BIOCHEMICAL INDICATORS FOR SALT TOLERANCE AND THEIR RELATIONSHIP TO NUTRITIONAL COMPOUNDS IN SORGHUM UNDER RAS SUDR CONDITIONS, SOUTH SINAI

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Although they belong to C4, bicolor sorghum plants are moderately resistant to salt. The growth and development of plants at the seedling stage are adversely affected by high saline levels, such as those found in the study area under consideration (more than 8000 ppm). Additionally, it has an impact on grain output, flower development, fertilization, and the contract process. As a result, the study looks at biochemical indicators stress variables to assess how seven varieties of bicolor sorghum (Roma, Cukorcirok, Ramada, Rex, Shandaweel-1, Shandaweel-15, and MN2756) thrive when exposed to high salinity and how this affects the grains yield, biochemical indicators and nutritional components. The study demonstrated that the Rex variety is distinguished from other sorghum varieties by short stem length, not surpassing 1.5 meters at harvest, medium weight of straw yield, and good grain yield. The outcomes indicated that Rex grain productivity percentage was 32.14% of the plant weight. Rex grains stand out for their high nutritional content, with phenolic compounds at 692.3 µg/g and amino acids at 297.12 mg/g in sorghum flour, respectively. As a result, the Rex variety is thought to be the greatest sorghum variety that was cultivated in Ras Sudr under salt stress conditions.

Keywords: sorghum, salinity stress, phenolic compounds, amino acids, sugars

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) ‘in two colours’ is a member of the grass family Poaceae, Andropogonae genus. It is a C4 grass, has an anatomical and biochemical makeup that enables it to thrive in dry and semi-arid environments with high crop yields, whether they are forage or grain crops. Two distinct types of chloroplasts are found in the cells of the bundle sheath in the leaves of C4 plants, which contain the enzyme Rubisco, and one

type is found in the mesophyll cells in the outer part of the leaf, which contains the enzyme PEP carboxylase. Pyruvate is changed into oxalate by PEP carboxylase, and oxalate is then delivered to the chloroplast of the leaf sheath as malate. With less CO_2 being used in the carbon fixation process thanks to the Rubisco enzyme found in leaf sheath chloroplast cells. Consequently, slows down the photorespiration process and plants lose less water through photorespiration. On the other hand, it speeds up photosynthesis, which helps plants develop more quickly. This is due to the carbon used to produce more roots and leaves. Additionally, it boosts the amount of glucose produced as a by-product of photosynthesis (Christin and Osborne, 2014). The height of sorghum plants ranges from 2.5 to 4 meters. Sorghum is a major food crop in many African and Asian nations, but it is largely used as a feed grain in the United States. Sorghum grains are a particularly well-balanced meal alternative that may assist manage several illnesses due to their high dietary fiber content, lack of gluten, and intriguing proteins and fats. Additionally, the grain is a rich source of phytochemicals, nutritional antioxidants, amino acids, sugars, and bioactive polyphenols (PPhs). These qualities include those that slow digestion, decrease cholesterol, prevent cardiovascular disease, and fight cancer (Adeyeye, 2008). Generally, sorghum types were rich in essential amino acids (40%) and hence nutritionally acceptable. However, they were deficient in other amino acids, which may be made up additional protein sources (Mokrane et al., 2010). In sorghum grain, the necessary amino acids make up between 21.5 and 30.7% of crude protein as previous results (Southgate et al., 1980 and Adeyeye, 2008), as well as between 53.1 and 56.7% (WHO, 1985). As with many fruits and vegetables, the colour of the outer layer of sorghum cultivars is not a sign of the presence of carotenes. Instead, it is due to the flavonoids, specifically 3-deoxyanthocyanidins and PPhs, which make up around 80% of the grains pericarp layer. All cultivars of sorghum include it, which is formed from anthocyanins and also represents the majority of the plant medicinal chemicals (Awika et al., 2004 and Yang et al., 2014). The sorghum grains health benefits and nutritional worth are enhanced by these special qualities. Red-brown grains are high in bioactive substances like tannins, PPhs, and flavonoids, while white grains are utilized for cooking. The biologically active molecules can be isolated and used to treat diabetes, inflammation, viruses, obesity, and cancer (Punia et al., 2021). Additionally, sorghum is the most significant source of starch and is closely related to other crops that could be used to produce biofuels. Sorghum has 25% sugar content, and the juicy stalks accumulate non-structural carbohydrates 1.4-2.7 times more than the grains do (Vietor and Miller, 1990 and Ming et al., 2001). The free sugar content of sorghum grains is well known to be high (1-1.4% ketose sugars and 0.2-0.5% reducing sugars). Maltose, glucose, sucrose, fructose, raffinose, and gypsum were detected in the free sugars examined by HPLC in the sorghum grains (Nordin, 1959 and Miafo et al., 2019). Sorghum has recently been found to flourish in arid regions where

other crops either fail to grow or produce poorly. Limited resources, such as water and fertilizers, along with high temperatures and other inputs, are characteristics of these ecosystems.

Salinity of soil has grown to be a significant issue on a global scale. Sodium chloride is the most common salt of all the salts found in soil. Salt is deposited in soils either naturally (primary) or because of human activity (secondary). Parent rock weathering, ocean sedimentation, and atmospheric deposition are the main processes. Poor sanitary conditions, irrigation using brackish groundwater, long periods of continuous irrigation, incorrect water management, and irrigated agriculture practices are examples of secondary processes. The water table is also raised when shallow-rooted annuals are used in place of deep-rooted perennials, which results in an increase in the level of saline groundwater (FAO, 2015). Salinity is one of the most important environmental stresses, which can severely restrict plant development and production. It influences the stages of germination and growth of plants. High salt concentrations in soil and water have a detrimental effect on several morphological traits such as reduction in plant height, delaying of cell division and elongation, differentiation, expansion, as well as physiological processes in plants, including photosynthesis, membrane permeability, trophic homeostasis, enzyme activity, metabolic activities, cellular homeostasis and hormone control. The generation of reactive oxygen species and enzymatic and non-enzymatic antioxidant activity are believed to be unbalanced, causing severe stress and plant death (Hasanuzzaman et al., 2012 and Mahmoud and Abdelhameed, 2021). Sorghum growth rates similarly slow down by high salinity. Jafari et al. (2009) found that plant height, fresh weight, and dry weight decreased from 1.8-2.9 m, 88.81 g, and 0.436 g/plant, respectively, to 80-120 cm, 6.77 g, and 0.032 /plant. Salinity, on the other hand, had no impact on the relative water content.

The purpose of this study is to examine the physiological and biochemical performance of seven sorghum varieties in South Sinai, Egypt, under saline circumstances. This is done to choose the best genetic combinations of sorghum, which is characterized by high grain productivity, salt stress resistance, and a high percentage of biologically beneficial substances, and to recommend advice cultivating it in areas with high salinity.

MATERIALS AND METHODS

1. Filed Experiment

1.1. Plant material and cultivation

Two field experiments were conducted in May 2022 and 2023 growing seasons in Ras Sudr experimental station, South Sinai governorate (an area of salinity stress) in Egypt. Egypt grains to evaluate performance were purchased from the Field Crop Institute at the Agricultural Research Center in Giza, Egypt, two sorghum varieties' grains (Shandaweel-1 and Shandaweel-

15) and five varieties of sweet sorghum grain carry codes Rex, Cukorcirok, Roma, MN2756, and Ramada, sorghum is planted from seed, usually in rows in middle May at the rate of 3 kg grains/fed approximately (7.5 kg/ha). The grains were sown with dibbling method in rows in three replications in a randomized complete block design. The distance between rows was 50 cm and between plants was 15 cm, about 2-4 grains were put in each hole in 2 cm depth from the soil surface, then reduced to 2 plants in each hole in sandy soil, sorghum drip-irrigated at rate of 4 liter in an hour for ½ h every 3 days, and fertilized regularly by fertilizers. All treatments received 37 kg P/ha and 150 kg K/ha as ordinary superphosphate of 68 g P/kg and K as potassium sulphate of 420 g K/kg. The chemical analysis of soil and water is represented in Table (1) and it was summarized where the pH of the soil was 7.46, EC= 3.16 dS/m, water pH= 7.06, EC=10.29 dS/m.

Table (1). Chemical properties of the experimental soil and underground irrigation water at Ras Sudr, South Sinai.

Sample	Depth	pH	EC (dS/m)	EC (ppm)	Cations (meq/l)				Anions (meq/l)			
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	SO_4^{-2}
Soil	0-30	7.46	3.16	2022.4	5.27	12.87	12.23	1.27	0	2.96	18.33	10.33
Water	---	7.06	10.29	6585.6	57.75	13.81	51.88	1.72	0	3.49	91.65	30.12

1.2. Sample collection, growth and yield determination

The plant samples were taken randomly from each variety as follows: fresh plants were collected after 60 days from sowing to growth traits determined including plant height (cm), fresh and dry weight (g), and relative water content (%) was calculated as RWC= (f.wt- d.wt)/ (t.wt- d.wt) (Netondo et al., 2004) where f.wt, d.wt, and t.wt are the fresh, oven dry and turgid weights, respectively and fresh leaves samples were kept in a deep freezer (-20°C) for stress biochemical indicators analysis [malondialdehyde (MDA), hydrogen peroxide (H_2O_2), and antioxidant capacity (%)], protein electrophoresis, at harvest stage, plants were collected and plant height, grain yield and straw yield were determined. Sorghum grains were collected and air dried then cleaned to remove chaff. Grain samples were ground in a grinder prior to laboratory analyses such as protein, lipid, fiber, ash, and moisture content determination. Also, fractions of amino acids, phenolic compounds as well as total anthocyanin and sugars content were determined.

2. Chemical Analysis

2.1. Biochemical indicators

2.1.1. Malondialdehyde content

According to a prior work by Heath and Packer (1968) and revised by Zhao et al. (1994), the color of the adduct generated in the reaction between thiobarbituric acid (TBA) and malondialdehyde (MDA) in the TBA assay was used to quantify the quantity of lipid peroxidation in sorghum leaves. The

supernatant was measured at 532 nm. The absorbance recorded at 532 nm was subtracted from each sample's nonspecific absorption, which was measured at 600 nm. The concentration of the MDA-TBA adduct was calculated from the MDA standard curve and converted to µg g^{-1} fresh weight.

