each replication. The numbers of tillers per plant were expressed as the mean of the counted tiller numbers from each replication. The green fodder harvested from each pot and each treatment was weighed *in situ* as kg/pot and then converted into kg/hato get the green fodder yield (GFY). The freshly harvested fodder samples were then air-dried and transferred to an oven at 65 °C, and dry fodder yield (DMY) was calculated.

Radiation use efficiency (RUE)

The data for solar radiation PAR was collected from the Department of Agricultural Meteorology, CCS HAU, Hisar, and RUE. Radiation use efficiency is defined as the amount of green fodder and dry matter accumulation per unit of intercepted photosynthetically active radiation (PAR) (Chavez *et al.,* 2022). RUE of sorghum from the date of sowing to first sampling, followed by first sampling to second sampling, was computed by the expression given below and expressed in (kg/ha^{-1} MJ^{-1}):

RUE = $\underline{\text{Yield of sorghum (kg/ha)/}}$ Accumulated iPAR (MJ) ……………Eq. 2

The average minimum and maximum temperatures received by the sorghum genotypes from sowing to harvesting under different dates are depicted in Table 2.

Heat susceptibility index (S)

Heat Susceptibility index (S) was calculated for seed yield as per Fischer and Maurer (1978) formula:

$S = (1-Y/Y_p)/(1-X/X_p)$ …………… .Eq.3

Where, Y = mean grain yield of genotypes under saline conditions; Y_p = mean grain yield of a genotype in control plants; X = mean Y of all the genotypes; X_p = mean Y_p of all genotypes

Growing-Degree-Day

The Growing-Degree-Day (GDD) or heat unit was estimated for different growth phases using the following equation:

$GDD = S\ [(T_{max} + T_{min})/2]-T_b$ ………………Eq. 4

Where,

T_{max} = maximum temperature of the day in °C; T_{min} = minimum temperature of the day in °C; T_b = base temperature in °C (10 °C)

Yield stability ratio (YS)

The yield stability ratio (YS) was calculated by taking the ratio of seed yield under stressed and normal conditions.

Statistical analysis

The data was expressed as Mean ± S.D. Two-way ANOVA was conducted to check the significance of the

Table 2. Mean minimum and maximum temperature (°C) during various growth stages of sorghum

Developmental stages	Sowing dates		
	2017-18	2018-19	2019-20
Sowing day	15th May (25.9-43.4°C)	15th June (31.5-40.2°C)	2nd July (26.2-38.6°C)
Vegetative stage	20th June (21.7-38.1°C)	20th July (24.9-35.1°C)	7th August (27.0-34.6°C)
Physiological maturity	20th August (27.0-34.4°C)	20th September (23.5-36.2°C)	7th October (21.0-38.1°C)

main treatments and their interaction on growth indices of sorghum, followed by a post-hoc Tuckey's test for mean comparison at a 5% level of significance using SPSS v25.0 (SPSS for Windows, Chicago, USA).

RESULTS AND DISCUSSION

Quality trait analysis

The results presented in Fig. 1a show the impact of salinity on crude protein (%) in sorghum genotypes. The crude protein decreased significantly at different salinity levels in different sorghum genotypes. SSG 59-3 had minimal salinity effects (11%) on crude protein, while PC-5 had the maximum reduction (34.3%) in crude protein at 100 mM NaCl. A further increase in NaCl significantly impacted the accumulation of crude protein in both genotypes. The reduction of crude protein to high salinity might be due to the plants' poor absorption of nitrogen content, which leads to a decrease in cellular protein synthesis, resulting in stunted and reduced plant growth (Punia *et al.,* 2021c). When compared to 35 DAS, the total mean value of crude protein content was greater at physiological maturity. The increased crude protein with plant growth stages may be due to continuous nitrogen absorption to synthesize proteins with plant age. Similar results were also reported in tomatoes, where crude protein accumulation decreased under salt stress (Amini *et al.,* 2007; Attia *et al.,* 2021).

IVDMD is a key indication of feed quality (Tokas*et al.,* 2021a; Malik *et al.,* 2022; Punia *et al.,* 2021). Forage crops are superior in fodder quality with a higher IVDMD content. Fig. 1b displayed the IVDMD content, which decreased significantly (at $p< 0.05$) in sorghum genotypes with an increase in salinity levels. SSG 59-3 preserved maximal IVDMD content during the vegetative stage (35 DAS) with only an 18.3% drop, but PC-5 exhibited a 52.5% reduction at 100 mM NaCl. At physiological maturity (95 DAS), similar findings were observed. Several other researchers concurred with the present research findings (Punia *et al.,* 2021f; Barnes *et al.,* 1971).

The results in Fig. 2a show that sorghum genotypes have substantial variations in crude protein yield (CPY). During the vegetative stage, SSG 59-h had the highest CPY with a value of 87.27 kg/ha, whereas PC-5 had the lowest with a value of 33.17 kg/ha at 100mM NaCl. Only the variations in the genetic makeup of all these genotypes may explain the disparity in behavior and biomass accumulation. Similar results were observed for digestible dry matter (DDM) (Fig. 2b). When exposed to 100 mM NaCl, SSG 59-3 attained maximum DDM (594.32 kg/ha) at 35 DAS, in contrast, the DDM accumulation was minimum in PC-5 (197.87 kg/ha). Similarly, at 95 DAS, maximum DDM was observed in SSG 59-3 (3242.41kg/ha) where a minimum was observed in PC-5 (1169.98 kg/ha).

The maximum DDM accumulation at physiological maturity resulted in a higher mean value as compared to the vegetative stage (35 DAS). These findings are also consistent with the results of many other researchers (Punia *et al.,* 2021b).Hydrocyanic acid (HCN) is a major aspect of sorghum quality traits. HCN concentration increased sharply as the concentration of salt increased (Fig. 3a). At 35 DAS, the PC-5 exhibited a higher increase in HCN with 45.2% and 63.1%, while the SSG 59-3 accumulated very less HCN with only 11.6 %and 21.1% at 100 and 120mM NaCl, respectively. HCN concentration was at its maximum in sorghum during the vegetative phase, as the crop developed to physiological maturity, it diminished sharply. The increased absorption of nitrogen content under stress conditions by the plants that produce HCN might explain the elevated HCN concentration (Azizinya*et al.,* 2005; Abusuwar and Elzilal, 2010).

Tannin is an important quality attribute for forage quality. Tannin content varied statistically in different sorghum genotypes at the vegetative stage (35 DAS) and physiological maturity (95 DAS) (Fig. 3b). At 120 mM NaCl, the tannin content increased significantly; PC-5 had a higher percent increase in tannin (68%), while SSG 59-3 had a lower (14%) increase. While attaining physiological maturity, the tannin content increased significantly. Similar results were obtained at 95 DAS. Besides being an anti-nutritional factor, it also promotes the production of milk, lambing percentage, and wool growth, lowers the chance of rumen bloat, and decreases the production of methane (CH_4) (Gong *et al.,* 2020; Awika*et al.,* 2009).

Agronomical traits

The genotypes of sorghum were considerably affected by salt stress in terms of yield characteristics, i.e., number of tillers per plant (Fig. 4a), seed yield (Fig. 4b), and number of leaves per plant (Fig. 5). One of the important factors that determines yield is the number of tillers per plant. At physiological maturity, there were more tillers per plant due to an increase in biomass and dry matter. At 100 mM NaCl, the harvested seeds in PC-5 exhibited a relatively larger reduction in seed production (42%), whereas SSG 59-3 showed a lower percentage reduction (13%). At all salinity levels, SSG 59-3 greatly excelled over other genotypes in maintaining maximum seed output and the number of leaves per plant. The data at both sample stages led to the conclusion that SSG 59-3 has more leaves per plant than PC-5. Due to the negative impact on the physiological process and dry matter buildup, which eventually decreased the seed yield, the reduction in yield characteristics was evident at high salt concentrations (120 mM). Reduction in seed yield and its attributes under stress

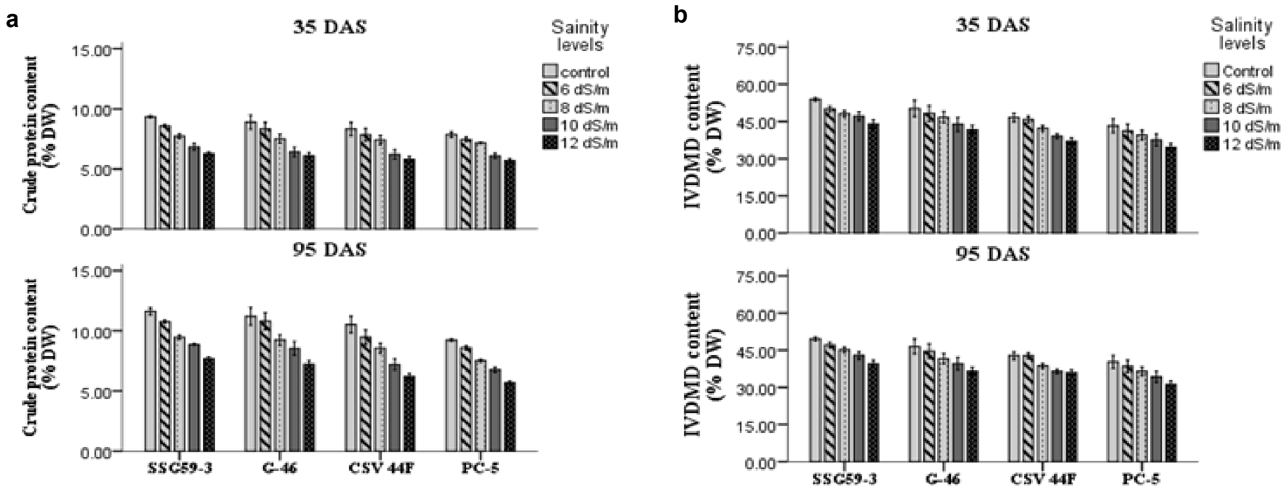

Fig. 1.*Crude protein (a) and (b) IVDMD content in sorghum genotypes at vegetative stage (35 DAS) and physiological maturity (95 DAS) under salt stress.*