2.1.2. Hydrogen peroxide content

Hydrogen peroxide (H_2O_2) was determined based on potassium iodide oxidation by H_2O_2 in acidic media, Velikova et al. (2000) method was used to measure H_2O_2 levels in fresh sorghum leaves. Spectrometric analysis was used to determine the color concentration. At 390 nm, the supernatant absorbance was determined. Using a standard curve, H_2O_2 concentration was calculated.

2.1.3. Antioxidant capacity (RSC%)

Radical scavenging capacity (RSC) was determined by DPPH scavenging method. The extracts antiradical activity was tested using the stable 2,2-diphenyl-1-picrylhydrazyl radical (DPPH) compound in accordance with the manufacturer's instructions (Castro-Vargas et al., 2010). The ability of the extracts to bleach the free radical was used to examine their ability to scavenge free radicals. The blank absorbance was measured at 515 nm using a 3.9 ml of 0.1 M DPPH solution (in methanol) and 0.1 ml methanol instead of the extract (A0). For the samples, 3.9 ml of 0.1 M DPPH solution was mixed with 0.1 ml of each extract, and afterward the mixtures were kept for 30 min at room temperature in the dark before the absorbance were recorded (Af). The inhibition percentage was calculated as follows: % Inhibition = [(A0 - A f)/A0] × 100.

2.1.4. Soluble proteins (SDS-PAGE)

Electrophoretic separation of soluble proteins was achieved by Laemmli (1970), based on the ratio between protein charges and its molecular weight. In this method, sodium dodecyl sulfate (SDS) is used to create the most common form of protein electrophoresis, SDS-polyacrylamide gel (SDS-PAGE).

2.2. Grains nutritional composition

2.2.1. Protein, lipid, fiber, ash, NEF and moisture content

Protein content was determined using the Kjeldahl digestion units to digest the samples. Finally, the digested solution was determined by acidimetric titration according to AOAC (1995), and by using 6.25 as conversion factor (Mariotti et al., 2008). **Lipid content** was estimated using petroleum ether as a fat solvent according to AOAC 920.39 (Horowitz and Latimer, 2006). The solvent was evaporated then placed in an oven at 105°C for 1 h and allowed to cool down and weighed. Percentage of crude fat was calculated as: fat (%) = [(MFR-MF)/m] x 100, where, MF - weight (g) of the flask, MFR - weight of flask with extracted residue (g), and m - the original sample weight (g). **Crude fiber** was determined gravimetrically after chemical digestion and solubilization of other compounds present with diluted sulphuric acid and sodium hydroxide (Palic et al., 2007). **Ash content** was determined according to AOAC 923.03 (Horowitz and Latimer, 2006). Two

grams of sample was added into a pre-weighed crucible was incinerated in muffle at 500°C. Ash (%) = [(W2-W3)/(W2-W1)]x100, where, W1-the weight of crucible, W2 - weight of the crucible and sample after incinerating at 500°C, and W3 – weight of the crucible and sample after cooling in an airtight homogenized vessel. **Nitrogen-free extract (NFE)** was determined by the difference between 100 and the total percentages of proteins, lipids, crude fibers, and ash (Horowitz and Latimer, 2006). **The moisture** content was carried out according to AACC methods 44-15A (Rasper and Walker, 2000).

2.2.2. Amino acids

Amino acid composition was determined by making acid hydrolysis of 0.4 g defatted sorghum flour in 5.0 ml of 6.0 N HCl during 24 h at 110°C. HCl was then removed by evaporation; the remaining solid fraction was first dispersed in 4.0 ml of water and filtered through a filter paper, then the filtrate was evaporated to dryness at 60-70°C till a dry film was obtained. Then, it dissolved in 1 ml sample dilution buffer and the solution was filtered through a 0.22 µm filter membrane. The samples were sorted at -20°C in sealed vials until the fractionation of the protein amino acids by amino acid analyzer of Sykam systems. Filtrate (100 µl) was injected in an analytical amino acid apparatus by a hydrolysate column and its temperature was 37°C. The amino acids were eluted at two flow rates; 0.25 ml/min for ninhydrin and 0.45 ml/min for buffer with buffer A pH 3.45, buffer B pH 10.85, and regeneration solution. The gradient conditions were previously optimized by Lamberts et al. (2008). The present technique was based on anion-exchange chromatography with integrated pulsed amperometric (IPA) detection. The amino acid standard consists of 17 amino acids obtained from Sigma-Aldrich (Steinheim, Germany) (Fa et al., 2013).

2.2.3. Phenolic compounds

A chromatographic profile of sorghum grains was created utilizing a Surveyor HPLC system. For the preparation and separation of phenolic compounds, as described by Păcularu-Burada et al. (2021). The samples were suspended in 5 ml of 70% (v/v) methanol prior to HPLC separations. The mixtures were dissolved in an ultrasonic bath (MRC, Holon, Israel) for 45 min, and the sample supernatants were centrifuged at 6000 rpm and 4°C for 10 min before being filtered through 0.22 µm syringe filters. HPLC was carried out using an Agilent 1260 series. The separation was carried out using Eclipse C18 column (4.6 mm x 250 mm i.d., 5 µm). The mobile phase consisted of water (A) and 0.05% trifluoroacetic acid in acetonitrile (B) at a flow rate 0.9 ml/min. The mobile phase was programmed consecutively in a linear gradient as follows: 0 min (82% A); 0-5 min (80% A); 5-8 min (60% A); 8-12 min (60% A); 12-15 min (82% A); 15-16 min (82% A) and 16-20 (82% A). The multi-wavelength detector was monitored at 280 nm. The injection volume was 5 µl for each of the sample solutions. The column temperature was maintained at 40°C. PPhs were identified using the retention

time for the commercially available standards as a guideline, and by comparison with the literature reviews.

2.2.4. Anthocyanins

Buffers preparations, sample extraction and data calculation were carried out according to Lee et al. (2005).

2.2.5. Sugars

Sorghum flour was thoroughly extracted with petroleum ether. The residue was refluxed for 30 min with 500 ml of 70% aqueous ethanol and filtered. The purified extract was concentrated under vacuum to be concentrated further for chromatographic analysis according to Nordin (1959).

HPLC conditions

HPLC analysis was carried out using Agilent Technologies 1100 series liquid chromatography equipped with an auto sampler and a refractive index detector (RID). The analytical column was a Shim-pack SCR-101N. The mobile phase consisted of ultrapure water. The flow rate was kept at 0.7 ml/min for a total run time of 20 min with isocratic elution. Each carbohydrate concentration was determined after integration of respective areas and their comparison with standard curves obtained with sucrose, glucose, fructose and arabinose (Sigma Aldrich).

3. Statistical Analysis

All statistical analyses were performed using the statistical analysis system SPSS software version 16 (SPSS, Richmond, USA). Data were subjected to one-way ANOVA and differences between means at the 5% probability level using Duncan's new multiple range test (Dytham, 2011).

RESULTS AND DISCUSSION

1. Growth Parameters

The information in Table (2) and Fig. (1) relates to growth traits [plant height (cm), fresh and dry plant weight (g), relative water content (%)] for seven sorghum varieties grown under saline conditions in Ras Sudr, South Sinai. The length of the sorghum varieties; Roma, Ramada, and MN2756 varieties, were of 146, 140, and 130 cm/plant, respectively, according to the results listed in the table, having the greatest plant height values. Additionally, the findings demonstrated that Rex variety had a mean length of 114 cm/plant. The lowest mean plant lengths per plant were 101 cm for both Shandaweel-15 and Cukorcirok varieties and 90 cm for Shandaweel-1 variety. In the same table, the highest mean fresh and dry weight values of sorghum plants were found in Ramada, Roma, and MN2756, with values of 210, 202, and 193 g/plant for fresh weight and 55.3, 51.8, and 51.0 g/plant for dry weight, respectively. The Shandaweel-15 variety, in contrast, produced the lowest mean fresh and dry weights, with a value of 74.4 g/plant for fresh weight and 18.6 g/plant for dry weight. The average fresh weight and dry weight of the

plants for the remaining varieties, Rex, Cukorcirok, and Shandaweel-1, were respectively 177, 144, and 108 g/plant for the fresh weight and 46.5, 40, and 27.5 g/plant for the dry weight.

Table (2). Growth parameters of the studied sorghum varieties exposed to salt stress at Ras Sudr, South Sinai.

Sorghum varieties	Growth parameters			
	Plant height (cm/plant)	Fresh weight (g/plant)	Dry weight (g/plant)	Relative water content (%)
Shandaweel-1	90.50 ± 0.29	108.73 ± 0.12 E	27.53 ± 0.14 D	74.65 ± 0.01 AB
Shandaweel-15	101.33 ± 0.14 E	74.47 ± 0.26 F	18.67 ± 0.20 E	74.92 ± 0.02 A
Rex	114.20 ± 0.31 D	177.00 ± 0.58 C	46.53 ± 0.27 B	74.13 ± 0.03 B
Cukorcirok	101.03 ± 0.35 E	144.33 ± 0.24 D	40.03 ± 0.09 C	72.28 ± 0.01 D
Roma	146.40 ± 0.23 A	202.43 ± 0.23 B	51.80 ± 0.11 AB	74.36 ± 0.01 B
MN2756	130.40 ± 0.26 C	193.27 ± 0.21 BC	51.05 ±0.03 AB	73.53 ± 0.01 C
Ramada	140.23 ± 0.18 B	210.27 ±0.18 A	55.30 ± 0.17 A	73.66 ± 0.02 C

Values followed by the same letter in columns are not different at $p < 0.05$ by Duncan's multiple range tests, and data are mean of 3 replicates, ± means standard error.

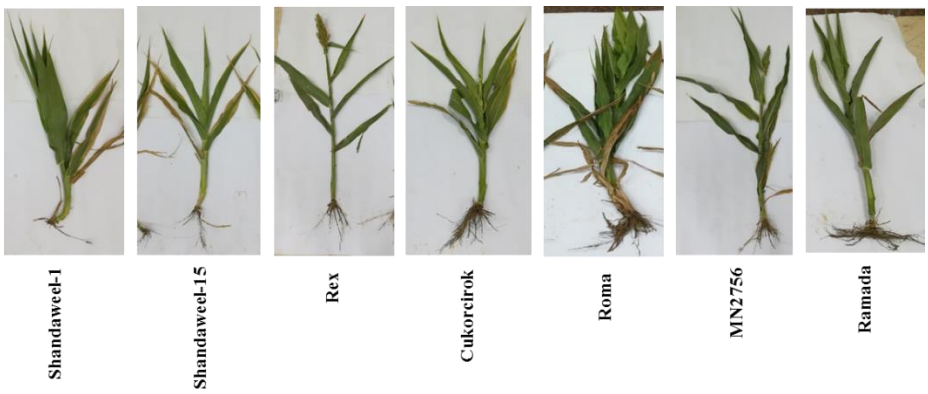

Fig. (1). Growth rate of the seven studied sorghum varieties exposed to salt stress at Ras Sudr, South Sinai.