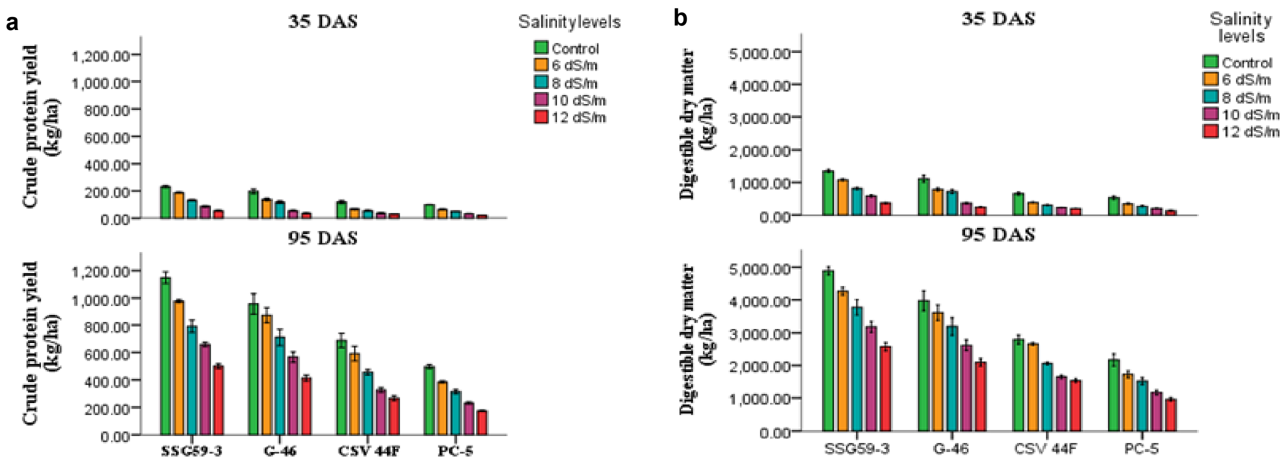

Fig. 2. *(a) crude protein yield (CPY) and (b) digestible dry matter (DDM) of sorghum genotypes at vegetative stage (35 DAS) and physiological maturity (95 DAS) under salt stress*

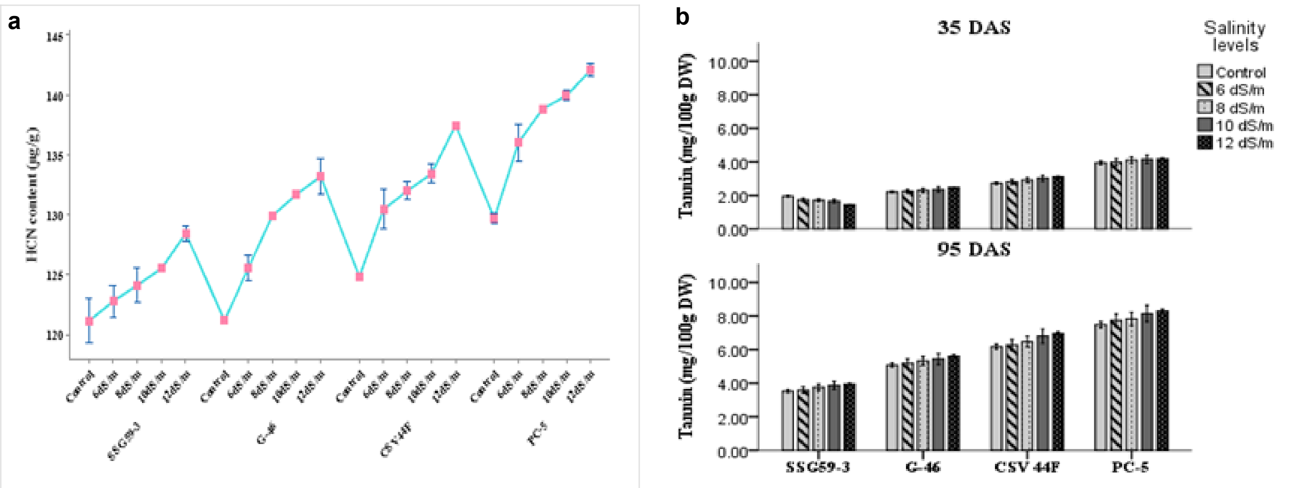

Fig. 3. *(a) HCN content in sorghum genotypes at the vegetative phase and (b) tannin content at the vegetative stage (35 DAS) and physiological maturity (95 DAS) under salt stress*

conditions may depend upon several external and internal factors like pollen germination, abortion, pollen sterility, and incompatible fertilization (Yang *et al.,* 2020). Under increasing salt concentrations, the GFY (Fig. 6a) and DMY (Fig. 6b) declined substantially among the studied sorghum genotypes. Salt-tolerant genotype SSG 59-3 had maximum GFY and DMY, and salt-sensitive genotypes had minimum values during 2018-