According to the results in the same table, the varieties Shandaweel-1, Shandaweel-15, Roma, and Rex all have a 74% relative water retention capacity inside the plant. The estimated relative water retention in the plant for the varieties Ramada and MN2756 was also the same, at 73%. With an estimated rate of 72%, Cukorcirok variety exhibited the lowest level of relative water retention. The results are supported by the previous studies of Jafari et al. (2009), Joardar et al. (2018) and Calone et al. (2020).

Due to genetic variations between varieties, dichroic sorghum may be tolerant to high salinity (El Naim et al., 2012 and Sun et al., 2014). In addition, sorghum is a C4 grass that exhibits high rates of photosynthesis. These high

rates of photosynthesis drive physiological processes like cell division and elongation, boost leaf and root growth, and ultimately increase plant weight through promoting plant growth and development. Additionally, the higher concentration of solutes inside the cell due to the increased accumulation of glucose produced as a byproduct of photosynthesis increases the osmotic pressure, which equalizes the external pressure and strengthens the plant resistance to salt stress. Additionally, photorespiration slows down, plants hold onto their water the longest and lose the least amount (Christin and Osborne, 2014).

2. Yield Parameters

The information in Table (3) displays the variety lengths of the sorghum plant at harvest as well as the yields of grain and straw. The findings showed that, by 222.7, 207.7, and 207.5 cm/plant, respectively, the varieties Shandaweel-15, Shandaweel-1, and Ramada were superior in terms of plant height at the end of the planting season. While the average lengths for the Roma and MN2756 varieties were 191.5 and 154.7 cm/plant, respectively. With an average of 124.8 and 110 cm/plant, respectively, Cukorcirok and Rex had the shortest plant lengths. The recorded results in the same table demonstrate how excellent each of the varieties Shandaweel-1, Shandaweel-15 and Cukorcirok were in terms of plant weight and straw production. The weights in plant and straw yield were lower for Roma and Ramada varieties. Rex and MN2756 varieties also had middle weights relative to the overall plant weight and production of straw. Additionally, the data show that the varieties Shandaweel-1 and Rex had the highest grain weight values. Shandaweel-15, Cukorcirok, and Roma grain yield weights did not significantly differ from one another. Similarly, the varieties MN2756 and Ramada, which represented the lowest average grain weight, showed no discernible change in grain weight. Combining the findings with earlier findings of Paterson et al. (2009), Kakani et al. (2011) and Ogbaga et al. (2014), the genetic variances of the varieties may be the cause of the variation in sorghum resistance to salt stress, which was manifested in variations in plant height, plant weight, grain production, and straw yield (Mawouma et al., 2022). Additionally, sorghum resistance, which was evident in the plants length and weight at the time of harvest as well as in the amount of grain and straw produced, may be caused sorghum is a C4 plant, it may undergo morphological, physiological, and chemical changes that make it more resistant to salt stress. Examples of these modifications include: physiological adaptations comprise changes in stomatal density to maximize water uptake and retention, morphological adaptations including the development of deep roots and modifications of leaf morphology and cuticle structure (Salih et al., 1999 and Carmo-Silva et al., 2009). Biochemical adaptations include possessing water-efficient photosynthetic pathways (CAM; C4) and accumulating suitable solutes, such as specific sugars, amino acids, proline

and glycine betaine (Kishor et al., 2005; Yobi et al., 2012 and Kavikishor and Sreenivasulu, 2014). Furthermore, the high concentration of PPhs, flavonoids, and anthocyanins in sorghum, along with an increase in the activity of antioxidant enzymes, give it the ability to fight off free radicals and withstand salt stress (Mawouma et al., 2022).

Table (3). Biological yield parameters of the studied sorghum varieties exposed to salt stress at Ras Sudr, South Sinai.

Sorghum varieties	Biological yield			
	Plant height (cm/plant)	Plant weight (g/plant)	Grains weight (g/plant)	Straw weight (g/plant)
Shandaweel-1	207.77 ± 0.56 B	349.37 ± 0.92 A	71.26 ± 0.52 A	277.84 ± 0.32 A
Shandaweel-15	222.77 ± 0.45 A	288.70 ± 0.62 B	39.76 ± 0.29 C	248.24 ± 0.65 B
Rex	110.37 ± 0.62 E	206.90 ± 0.39 C	66.50 ± 0.67 B	140.37 ± 0.62 C
Cukorcirok	124.80 ± 0.63 D	318.00 ± 0.82 AB	35.89 ± 0.88 C	282.17 ± 0.38 A
Roma	191.52 ± 0.42 BC	129.60 ± 0.27 E	36.67 ± 0.96 C	93.73 ± 0.87 D
MN2756	154.74 ± 0.87 C	157.57 ± 0.75 D	28.43 ± 0.54 D	129.06 ± 0.63 C
Ramada	207.53 ± 0.62 B	107.60 ± 0.54 F	29.95 ± 0.62 D	78.86 ± 0.78 E

Values followed by the same letter in columns are not different at $p < 0.05$ by Duncan's multiple range tests, and data are mean of 3 replicates, ± means standard error.

3. Biochemical Indicators

3.1. Malondialdehyde and hydrogen peroxide content

The information in Table (4) demonstrates the biochemical stress variables in the green leaves of sorghum plants cultivated under salt stress in Ras Sudr, South Sinai. The MDA is a marker for membrane oxidation, which under salt stress circumstances is a sign of membrane breakdown and leakage. According to the findings, the varieties Shandaweel-1, Shandaweel-15, and MN2756, have the lowest levels of MDA. The Roma variety also received an average grade for the MDA level. The varieties Rex, Cukorcirok, and Ramada on the other hand, were the ones that were most severely damaged by salt stress and had the highest amounts of MDA. Using colorimetric techniques, determine the H_2O_2 content of green sorghum leaves to assess the plant's capacity to eliminate free radicals that have accumulated as a result of salt stress. Shandaweel-1, Shandaweel-15, and MN2756 varieties are those that collect the least H_2O_2, according to the data assembled in the same table. In contrast to the Roma variety, which had a moderate level of H_2O_2 accumulation, the varieties Rex, Cukorcirok, and Ramada had the highest levels of H_2O_2 accumulation. According to this study, there are variations in the rate of lipid oxidation and H_2O_2 accumulation among the various varieties of sorghum grown in saline circumstances and Mulaudzi et al. (2022) backed up this finding. It has been demonstrated that when plants are exposed to salinity, oxidative stress occurs in plant tissues. Indicators of oxidative stress include H_2O_2 and lipid oxidation. In stressed sorghum, they discovered a rise

in H_2O_2 by 44% and MDA by 125% (Costa et al., 2005); nevertheless, Zhang and Kirkham (1996) provided evidence to the contrary. Both salt stress and dryness had no effect on MDA. In general, sorghum varieties that were resistant to abiotic stress had higher levels of proanthocyanidins, 3-deoxyanthocyanidins, and flavan-4-ols may have a wide spectrum of cellular harm prevention mechanisms (Dicko et al., 2005).

Table (4). Biochemical indicators in sorghum leaves of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Sorghum varieties	Biochemical indicators		
	MDA (µg/g FW)	H_2O_2 (µg/g FW)	RSC (%)
Shandaweel-1	1.88 ± .02 D	13.72 ± 0.02 C	55.32 ± 0.01 C
Shandaweel-15	1.74 ± 0.01 E	9.82 ± 0.03 D	70.14 ± 0.04 B
Rex	4.95 ± 0.02 A	20.26 ± 0.01 AB	37.75 ± 0.08 E
Cukorcirok	4.47 ± 0.01 AB	20.75 ± 0.01 A	75.86 ± 0.02 B
Roma	3.78 ± 0.03 B	18.95 ± 0.02 B	46.65 ± 0.07 D
MN2756	2.39 ± 0.05 C	17.65 ± 0.05 BC	89.94 ± 0.03 A
Ramada	4.56 ± 0.03 A	20.74 ± 0.04 A	42.14 ± 0.08 D

Values followed by the same letter in columns are not different at $p < 0.05$ by Duncan's multiple range tests, and data are mean of 3 replicates, ± means standard error. FW: Fresh weight

3.2. Antioxidant capacity content

The percentage of radical scavenging capacity (RSC%) in fresh sorghum leaves is shown in Table (4). The largest relative RSC was reported by the varieties MN2756, Cukorcirok, and Shandaweel-15, with values of 89.94, 75.86, and 70.14%, respectively. In contrast, the RSC of Shandaweel-1 and Roma varieties was 55.32 and 46.65%, respectively. The percentages of RSC of Rex and Ramada varieties were the lowest, calculated as 37.75 and 42.14%, respectively. This outcome was similar with Mawouma et al. (2022), who discovered that red sorghum (81.15%) and pale yellow sorghum (87.71%) had the highest antioxidant activity against DPPH. The red and brown pericarp of sorghum grains has the highest concentration of phenolic and flavonoid chemicals and is substantially and favorably related to improved antioxidant activity (Kumari et al., 2017 and Punia et al., 2021).

3.3. Electrophoresis patterns of soluble proteins

Table (5) and Fig. (2) illustrate the results of the electrophoresis of soluble protein isolated from the leaves of seven varieties of salinity-stressed sorghum using the SDS-PAGE. According to the findings, the varieties of the sorghum under investigation comprised four to eight bands with molecular weights ranging from 108 to 17.5 kDa. The major bands present in all sorghum varieties had molecular weights of 52.4 and 30.4 kDa. All sorghum varieties, with the exception of Ramada variety, had the band with a molecular weight 17.5 kDa. Except for Cukorcirok variety, all sorghum varieties had the band

with a molecular weight of 20.7 kDa. In addition, all varieties, except MN2756 and Ramada varieties, had the band with a molecular weight of 22 kDa. The varieties of Shandaweel-1, Shandaweel-15 as well as Rex, Cukorcirok, and Roma were found to have 7, 5, 6, 4, and 6 protein bands, respectively, according to the data. Their molecular weights were between 52.4 and 17.5 kDa. Shandaweel-1 and Roma varieties were each represented by the more intense band, which had a molecular weight of 52.4 kDa. Additionally, Shandaweel-15, Rex, and Cukorcirok varieties showed the densest band, which had a molecular weight of 30.4 kDa. In the other, Shandaweel-15, Rex, Cukorcirok, and Roma varieties displayed the lowest intensity band, which had a molecular weight of 22 kDa. Additionally, the band with a molecular weight of 20.7 kDa for Shandaweel-1 variety was the least dense band. Furthermore, eight protein bands with molecular weights ranging from 108 to 17.5 kDa were present in MN2756 variety. Five protein bands with molecular weights ranging from 64.5 to 20.7 kDa were found in Ramada variety. The band with a molecular weight of 52.4 kDa was the most density band in MN2756 and Ramada varieties. For Ramada variety, the band with the lowest density had a molecular weight of 24.3 kDa, and for MN2756 variety, the band with the lowest molecular weight was 78 kDa.