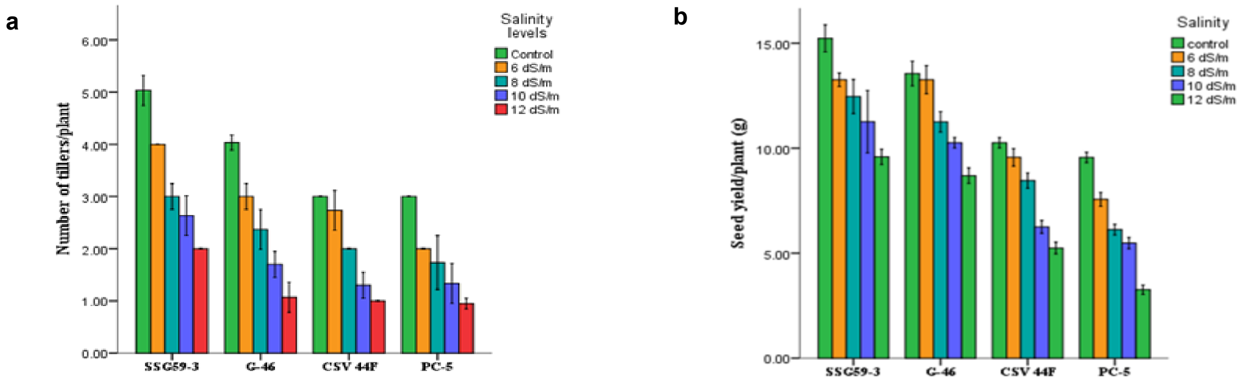

Fig. 4. *Effect of salinity on (a) number of tillers per plant and (b) seed yield/plant of sorghum genotypes at 95 DAS*

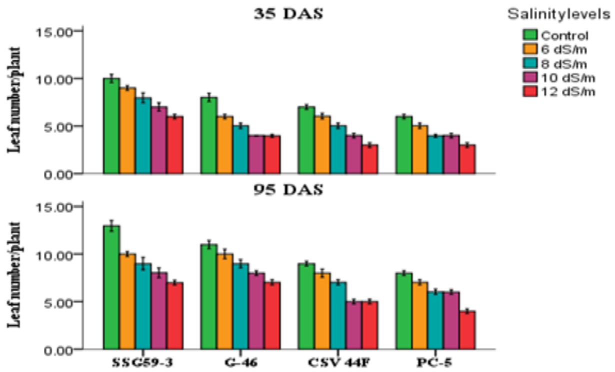

Fig. 5. *Effect of salt stress on the number of leaves/plant of sorghum genotypes at physiological maturity (95 DAS)*

19. The enhanced accumulation of protoplasmic components and accelerated cell division and elongation in resistant genotypes may be responsible for the enhanced accumulation of fresh biomass and dry matter and the luxury of vegetative development. According to Rana *et al.* (2013) multi-cut sorghum genotypes had greater levels of DDM, GFY,DMY, and the number of tillers which could be favorable in saline-prone regions.

Radiation use efficiency

The highest radiation use efficiency (RUE) of GFY was computed in the genotype SSG 59-3 (210.36±0.419 kg/ha^{-1} MJ^{-1}) concerning control (281.23±1.12 kg/ha^{-1} MJ^{-1}), which was on par with G-46 while lower RUE was observed in (145.23±0.961 kg/ha^{-1} MJ^{-1}) at 120mM NaCl as illustrated in Table 3.

Maximum RUE of total dry matter was analyzed in SSG 59-3 (45.23±0.592 kg/ha^{-1} MJ^{-1}) to control (59.36±0.174 kg/ha^{-1} MJ^{-1}) while minimum was observed in (19.66±0.192 kg/ha^{-1} MJ^{-1}) at 120mM NaCl. The amount of sunlight absorbed by the canopy determines how much dry matter accumulates in the plant (Punia *et al.,* 2020a; Attia *et al.,* 2021; Satpal *et al.,* 2018). The amount of radiation absorbed plays a vital role in germination, subsequently affecting growth, development, and finally yield (Tokas*et al.,* 2021b). Data given in Ta-

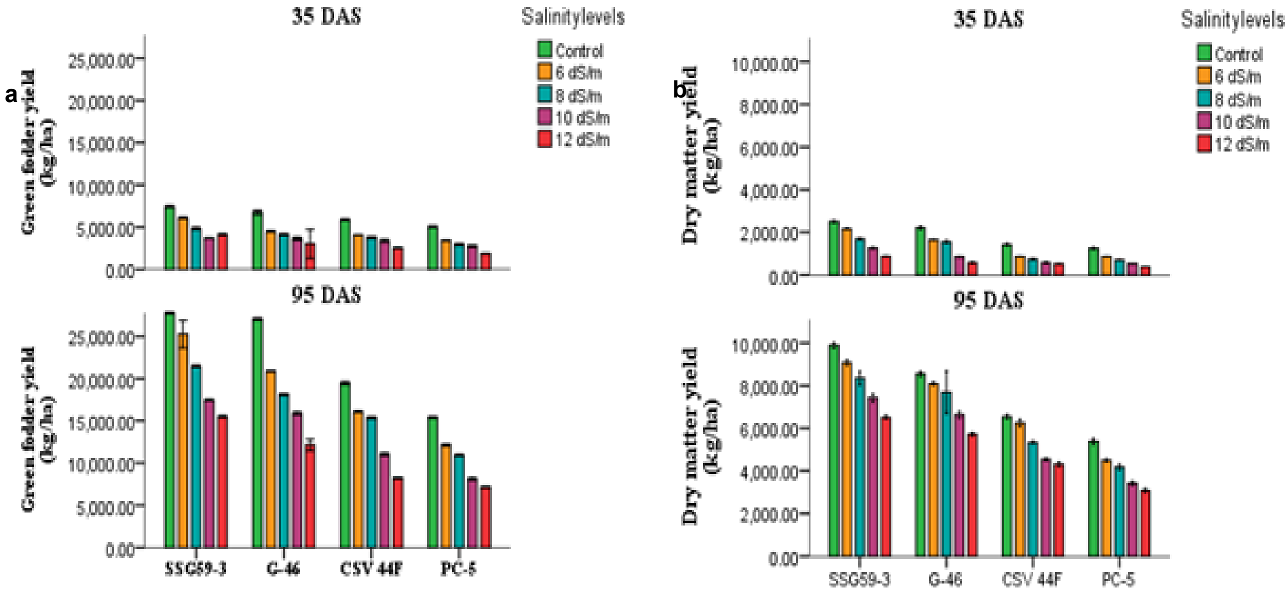

Fig. 6. *(a) green fodder yield (GFY) and (b) dry matter yield (DMY) of sorghum genotypes at the vegetative stage (35 DAS) and physiological maturity (95 DAS) under salt stress*

Table 3. Radiation use efficiency (RUE) under different salinity levels of sorghum genotypes (Data pooled over 3 years)

Treatments	**RUE of GFY (kg/ha^{-1} MJ^{-1})**				**RUE of DMY (kg/ha^{-1} MJ^{-1})**			
	SSG 59-3	G-46	CSV 44F	PC-5	SSG 59-3	G-46	CSV 44F	PC-5
Control	281.23±1.12	269.37±0.291	241.15±0.231	212.36±0.287	59.36±0.174	52.12±0.823	45.26±0.821	38.69±0.386
60 mM	265.26±0.985	245.36±0.741	218.36±0.426	191.33±0.983	54.26±0.107	46.26±1.09	40.29±0.893	33.49±0.769
80 mM	241.31±1.32	220.44±0.236	195.68±0.287	175.69±0.738	50.46±0.286	40.28±0.294	34.26±0.285	27.46±0.296
100 mM	232.36±0.624	206.56±0.918	174.11±0.298	165.26±0.743	48.69±0.274	34.26±0.752	28.69±0.994	21.26±0.185
120 mM	210.36±0.419	198.56±0.267	152.33±0.354	145.23±0.961	45.23±0.592	30.26±0.243	24.69±0.752	19.66±0.192
CD	32.6	33.2	31.6	30.5	5.6	6.2	6.0	5.9
	RUE of CPY (kg/ha^{-1} MJ^{-1})				RUE of DDM (kg/ha^{-1} MJ^{-1})			
	SSG 59-3	G-46	CSV 44F	PC-5	SSG 59-3	G-46	CSV 44F	PC-5
Control	6.2±0.328	5.9±0.817	4.9±0.381	4.3±0.171	33.36±0.270	30.33±0.280	26.45±0.822	22.16±0.538
60 mM	5.8±0.284	5.55±0.284	4.4±0.528	4.0±0.194	30.16±0.164	28.56±0.175	24.26±0.751	17.56±0.632
80 mM	5.7±0.195	5.3±0.591	4.1±0.589	3.4±0.148	28.56±0.193	24.26±0.274	22.03±0.429	15.69±0.598
100 mM	5.4±0.738	5.0±0.629	3.6±0.273	3.0±0.171	25.16±0.728	22.16±0.610	18.56±0.451	11.26±0.841
120 mM	5.1±0.285	4.7±0.174	3.1±0.294	2.9±0.271	21.03±0.274	18.65±0.728	15.69±0.817	9.57±0.325
CD	0.6	0.8	0.4	0.5	2.3	2.1	2.6	2.5

*GFY–Green fodder yield, CPY–Crude protein yield, DMY–Dry matter yield, DDM–Digestible dry matter.

ble 2 further revealed that the highest RUE of total CPY and total DDM was higher in the SSG 59-3 genotype, i.e., 5.1±0.285 kg/ha^{-1} MJ^{-1} and 21.03±0.274 kg/ha^{-1} MJ^{-1}, respectively, as compared with their respective controls, i.e., 6.2±0.328 kg/ha^{-1} MJ^{-1} and 33.36±0.270 kg/ha^{-1} MJ^{-1}, respectively. The performance of SSG 59-3 and G-46 was better in terms of RUE. Being a climate-resilient crop, sorghum efficiently harnesses maximum productivity under wide variations in atmospheric temperature. Similar results were observed by workers in lettuce where plant density had no discernible impact on RUE; therefore, the rise in biomass production with density must be mostly attributed to higher PAR interception (Punia *et al.,* 2021b; Tei *et al.,* 2002; Marsalis *et al.,* 2010).