Table (5). Electrophoresis patterns of soluble proteins of sorghum studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Band number	Molecular weight (kDa)	Band intensity of sorghum varieties						
		Sh-1	Sh-15	Rex	Cukorcirok	Roma	MN2756	Ramada
1	**108.0**	0.00	0.00	0.00	0.00	0.00	1.40	0.00
2	**78.0**	0.00	0.00	0.00	0.00	0.00	1.01	0.00
3	**64.5**	0.00	0.00	0.00	0.00	0.00	2.34	1.88
4	**52.4**	2.17	2.59	3.14	2.98	4.32	6.54	4.07
5	**38.0**	0.00	0.00	0.00	0.00	2.94	4.63	0.00
6	**30.4**	1.91	3.30	3.66	4.28	3.56	4.73	3.69
7	**24.3**	1.83	0.00	2.61	0.00	0.00	0.00	1.00
8	**23.0**	1.63	0.00	0.00	0.00	0.00	0.00	0.00
9	**22.0**	1.90	2.05	2.19	1.88	2.66	0.00	0.00
10	**20.7**	1.20	2.16	3.42	0.00	3.21	4.11	2.85
11	**17.5**	1.92	2.49	2.65	2.56	2.73	2.20	0.00
Total bands		**7**	**5**	**6**	**4**	**6**	**8**	**5**

Where; 0 = refers to no band, 1.0 = refer to lowest band intensity 6.54 = refer to highest band intensity, Sh-1= Shandaweel-1 and Sh-15= Shandaweel-15

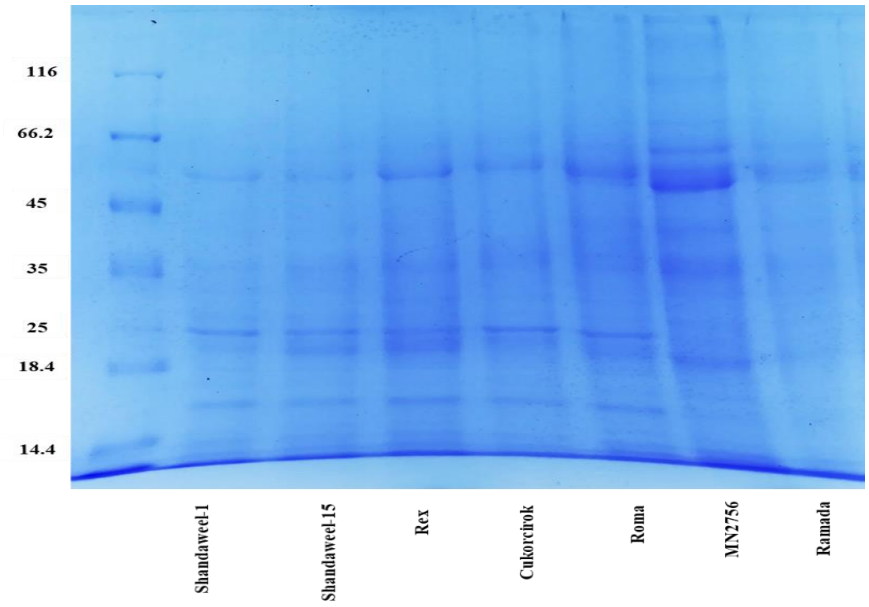

Fig. (2). Electrophoresis patterns of soluble proteins in sorghum studied varieties exposed to salt stress at Ras Sudr, South Sinai.

These results are also supported by Capouchová et al. (2006), Musigakun and Thongngam (2007) and Punia et al. (2020), who found that, the differences in the number and density of protein bands in sorghum varieties depend on the degree of stress resistance. And based on the physiological differences of the photosynthetic apparatus. Depending on the capacity of each variety to withstand stress conditions, the number of protein bands varies. The more resistant varieties have more protein bands as a result of the significant association between the accumulation of kafirin protein in sorghum grains and the gene expression of genes encoding for the synthesis of salinity-tolerant proteins (Musigakun and Thongngam, 2007). Additionally, under stressful circumstances, the gene expression of genes that code for the synthesis of proline and glycine betaine is increased (Rhodes and Hanson, 1993 and Khalil, 2013).

4. Grains Nutritional Composition

4.1. Protein, lipid, fiber, ash, NEF and moisture content

Sorghum grains are particularly well-balanced meal options that may aid in the management of many illnesses due to their high dietary fiber content, lack of gluten, and intriguing proteins and fats. As a result, the presence of these chemicals in grains made from plants cultivated in salinity was assessed. According to the information in Table (6) and Fig. (3), the percentage of chemical elements in sorghum grains that were cultivated under salty conditions was as follows: sorghum grains had a moisture content that ranged

from 6.92 to 7.65%, according to the findings shown in the same table. A high percentage of oil, 5.53, 5.09, and 4.99%, respectively, was a distinguishing feature of Roma, MN2756, and Ramada varieties. The varieties Rex, Cukorcirok, and Shandaweel-1, on the other hand, had low oil percentages of 3.17, 3.59, and 3.61%, respectively.

Table (6). Grains nutritional composition (moisture, oil, protein, ash, fiber, and NFE) of sorghum studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Sorghum varieties	Moisture (%)	Chemical composition (%)				
		Oil	Protein	Ash	Fiber	NFE
Shandaweel-1	7.21 ± 0.17 C	3.61 ± 0.11 C	20.37 ± 0.81 B	5.76 ± 0.61 B	3.49 ± 0.03 C	66.77 ± 0.25 C
Shandaweel-15	7.34 ± 0.22 BC	4.87 ± 0.22 B	22.94 ± 0.53 A	5.03 ± 0.21 D	3.05 ± 0.07 D	64.11 ± 0.36 D
Rex	6.92 ± 0.05 D	3.17 ± 0.32 D	20.07 ± 0.21 B	5.32 ± 0.41 C	4.19 ± 0.02 A	67.25 ± 0.42 B
Cukorcirok	7.26 ± 0.18 C	3.59 ± 0.27 C	17.94 ± 0.43 D	4.65 ± 0.38 E	3.17 ± 0.03 D	70.65 ± 0.55 A
Roma	7.46 ± 0.21 B	5.53 ± 0.31 A	23.27 ± 0.55 A	4.21 ± 0.39 F	3.58 ± 0.01 BC	63.41 ± 0.67 E
MN2756	7.65 ± 0.24 A	5.09 ± 0.36 B	22.30 ± 0.47 AB	4.84 ± 0.22 D	3.67 ± 0.04 B	64.10 ± 0.51 D
Ramada	7.61 ± 0.31 A	4.99 ± 0.33 B	18.66 ± 0.72 C	6.12 ± 0.18 A	3.82 ± 0.03 B	66.41 ± 0.39 C

Values followed by the same letter in columns are not different at $p < 0.05$ by Duncan's multiple range tests, and data are mean of 3 replicates, ± means standard error.

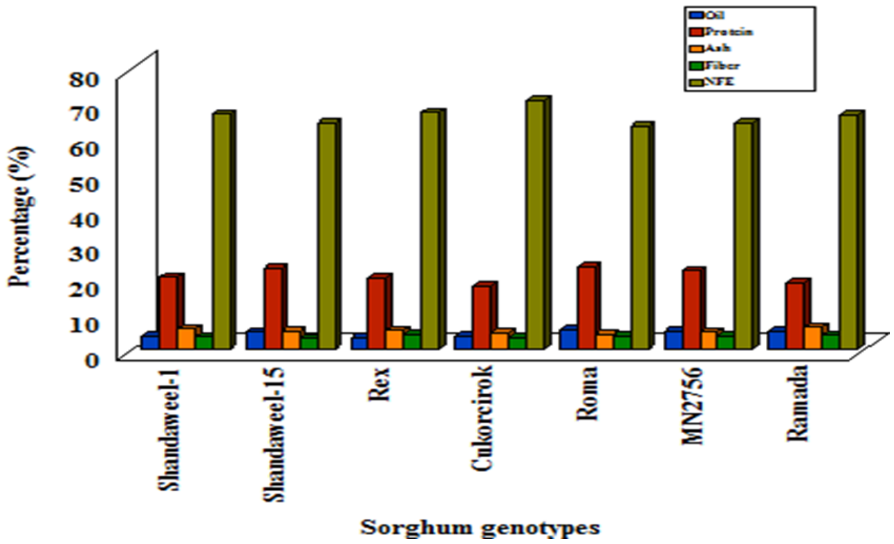

Fig. (3). Grains nutritional composition (protein, lipid, fiber, ash and NFE) of sorghum studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Data in the same table demonstrate that the protein content of sorghum grains ranged from 17.94 to 23.27%. In terms of protein accumulation inside sorghum grains, Roma, Shandaweel-15, and MN2756 varieties were superior

by 23.27, 22.94, and 22.3%, respectively. In contrast, Ramada and Cukorcirok varieties had very low protein accumulation rates, coming in at 18.66 and 17.94%, respectively. Furthermore, Shandawee-1 and Rex varieties produced similarly high rates of protein accumulation (20.37 and 20.07%, respectively).