Effect of temperature on agro-meteorological indices

The accumulation of growing degree days was larger in 2018–19 at physiological maturity but lower in 2018–19 at the vegetative stage, indicating that 2018–19's mean minimum and maximum temperatures were higher than those of 2017–18 and 2019–20. The length of several phenological phases for sorghum genotypes during three subsequent years of monitoring (Table 4) showed that the cumulative GDD for reaching vegetative and other growth stages decreased with delayed planting. When compared to the sorghum planted on June 15th, the crop planted on July 2nd received more GDD to reach the vegetative stage. At physiological maturity, the accumulated GDD was 2254, 2356, and 2266 for 15thMay, 15th June, and 2nd July sown crops, respectively during 3 years of experiment. These results were supported by the previous reultsChaver *et al.*(2022), who claimed that rice had greater accumulated GDD. SSG 59-3 genotype had the largest GDD accumulation throughout all phenophases, followed by G-46 and CSV 44F while lower was in PC-5. In comparison to the second year, the first and third years' variations were more pronounced. Similar results were also reported in pea (Bourgeois *et al*., 2000), potato, onion (Tesfay *et al.,* 2006; Tesfay *et al.,* 2011), and tomato (Pathak and Stoddard, 2018) .

Heat susceptibility index (S) ranged from 0.42% (SSG 59-3) to 1.03 % (PC-5) and yield stability ratio (YS) ranged from 46.7% (PC-5) to 87.2% (SSG 59-3) among different sorghum genotypes (Table 5). In later phases (anthesis), the SSG 59-3 genotype demonstrated endurance to temperature stress; as a result, it recorded a low heat susceptibility index and a higher yield stability ratio. The genotype PC-5, on the other hand, had a relatively greater heat susceptibility index (1.03%) and a poor yield stability ratio (46.7%), indicating their sensitivity to late planting and consequent vulnerability to temperature rise during later growth stages. Therefore,

Table 4. Growing degree days (GDD) at different stages of sorghum affected by sowing dates and genotypes

Treatment	Vegetative stage			Physiological maturity		
	2017-18	2018-19	2019-20	2017-18	2018-19	2019-20
Date of sowing						
15th May	1975	1984	1942	2254	2356	2266
15th June	1959	1942	1923	2237	2312	2231
2nd July	1946	1836	1816	2190	2216	2257
CD	9.6	8.6	10.4	15.6	18.6	17.4
Genotypes						
SSG 59-3	1079	1165	1089	2246	2367	2246
G-46	984	1047	1011	2212	2289	2189
CSV 44F	849	964	864	2174	2016	2049
PC-5	827	842	746	1056	964	1946
CD	7.6	8.6	9.4	14.6	17.6	15.2

Table 5. Heat susceptibility index and yield stability index of sorghum genotypes growing during *Kharif* season (Data pooled over 3 years)

Sorghum genotypes	Heat susceptibility index (%)	Yield stability index (%)
SSG 59-3	0.42	87.2
G-46	0.52	78.4
CSV 44F	0.89	59.5
PC-5	1.03	46.7
CD	0.65	12.1

an ideal sowing period for sorghum genotypes was found to be mid-June (15thJune), which decreased the likelihood of high-temperature stress at later developmental stages.

Conclusion

The study comprehensively investigated the intricate dynamics between sorghum (*Sorghum bicolor* L.) genotypes, saline environments, and fodder quality, shedding light on crucial aspects for sustainable agricultural practices in semi-arid regions. SSG 59-3 emerged as a promising genotype, exhibiting robust tolerance to salinity while maintaining superior fodder quality attributes across various growth stages. The genotype's exceptional performance in terms of crude protein content, in-vitro dry matter digestibility, and yield stability underscores its potential as a resilient fodder crop in saline-prone regions. By quantifying RUE across different salinity levels, we elucidated the genotype-specific energy utilization patterns, providing valuable insights for optimizing resource allocation and enhancing biomass production in saline environments. Hence, SSG 59-3 has the greatest potential for application in hot, semi-arid climates and provides higher grain yields, dry matter, and grain heat use efficiency. By leveraging genetic diversity and agronomic interventions, there is a need to understand further and explore harnessing the adaptive potential of sorghum to address food security challenges and promote livelihood resilience in environments.

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Conflict of interest
The authors declare that they have no conflict of interest.

REFERENCES

1. Abusuwar, A.O. & El, Zilal. H.A. (2010). Effect of chicken manure on yield, quality, and HCN concentration of two forage Sorghum (Sorghum bicolor (L) Moench) cultivars. *Agric Biol JN Am.*1, 27–31.
2. Afshar, R.K., Chaichi, M.R., Assareh, M.H., Hashemi, M. &Liaghat, A. (2014). Interactive effect of deficit irrigation and soil organic amendments on seed yield and flavonolignan production of milk thistle (Silybum marianum L. Gaertn.). *Ind Crops Prod*. 58, 166–172.
3. Amini, F., Ehsanpour, A.A., Hoang, Q.T., & Shin, J.S. (2007). Protein pattern changes in tomato under in vitro salt stress. *Russian Journal of Plant Physiology*. 54, 464–

471.