Data also reveal the range of sorghum grains ash percentage in salinity circumstances, which was between 4.21 and 6.12%. Additionally, the range for the fiber content of sorghum grains was 3.05 to 4.19%. According to the results in the same table, the proportion of the extract that was NFE ranged from 63.41 to 70.65%. In this respect. NFE was present in significant concentrations in Cukorcirok, Rex, Shandaweel-1, and Ramada varieties (70.65, 67.25, 66.77, and 66.41%, respectively). The rates of NFE for Shandaweel-15 and MN2756 varieties were similar of 64.1% for each, followed by Roma variety, whose grains contained 63.41% of NFE. These findings are supported by an earlier research of Mawouma et al. (2022), who discovered that sorghum grains moisture, protein, fat, crude fiber, ash, and carbohydrate contents varied in the ranges of 8.51-9.33%, 19.62-23.78%, 2.74-3.32%, 2.56-4.70%, 1.15-1.59%, and 67.281-72.71%, respectively. It is possible that genetic variables played a major role in the variances in the proximate compositions of the samples from the different sorghum varieties (Taleon et al., 2012).

4.2. Amino acids content

Table (7) and Fig. (4) demonstrate the findings of the chromatographic separation of the amino acids found in sorghum grains as a result of plant growth under salt stress conditions. The information demonstrated that all sorghum varieties had eight necessary amino acids. In all sorghum varieties, the bulk-forming amino acids were leucine, valine, and histidine, except in Shandaweel-15 and MN2756 varieties, where the bulk-forming amino acids were isoleucine, leucine, and then valine, and leucine, phenylalanine, then valine respectively. The essential amino acids threonine and lysine, on the other hand, were present in extremely tiny levels in all varieties of sorghum.

The findings also demonstrated that MN2756 and Rex varieties were superior in terms of essential amino acid accumulation, whereas Cukorcirok variety had the lowest levels of essential amino acid accumulation in the grain. The information presented in the same table revealed that all sorghum varieties included seven non-essential amino acids. Wherein all sorghum varieties accounted for small levels of the non-essential acids; glycine and tyrosine and substantial amounts of the amino acids glutamic, proline, and ultimately alanine. The highest accumulation of non-essential amino acids was found in Rex, Ramada, and MN2756 varieties, whereas the lowest accumulation of non-essential amino acids was found in Cukorcirok variety. The information in the table demonstrated how semi-essential amino acids (cystine and arginine) accumulated in all varieties. In comparison to the other varieties, Shandaweel-15, Rex, and Ramada varieties were more effective at synthesizing semi-essential amino acids. Finally, the data show that under salt

stress circumstances, Rex, MN2756 and Ramada varieties produce the most amino acids, whilst Cukorcirok variety produces the least. Previous research of Adeyeye (2008) and Mahmoud et al. (2022), which confirmed that sorghum grains contain 17 amino acids with an absence of the amino acid tryptophan, is consistent with these findings. According to the previous studies, glutamic acid, isoleucine, histidine, phenylalanine, proline and alanine are the amino acids with the highest concentrations, while lysine has the lowest concentrations.

Table (7). Amino acids content (mg/g sorghum flour) in sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

	Amino acids (mg/g sorghum flour)	Sorghum varieties						
		Sh-1	**Sh-15**	**Rex**	**Cukorcirok**	**Roma**	**MN2756**	**Ramada**
Essential	**Threonine**	5.63	5.92	7.05	4.38	5.82	5.74	6.29
	Valine	15.36	15.38	17.64	13.62	15.80	16.92	14.58
	Methionine	8.63	7.14	7.96	5.94	6.90	10.11	7.23
	Isoleucine	9.45	9.45	11.71	8.26	9.90	11.73	8.70
	Leucine	28.32	29.10	35.73	24.00	30.77	35.19	31.28
	Phenylalanine	9.04	9.85	12.21	8.09	9.93	17.87	10.15
	Histidine	12.32	12.85	14.03	12.58	12.45	12.22	13.79
	Lysine	5.52	6.60	6.23	4.63	5.21	4.44	7.24
	Total	**94.27**	**96.29**	**112.56**	**81.49**	**96.79**	**114.22**	**99.26**
Non- essential	**Aspartic acid**	17.60	19.20	23.31	12.93	18.58	18.13	20.23
	Serine	8.27	9.20	11.00	7.68	9.53	9.10	9.47
	Glutamic acid	43.18	47.00	56.44	35.34	49.24	51.11	51.51
	Proline	32.58	34.36	41.08	29.15	34.89	36.98	38.29
	Glycine	6.20	6.75	7.41	5.16	6.11	5.79	7.56
	Alanine	20.41	21.65	26.95	17.31	23.00	23.68	24.52
	Tyrosine	3.52	3.23	4.68	3.39	3.18	6.43	5.39
	Total	**131.76**	**141.39**	**170.86**	**110.97**	**144.54**	**151.21**	**156.98**
Semi-essential	**Arginine**	8.65	10.08	9.83	7.19	7.94	7.20	10.25
	Cystine	4.12	3.86	3.87	3.24	3.56	3.56	3.06
	Total	**12.77**	**13.94**	**13.70**	**10.44**	**11.50**	**10.75**	**13.31**
Total amino acids		**238.80**	**251.62**	**297.12**	**202.90**	**252.83**	**276.18**	**269.54**

Amino acids which separated from hydrolysate column of amino acid analyzer apparatus. Sh-1= Shandaweel-1 and Sh-15= Shandaweel-15

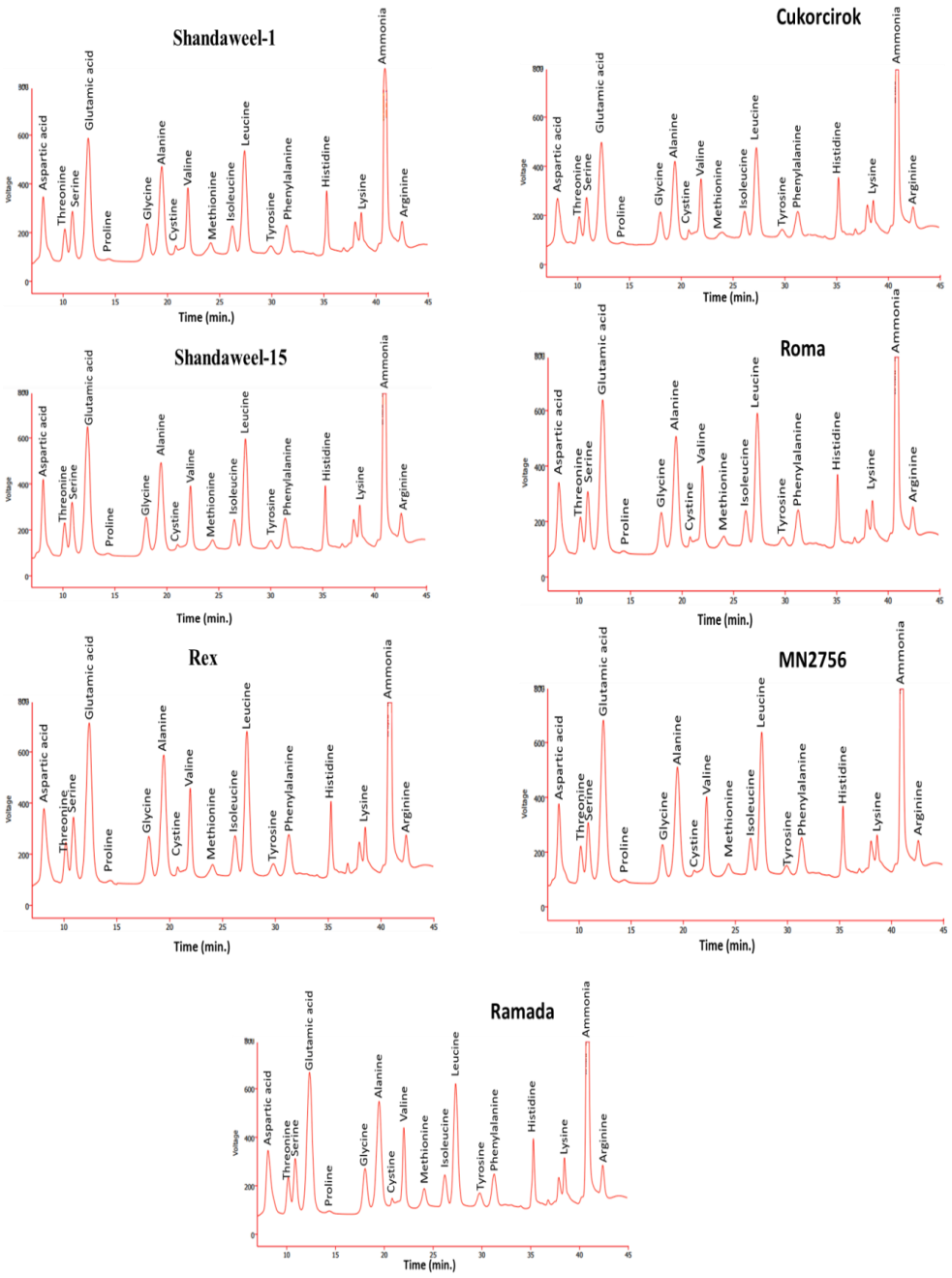

Fig. (4). Amino acids content in sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

The percentage of essential, semi-essential, and non-essential amino acids in all studied varieties of sorghum cultivated in salinity is shown in Table (8). Where the findings show that there are two varieties; Cukorcirok and MN2756 had the capacity to synthesize amino acids in total ratios of 45.3 and 45.25% each for essential and semi-essential amino acids, respectively. In the same direction, the ability to synthesize substantial amounts of non-essential amino acids was higher in Rex, Roma, and Ramada varieties by 57.5, 57.17, and 58.24%, respectively. While the total percentages of essential and semi-essential amino acids (which were 44.83 and 43.81%, respectively) and non-essential amino acids (which were 55.18 and 56.19%, respectively) in the Shandaweel models 1 and 15 were similar. This study discovered that the percentage of essential amino acids in sorghum grains ranged from 41.7 to 45.3%, which is consistent with the findings of Paul et al. (1980) and Adeyeye (2008), who discovered that the percentage of essential amino acids in sorghum grains ranged from 21.5 to 30.7%, and WHO (1985), it was found that the percentage of essential amino acids ranged from 53.1 to 56.7% in sorghum grains.

Table (8). Percentage of essential, non- essential, and semi-essential amino acids in sorghum grain of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Sorghum varieties	Essential amino acids (%)	Non- essential amino acids (%)	Semi-essential amino acids (%)
Shandaweel-1	39.48	55.18	5.35
Shandaweel-15	38.27	56.19	5.54
Rex	37.88	57.50	4.61
Cukorcirok	40.16	54.69	5.14
Roma	38.28	57.17	4.55
MN2756	41.36	54.75	3.89
Ramada	36.83	58.24	4.94

4.3. Phenolic and anthocyanins content

Sorghum bicolor grains contained a large number of phenolic and flavonoid chemicals, which are credited with giving the grains their colour because they are abundant in the outer membrane of the grains and have antioxidant characteristics. In this study, by using 20 chemicals from seven sorghum varieties, the chromatographic profile of phenolic compounds in sorghum flour is described and quantified in Table (9) and Fig. (5).

The information indicated the existence of two PPhs, chlorogenic acid and ellagic acid, nine phenolic compounds, including gallic acid, methyl gallate, coffeic acid, syringic acid, pyro-catechol, coumaric acid, vanillin, ferulic acid, and cinnamic acid and nine flavonoid compounds, including catechin, rutin, naringenin, daidzein, querectin, apigenin, kaempferol,

hesperetin, and anthocyanins. All varieties had chlorogenic acid PPhs, however all varieties other than Cukorcirok, Roma, and Ramada lost ellagic acid. In terms of phenolic components, the findings revealed that coumaric acid was only found in trace amounts in all varieties under examination, whereas gallic acid and ferulic acid, coffeic acid, and methyl gallate were the next most abundant phenolic acids. Syringic acid and vanillin were also seen to disappear from the Ramada and Shandaweel-15 varieties, respectively. Cinnamic acid also vanished from Shandaweel-1 and Ramada varieties in the same manner as pyro-catechol vanished from all varieties with the exception of Rex, Cukorcirok, and Ramada. Regarding flavonoids, all sorghum varieties contained catechin, apigenin, and kaempferol. On the other hand, the MN2756 variety lacked rutin, naringenin, and hesperetin. Additionally, the varieties of Shandaweel-1, and Cukorcirok were deficient in daidzein and querectin, and also daidzein was not present in the Shandaweel-15 variety. Similar outcomes were found in earlier studies of Van Hung (2016), Ghinea et al. (2021) and Pontieri et al. (2021). They discovered a variety of PPhs isolated from sorghum extracts, including the following: ellagic acid, gallic acid, sinapic acid, syringic acid, vanillic acid, apigenin, caffeic acid, epicatechin, ferulic acid, chlorogenic acid, *p*-coumaric acid, daidzein, rutin, hyperoside, quercetin, naringenin, and genistein. The phenolic component was more significant in red sorghum. Red and yellow sorghum had higher levels of ferulic acid while yellow sorghum had higher levels of chlorogenic acid. The varying levels of phenolic compounds were related to genetic variations since the largest levels of phenols were found in sorghum with pigmented and widely distributed genes (B1, and B2) and their expression. The amount of phenols was also higher in sorghum with purple/red plants and thick (z) pericarp genes (de Morais et al., 2015 and Punia et al., 2020). Likewise, the interaction among several genes (the gene responsible for color, the yellow $seed_1$ gene, and the gene responsible for the synthesis and accumulation of 3-deoxyanthocyanidins, the P_1 gene). Additionally, higher enzyme activity may be the reason why colored sorghum has higher levels of total 3-deoxyanthocyanidins, favones, dihydrofavonol, and favanone than white sorghum (Awika et al., 2004 and Dykes et al., 2005).

The findings of the colorometric study using the spectrophotometer, which determined the total amount of anthocyanin in the bicolor sorghum grains cultivated under salinized circumstances in South Sinai, were compiled in Table (9) and Fig. (6). The color of the pericarp of sorghum grains is attributed to the anthocyanin. Total anthocyanin in the study made up a significant portion of the Roma and Rex varieties, at rates 191.42 and 123.16 µg/g sorghum flour, respectively. In Ramada, Cukorcirok, and MN2756 varieties, the quantity of anthocyanin was moderated about 48.03, 35.49 and 25.06 µg/g sorghum flour, respectively. The varieties Shandaweel-1 and Shandaweel-15 have low anthocyanin content, with estimates of 2.02 and 19.88 µg/g sorghum flour, respectively. The varieties Rex, Roma, Cukorcirok,

and Ramada were superior, according to the data, in the accumulation of phenolic compounds inside sorghum grains, whereas the MN2756 variety had the lowest proportion of phenolic compound accumulation. The quantity of phenolic compound accumulation was similar across the varieties Shandaweel-1 and Shandaweel-15, with a total of 58.49 µg/g and 56.84 µg/g sorghum flour, respectively. The outcomes attained are in line with de Morais et al. (2015), Shen et al. (2018) and Punia et al. (2021), who found that, the pericarp color had an impact on the sorghum flavone profile and antioxidant activity.

Table (9). Phenolic compounds content (µg/g sorghum flour) in sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Where; phenolic compounds which separated from C18 column of HPLC apparatus, except for the anthocyanin, they was estimated by colorimetric methods using the spectrophotometer and calculated using the standard (cyaniding-3-glucoside equivalents), and data values followed by the same letter in rows are not different at $p < 0.05$ by Duncan's multiple range tests, and data are mean of 3 replicates, ± means standard error -Nd: not detectable, PPhs: polyphenols, Sh-1= Shandaweel-1 and Sh-15= Shandaweel-15

Type	Bioactive compounds (µg/g sorghum flour)	Sorghum varieties						
		Sh-1	Sh-15	Rex	Cukorcirok	Roma	MN2756	Ramada
PPhs	Chlorogenic acid	3.82	5.37	4.10	26.33	40.20	6.24	20.83
	Ellagic acid	Nd	Nd	Nd	0.27	15.86	Nd	2.54
Phenol	Gallic acid	10.83	10.14	32.22	44.71	35.49	10.07	29.48
	Methyl gallate	2.66	1.14	29.73	1.30	12.74	0.76	4.28
	Coffeic acid	3.57	2.10	9.56	1.35	4.66	4.22	2.65
	Syringic acid	0.89	0.89	8.69	6.56	1.54	0.51	Nd
	Pyro-catechol	Nd	Nd	0.73	0.35	Nd	Nd	4.46
	Coumaric acid	0.82	1.19	1.86	1.13	2.49	0.97	0.84
	Vanillin	0.22	Nd	1.82	2.65	3.75	0.13	2.65
	Ferulic acid	0.48	1.36	6.00	39.76	43.61	0.93	22.19
	Cinnamic acid	Nd	0.06	3.28	0.80	0.52	0.06	Nd
Flavonoide	Catechin	7.50	0.42	1.26	9.44	11.90	1.57	3.98
	Rutin	20.91	10.08	182.91	96.62	5.35	Nd	8.92
	Naringenin	0.90	1.28	17.84	4.69	25.62	Nd	7.05
	Daidzein	Nd	Nd	7.67	Nd	2.54	0.71	1.20
	Querectin	Nd	1.18	5.26	Nd	5.49	0.88	2.62
	Apigenin	1.80	1.10	199.51	12.22	33.58	0.50	1.21
	Kaempferol	1.66	0.49	46.45	7.46	11.34	1.79	4.62
	Hesperetin	0.42	0.17	10.24	3.86	1.84	Nd	1.83
	Anthocyanins	2.02 ±0.01 F	19.88 ±0.02 E	123.16 ±0.2 B	35.49 ±0.53 D	191.4 ±0.83	25.06 ±0.44 E	48.03 ±0.74 C
	Total	**58.49**	**56.84**	**692.30**	**294.97**	**449.95**	**54.40**	**169.37**

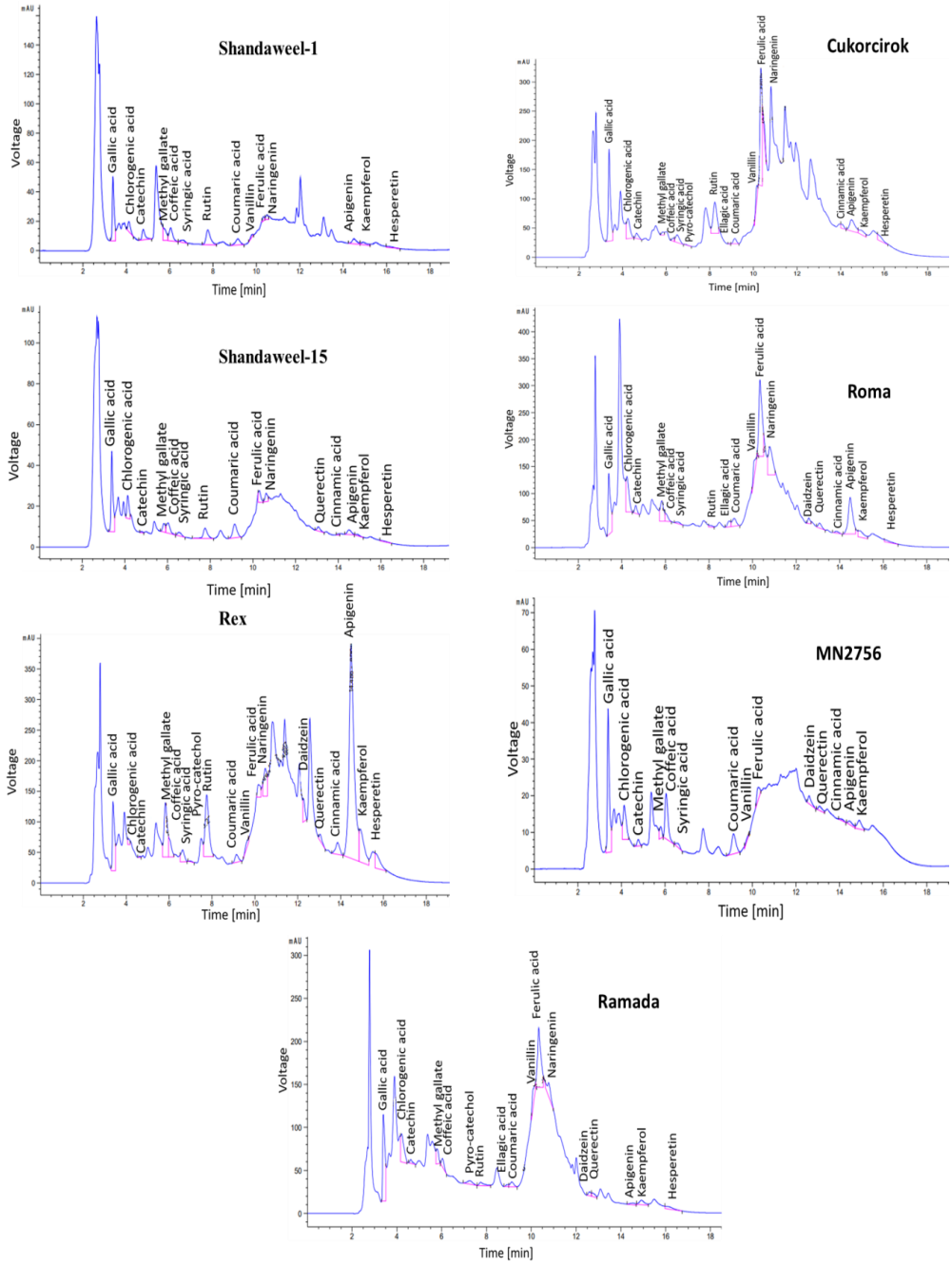

Fig. (5). Phenolic compounds content in sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