4. Attia, M.S., Osman, M.S., Mohamed, A.S., Mahgoub, H.A., Garada, M.O., &Abdelmouty, E.S. et al. (2021). Impact of foliar application of chitosan dissolved in different organic acids on isozymes, protein patterns, and physio-biochemical characteristics of tomato grown under salinity stress. *Plants.*10, 388.
5. Awika, J.M., Yang, L., Browning, J.D., & Faraj, A. (2009). Comparative antioxidant, antiproliferative, and phase II enzyme inducing potential of sorghum (Sorghum bicolor) varieties. *LWT-Food Science and Technology.* 42,1041–1046.
6. Azeem, M., Pirjan, K., Qasim, M., Mahmood, A., Javed, T. & Muhammad, H., et al. (2023). Salinity stress improves antioxidant potential by modulating physio-biochemical responses in Moringa oleifera Lam. *Sci Rep.,* 13, 2895.
7. Azizinya, S., Ghanadha, M.R., Zali, A.A., Samadi, B.Y., & Ahmadi, A. (2005). An evaluation of quantitative traits related to drought resistance in synthetic wheat genotypes in stress and non-stress conditions. *Iranian Journal of Agricultural Sciences*. 36, 281–293.
8. Barnes, R.F., Muller, L.D., Bauman, L.F., &Colenbrander, V.F. (1971). In vitro dry matter disappearance of brown midrib mutants of maize (Zea mays L.). *J Anim Sci.* 33: 881–884.
9. Bourgeois, G., Jenni, S., Laurence, H., & Tremblay, N. (2000). Improving the prediction of processing pea maturity based on the growing-degree day approach. *HortScience.* 35, 611–614.
10. Burns, R.E. (1971). Method for estimation of tannin in grain sorghum 1. *Agron J.* 63, 511–512.
11. Chavez, J.C., Ganjegunte, G.K., Jeong, J., Rajan, N., Zapata, S.D., & Ruiz-Alvarez, O., et al. (2022). Radiation use efficiency and agronomic performance of biomass sorghum under different sowing dates. *Agronomy.* 12, 1252.
12. Dehnavi, R.A., Zahedi, M. & Piernik, A. (2024) Understanding salinity stress responses in sorghum: exploring genotype variability and salt tolerance mechanisms. Front. *Plant Sci.* 14,1296286. doi: 10.3389/fpls.2023.1296286
13. Franzoni, G., Cocetta, G., Trivellini, A., & Ferrante, A. (2020). Transcriptional Regulation in Rocket Leaves as Affected by Salinity. *Plants*, 9, 20.
14. Gilchrist, D.G., Lueschen, W.E., & Hittle, C.N. (1967). Revised Method for the Preparation of Standards in the Sodium Picrate Assay of HCN 1. *Crop Sci.* 7, 267–268.
15. Gong, Z., Xiong, L., Shi H., Yang S., Herrera-Estrella L.R., & Xu G., et al. (2020). Plant abiotic stress response and nutrient use efficiency. *Sci China Life Sci*. 63, 635–674.
16. Hossain, S.M., Islam, N.M., Rahman, M.M., Mostafa, M. G. & Khan, R.A.M. (2022) Sorghum: A prospective crop for climatic vulnerability, food and nutritional security. *Journal of Agriculture and Food Research*. 8, 100300.
17. Malik, A., Punia, H., Singh, N., & Singh, P. (2022). Bionanomaterial-mediated seed priming for sustainable agricultural production. Bionanotechnology: Emerging Applications of Bionanomaterials, *Elsevier*, pp. 77–99.
18. Marsalis, M.A., Angadi, S.V., & Contreras, Govea F.E. (2010). Dry matter yield and nutritive value of corn, forage sorghum, and BMR forage sorghum at different plant populations and nitrogen rates. *Field Crops Res.* 11,: 52–57.
19. Mohapatra, S., Tripathy, S.K., Mohanty, A.K., & Tripathy, S. (2021). Effect of heat stress on yield and economics of rice (*Oryza sativa L.*) cultivars under different sowing dates.*J. Agrometeorol*. 23: 38–45.
20. Pathak, T.B., & Stoddard, C.S. (2018). Climate change effects on the processing tomato growing season in California using growing degree day model. *Model Earth Syst Environ.* 4, 765–775.
21. Punia, H., Tokas, J., Bhadu, S., Mohanty, A.K., Rawat, P., Malik, A., et al. (2020). Proteome dynamics and transcriptome profiling in sorghum [*Sorghum bicolor* (L.) Moench] under salt stress. *3 Biotech.*;10: 412. doi:10.1007/s13205-020-02392-1
22. Punia, H., Tokas, J., Malik, A., & Yashveer, S. (2022). Reconnoitering Bionanomaterials for Mitigation of Abiotic Stress in Plants. In *Bionanotechnology: Emerging Applications of Bionanomaterials*; *Elsevier*: Amsterdam, The Netherlands, pp. 101–126.
23. Punia, H., Tokas, J., Malik, A., Bajguz, A., El-Sheikh, MA., & Ahmad, P. (2021b). Ascorbate–Glutathione Oxidant Scavengers, Metabolome Analysis and Adaptation Mechanisms of Ion Exclusion in Sorghum under Salt Stress. *Int J Mol Sci*. 22, 13249.
24. Punia, H., Tokas, J., Malik, A., Kharor, N. & Yashveer, S. (2021a). Deciphering Biochemical Responses, Metabolome Analysis, and Key Genes Controlling Sorghum [*Sorghum bicolor (L.)* Moench] Ion Transport in Responses to Salt Stress. Available online: https://www. researchsquare.com/article/rs-576430/v1 (accessed on 18 October 2023).
25. Punia, H., Tokas, J., Malik, A., Rani, A., Gupta, P., Kumari, A., Mor, V.S., Bhuker, A., & Kumar, S. (2020). Solar Radiation and Nitrogen Use Efficiency for Sustainable Agriculture. In *Resources Use Efficiency in Agriculture*; Springer: Berlin/Heidelberg, Germany, pp. 177–212.
26. Punia, H., Tokas, J., Malik, A., Rani, A., Gupta, P., Kumari, A., Mor, V.S., Bhuker, A., & Kumar, S., (2020). Solar Radiation and Nitrogen Use Efficiency for Sustainable Agriculture. In: Kumar, S., Meena, R.S., Jhariya, M.K. (eds) Resources Use Efficiency in Agriculture. Springer, Singapore. https://doi.org/10.1007/978-981-15-6953-1_6
27. Punia, H., Tokas, J., Malik, A., Sangwan, S., Rani, A., & Yashveer, S., et al. (2021d). Genome-Wide Transcriptome Profiling, Characterization, and Functional Identification of NAC Transcription Factors in Sorghum under Salt Stress. *Antioxidants*. 10, 1605.
28. Punia, H., Tokas, J., Malik, A., Singh, S., Phogat, D.S., &Bhuker, A. et al. (2021c). Discerning morpho-physiological and quality traits contributing to salinity tolerance acquisition in sorghum [*Sorghum bicolor (L.)* Moench]. *South African Journal of Botany.* 140, 409–418.
29. Punia, H., Tokas, J., Malik, A., Singh, S., Phogat, D.S., Bhuker, A. et al. (2021). Discerning morpho-physiological and quality traits contributing to salinity tolerance acquisition in sorghum [Sorghum bicolor (L.) Moench]. *South African Journal of Botany*. 140, 409–418.
30. Punia, H., Tokas, J., Mor, V.S., Bhuker, A., Malik, A., Singh, N., et al. (2021). Deciphering reserve mobilization, antioxidant potential, and expression analysis of starch synthesis in sorghum seedlings under salt stress. *Plants.*10, 2463.
31. Rana, D.S., Singh, B., Gupta, K., Dhaka, A.K., & Pahuja, S.K. (2013). Effect of fertility levels on growth, yield and