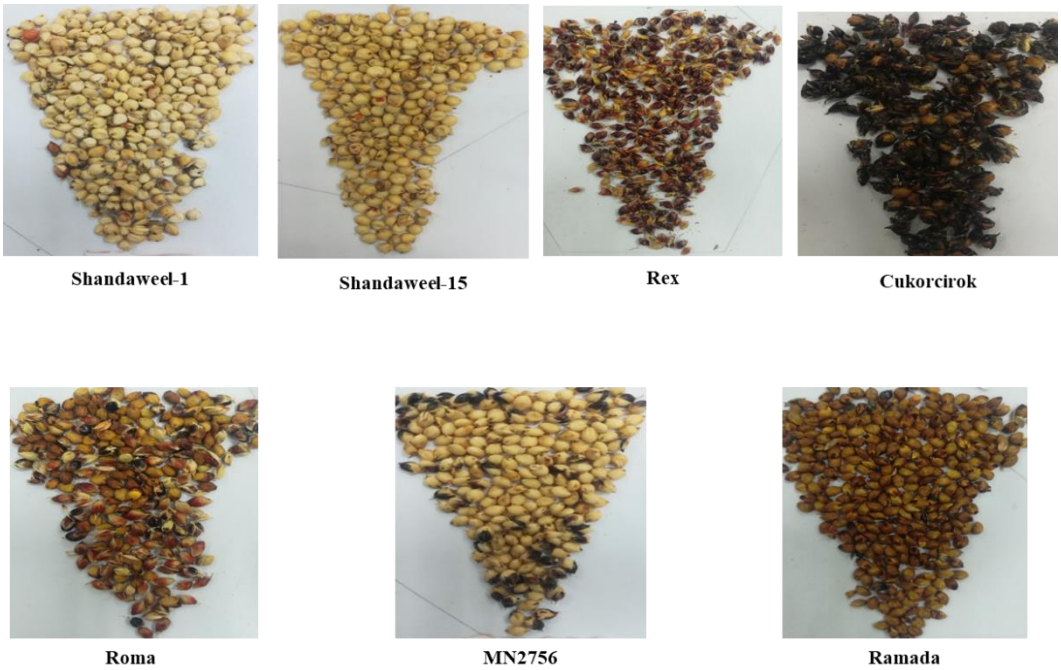

Fig. (6). Effect of phenolic compounds and anthocyanin content on pericarp color in sorghum grains of the studied varieties grown under saline conditions in Ras Sudr, South Sinai.

4.4. Sugars content

The findings of the chromatographic separation of the sugars found in the ethanolic extract of sorghum grains obtained from plants developed in saline circumstances are displayed in Table (10) and Fig. (7). Numerous sugars were separated, as seen in the results, but only four kinds could be distinguished using an outside standard. These were monosaccharides, such as glucose and arabinose (the two forms of aldehyde sugars). Except for MN2756 variety, arabinose sugar was present in all varieties and ranged from 0.19 to 1.35 µg/g sorghum flour. The amount of glucose sugar ranged from 0.23 to 51.08 µg/g sorghum flour and was detected in all varieties of the studied sorghum varieties. Fructose, a ketone monosaccharide, was present in all varieties and ranged from 1.5 to 57.06 µg/g sorghum flour. Disaccharides (sucrose), the result of combining glucose and fructose, range in concentration from 1.48 to 33.75 µg/g sorghum flour in all varieties. The high sugar output of the Cukorcirok variety, which had a total sugar content of 143.24 µg/g sorghum flour, was its distinguishing feature. The productivity of the hay fever samples, Shandaweel-15 and Rex, on the other hand, was incredibly low in sugars, coming up to 3.52 and 7.46 µg/g sorghum flour, respectively. The output of sugars varied among the other varieties, with

Ramada, MN2756, Roma, and Shandaweel-1 recording productions of 36.37, 24.16, 19.99, and 11.12 µg/g sorghum flour, respectively.

Table (10). Sugars content (µg/g sorghum flour) in sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

Sugars composition (µg/g sorghum flour)	Sorghum varieties						
	Sh-1	**Sh-15**	**Rex**	**Cukorcirok**	**Roma**	**MN2756**	**Ramada**
Sucrose	4.28	1.48	3.97	33.75	6.83	8.41	13.07
Glucose	0.92	0.23	0.36	51.08	1.35	5.49	6.05
Frucotse	5.24	1.50	2.93	57.06	10.83	10.26	16.71
Arabinose	0.68	0.30	0.19	1.35	0.98	Nd	0.54
Total	**11.12**	**3.52**	**7.46**	**143.24**	**19.99**	**24.16**	**36.37**

Sugars in the table which separated from Shim-pack SCR-101N column of HPLC apparatus. - Nd: not detectable, Sh-1= Shandaweel-1 and Sh-15= Shandaweel-15

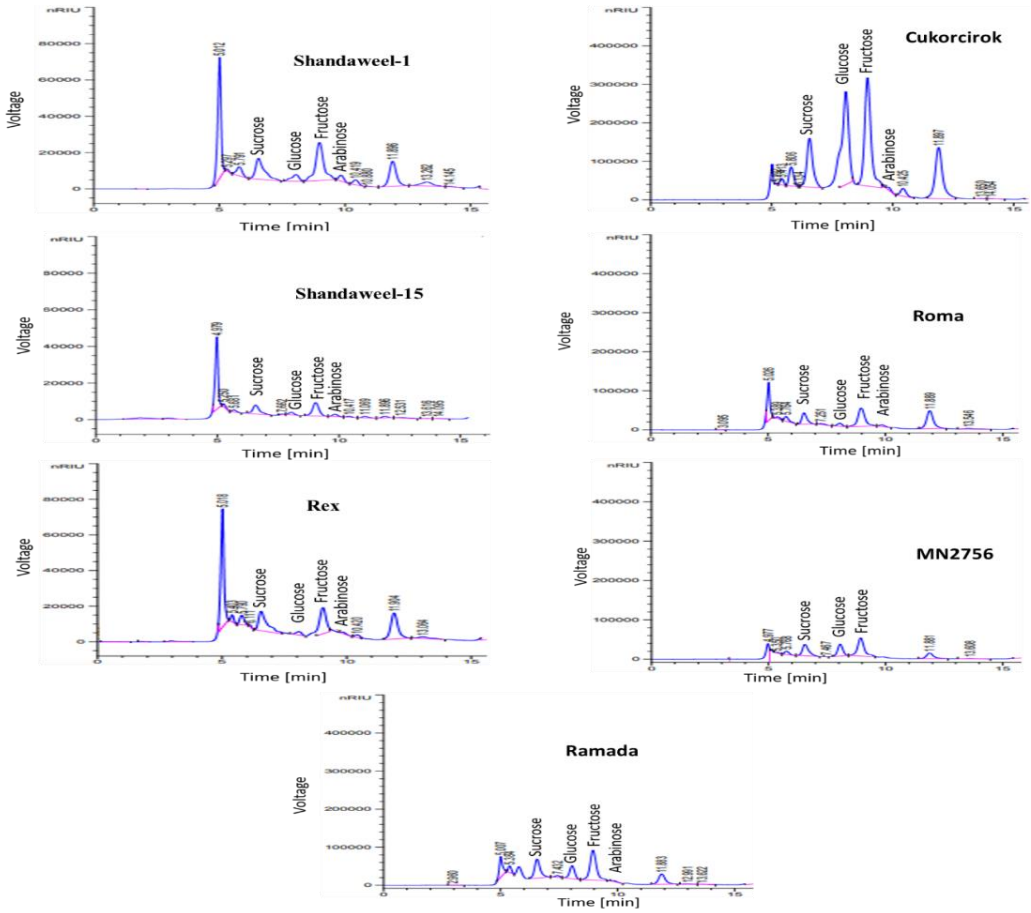

Fig. (7). Sugars content in the sorghum grains of the studied varieties exposed to salt stress at Ras Sudr, South Sinai.

The results obtained are consistent with earlier studies of Verbruggen et al. (1995), Nandini and Salimath (2001) and Miafo et al. (2019). According to these earlier investigations, the primary sugars found in sorghum grains were arabinose, xylose, galactose, and glucose. Mannose and rhamnose were the minors. Likewise, the presence of considerable levels of free sugars in sorghum grains has been determined by chromatography to be in the range of 1–1.4% of ketose sugars (fructose, sucrose, raffinose, and stachyose) and 0.2-0.5% of reducing sugars (glucose and fructose) (Nordin, 1959). The variation in the varieties of the cereal-associated sugar crop characteristic is what causes the variance in the concentration of free sugars in the varieties under consideration (Jackson, 2005). Furthermore, the genetic chromosomes of the sorghum crop, a sugar crop, are impacted by environmental stress (Bennetzen et al., 2001).

CONCLUSION

The seven sorghum varieties were found to be tolerant to high salt. Additionally, it exhibits resilience to oxidative stress brought on by high salinity due to the abundance of antioxidants such phenols, flavonoids, and anthocyanins. Buildup of proline, unrestricted carbohydrates, and proteins that can withstand salt. The seven varieties can be grouped into the following groups based on the pericarp colour of the grains of Shandaweel-1 and Shandaweel-15, which have pericarps that are white and yellow; Cukorcirok, which is brown; and the remaining varieties, which range in colour from red to purple. For the largest concentrations of medicinal compounds to benefit from them in the treatment of many diseases and to manufacture other essential chemicals that join the market, these genetic structures require more genetic studies and the job of adapting them in harsh saltwater environments.

REFERENCES

Adeyeye, E.I. (2008). The intercorrelation of the amino acid quality between raw, steeped and germinated guinea corn (*Sorghum bicolor*) grains. Bulletin of the Chemical Society of Ethiopia, 22 (1): 11-17.

AOAC (1995). In: 'Official Methods of Analysis' 16th Ed. Association of Official Analytical Chemists. Washington DC, USA.