quality of multicut forage sorghum [Sorghum bicolor (L.) Moench] genotypes. *Forage Research.* 39, 36–38.
32. Rao, A.Q., ud, Din. S., Akhtar, S., Sarwar, M.B., Ahmed, M., Rashid, B., et al. (2016). Genomics of salinity tolerance in plants. *Plant Genomics InTech.* 273–299.
33. Satpal, J.T., Kumar, A., & Kumar, S.R. (2018). Potential productivity and radiation use efficiency of multi-cut forage sorghum [Sorghum bicolor (L.) Moench] genotypes. *Journal of Agrometeorology.* 20, 364–367.
34. Somegowda, V.K., Vemula, A., Naravula, J., Prasad, G., Rayaprolu, L., & Rathore, A., (2021). Evaluation of fodder yield and fodder quality in sorghum and its interaction with grain yield under different water availability regimes. *Curr Plant Biol.* 25:,100191.
35. Tei, F., Benincasa, P., Guiducci, M. (2002). Critical nitrogen concentration in lettuce. XXVI International Horticultural Congress: Toward Ecologically Sound Fertilization Strategies for Field Vegetable Production 627. pp. 187–194.
36. Tesfay, S.Z., Bertling, I., Odindo, A.O., Greenfield, P.L., and Workneh, T.S. (2011). Growth responses of tropical onion cultivars to photoperiod and temperature based on growing degree days. *Afr. J. Biotechnol.* 10, 15875-15882.
37. Tesfay, S.Z., Modi, A.T., & Mohammed, F. (2006). The effect of temperature in moringa seed phytochemical compounds and carbohydrate mobilization. *South African Journal of Botany*. 102, 190–196.
38. Tokas, J., Kumari, P., & Thakral, N.K. (2017). Evaluation of forage sorghum [Sorghum bicolor (L.) Moench] genotypes for quality and yield. *Forage Research.* 43, 235–238.
39. Tokas, J., Punia, H., Malik, A., Sangwan, S., Devi, S.& Malik, S. (2021). Growth performance, nutritional status, forage yield and photosynthetic use efficiency of sorghum [*Sorghum bicolor* (L.) Moench] under salt stress. *Range Management and Agroforestry*. 42, 59–70.
40. Yang, Z., Li, J.L., Liu, L.N., Xie, Q., & Sui, N. (2020). Photosynthetic regulation under salt stress and salt-tolerance mechanism of sweet sorghum. *Front Plant Sci.* 10, 1722.
41. Zeeshan, M., Lu, M., Sehar, S., Holford, P., & Wu, F. (2020). Comparison of biochemical, anatomical, morphological, and physiological responses to salinity stress in wheat and barley genotypes deferring in salinity tolerance. *Agronomy*. 10, 127.