Awika, J.M., L.W. Rooney and R.D. Waniska (2004). Properties of 3-deoxyanthocyanins from sorghum. Journal of Agricultural and Food Chemistry, 52 (14): 4388-4394.

Bennetzen, J.L., V. Subramanian, J. Xu, S.S. Salimath, S. Subramanian, D. Bhattramakki and G.E. Hart (2001). A Framework Genetic Map of Sorghum Containing RFLP, SSR, and Morphological Markers. In: 'Phillips R.L. and I.K. Vasil (ed.)' DNA-Based Markers in Plants. 2nd Ed. Kluwer Academic, Boston, MA, pp. 347–356.

Calone, R., R. Sanoubar, C. Lambertini, M. Speranza, A.L. Vittori, G. Vianello and L. Barbanti (2020). Salt tolerance and Na allocation in *Sorghum bicolor* under variable soil and water salinity. Journal of Plants, 9 (5): 561-580.

Capouchová, I., J. Petr and L. Krejčířová (2006). Protein composition of sorghum and oat grain and their suitability for gluten-free diet. Journal of Žemdirbystė, 93 (4): 271-284.

Carmo-Silva, A.E., A. Francisco, S.J. Powers, A.J. Keys, L. Ascensão, M.A.J. Parry and M.C. Arrabaça (2009). Grasses of different C4 subtypes reveal leaf traits related to drought tolerance in their natural habitats: Changes in structure, water potential, and amino acid content. American Journal of Botany, 96 (7): 1222-1235.

Castro-Vargas, H.I., L.I. Rodríguez-Varela, S.R.S. Ferreira and F. Parada-Alfonso (2010). Extraction of phenolic fraction from guava seeds (*Psidium guajava* L.) using supercritical carbon dioxide and co-solvents. Journal of Supercritical Fluids, 51 (3): 319-324.

Christin, P.A. and C.P. Osborne (2014). The evolutionary ecology of C4 plants. Journal of New Phytologist, 204 (4): 765-781.

Costa, P. H. A., A.D.A. Neto, M.A. Bezerra, J.T. Prisco1 and E. Gomes-Filho (2005). Antioxidant-enzymatic system of two sorghum genotypes differing in salt tolerance. Brazilian Journal of Plant Physiology, 17 (4): 353-362.

de Morais, C.L., S.S. Pinheiro, C.W.P. de Carvalho, V.A.V. Queiroz, C.B. de Menezes, A.V.B. Moreira, F.A.R. de Barros, J.M. Awika, H.S.D. Martino and H.M. Pinheiro-Sant'Ana (2015). Phenolic compounds profile in sorghum processed by extrusion cooking and dry heat in a conventional oven. Journal of Cereal Science, 65: 220-226.

Dicko, M.H., H. Gruppen, C. Barro, A.S. Traore, W.J.H. van Berkel and A.G.J. Voragen (2005). Impact of phenolic compounds and related enzymes in sorghum varieties for resistance and susceptibility to biotic and abiotic stresses. Journal of Chemical Ecology, 31 (11): 2671-2688.

Dykes, L., L.W. Rooney, R.D. Waniska and W.L. Rooney (2005). Phenolic compounds and antioxidant activity of sorghum grains of varying genotypes. Journal of Agricultural and Food Chemistry. 53 (17): 6813-6818.

Dytham, C. (2011). In: 'Choosing and Using Statistics: A Biologist's Guide'. Hoboken: John Wiley & Sons.

El Naim, A.M., K.E. Mohammed, E.A. Ibrahim and N.N.Suleiman (2012). Impact of salinity on seed germination and early seedling growth of three sorghum (*Sorghum biolor* L. Moench) cultivars. Journal of Science and Technology, 2 (2): 16-20.

Fa, Y., H. Yang, C. Ji, H. Cui, X. Zhu, J. Du and J. Gao (2013). Simultaneous determination of amino acids and carbohydrates in culture media of

Clostridium thermocellum by valve-switching ion chromatography. Journal of Analytica Chimica Acta, 798: 97-102.

FAO, Food and Agriculture Organization (2015). Status of the Worlds's Soil Resources (SWSR)-Main Report, United Nations. Rome: Food and Agriculture Organization.

Ghinea, I.O., M.D.I. Mihaila, G.-V. Blaga, S.M. Avramescu, M. Cudalbeanu, S.-F. Isticioaia, R.M. Dinica and B. Furdui (2021). HPLC-DAD polyphenolic profiling and antioxidant activities of *Sorghum bicolor* during germination. Journal of Agronomy, 11 (3): 417-425.

Hasanuzzaman, M., M.A. Hossain, J.A.T. da Silva and M. Fujita (2012). Plant Response and Tolerance to Abiotic Oxidative Stress: Antioxidant Defense is A Key Factor. In: 'Crop Stress and its Management: Perspectives and Strategies'. Springer, pp. 261-315.

Heath, R.L. and L. Packer (1968). Photoperoxidation in isolated chloroplasts: I. Kinetics and stoichiometry of fatty acid peroxidation. Archives of Biochemistry and Biophysics, 125 (1): 189-198.

Horowitz, W. and G. Latimer (2006). In: 'Official Methods of Analysis of AOAC International. 18th Ed., Gaithersburg Md.

Jackson, P.A. (2005). Breeding for improved sugar content in sugarcane. Journal of Field Crops Research, 92 (2-3): 277-290.

Jafari, M.H.S., M. Kafi and A. Astaraie (2009). Interactive effects of NaCl induced salinity, calcium and potassium on physiomorphological traits of sorghum (*Sorghum bicolor* L.). Pakistan Journal of Botany, 41 (6): 3053-3063.

Joardar, J., S. Razir, M. Islam and M. Kobir (2018). Salinity impacts on experimental fodder sorghum production. SAARC Journal of Agriculture, 16 (1): 145-155.

Kakani, V.G., J.C. Vu, J.L.H. Allen and K.J. Boote (2011). Leaf photosynthesis and carbohydrates of CO_2-enriched maize and grain sorghum exposed to a short period of soil water deficit during vegetative development. Journal of Plant Physiology, 168 (18): 2169-2176.

Kavikishor, P.B. and N. Sreenivasulu (2014). Is proline accumulation per se correlated with stress tolerance or is proline homeostasis a more critical issue? Journal of Plant Cell and Environment, 37 (2): 300-311.

Khalil, R.M. (2013). Molecular and biochemical markers associated with salt tolerance in some sorghum genotypes. World Appl. Sci. J., 22 (4): 459-469.

Kishor, P.K., S. Sangam, R. Amrutha, P.S. Laxmi, K. Naidu, K.S. Rao, S. Rao, K. Reddy, P. Theriappan and N. Sreenivasulu (2005). Regulation of proline biosynthesis, degradation, uptake and transport in higher plants: its implications in plant growth and abiotic stress tolerance. Journal of Current Science, 88 (3): 424-438.

Kumari, D., T. Madhujith and A. Chandrasekara (2017). Comparison of phenolic content and antioxidant activities of millet varieties grown in different locations in Sri Lanka. Journal of Food Science and Nutrition, 5 (3): 474-485.

Laemmli, U.K. (1970). Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature, 227 (5259): 680-685.

Lamberts, L., I. Rombouts and J.A. Delcour (2008). Study of nonenzymic browning in α-amino acid and γ-aminobutyric acid/sugar model systems. Journal of Food Chemistry, 111 (3): 738-744.

Lee, J., R.W. Durst, R.E. Wrolstad, C. Kupina and J.D. Smsmbmtpfrasgtuw (2005). Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study. Journal of AOAC international, 88 (5): 1269-1278.

Mahmoud, N.E. and R.M. Abdelhameed (2021). Superiority of modified graphene oxide for enhancing the growth, yield, and antioxidant potential of pearl millet (*Pennisetum glaucum* L.) under salt stress. Journal of Plant Stress, 2: 100025.

Mahmoud, N.E., A. Hassan and R.M. Abdelhameed (2022). Microwave-assisted functionalization of graphene oxide with amino acid behaviour on the chemical constituents and specific molecular pathways of pearl millet grains under saline conditions. Journal of Plant Nano Biology, 2: 100020.

Mariotti, F., D. Tomé and P.P. Mirand (2008). Converting nitrogen into protein-beyond 6.25 and Jones' factors. Critical Reviews in Food Science and Nutrition, 48 (2): 177-184.

Mawouma, S., N.N. Condurache, M. Turturică, O.E. Constantin, C. Croitoru and G. Rapeanu (2022). Chemical composition and antioxidant profile of sorghum (*Sorghum bicolor* (L.) moench) and pearl millet (*Pennisetum glaucum* (L.) R. Br.) grains cultivated in the far-North region of Cameroon. Journal of Foods, 11 (14): 2026-2035.

Miafo, A.P.T., B.B. Koubala, G. Kansci and G. Muralikrishna (2019). Free sugars and non-starch polysaccharides–phenolic acid complexes from bran, spent grain and sorghum seeds. Journal of Cereal Science, 87: 124-131.

Ming, R., S.C. Liu, P.H. Moore, J.E. Irvine and A.H. Paterson (2001). QTL analysis in a complex autopolyploid: genetic control of sugar content in sugarcane. Journal of Genome Research, 11 (12): 2075-2084.

Mokrane, H., H. Amoura, N. Belhaneche-Bensemra, C.M. Courtin, J.A. Delcour and B. Nadjemi (2010). Assessment of algerian sorghum protein quality [*Sorghum bicolor* (L.) Moench] using amino acid analysis and *in vitro* pepsin digestibility. Journal of Food Chemistry, 121 (3): 719-723.

Mulaudzi, T., M. Nkuna, G. Sias, I.Z. Doumbia, N. Njomo and E. Iwuoha (2022). Antioxidant capacity of chitosan on sorghum plants under salinity stress. Journal of Agriculture, 12 (10): 1544.

Musigakun, P. and M. Thongngam (2007). Characteristics and functional properties of sorghum protein (kafirin). Journal of Agriculture and Natural Resources, 41 (5): 313-318.

Nandini, C.D. and P.V. Salimath (2001). Structural features of arabinoxylans from sorghum having good roti-making quality. Journal of Food Chemistry, 74 (4): 417-422.

Netondo, G.W., J.C. Onyango and E. Beck (2004). Sorghum and salinity: I. Response of growth, water relations, and ion accumulation to NaCl salinity. Journal of Crop Science, 44 (3): 797-805.

Nordin, P. (1959). Sorghum Grain: The Soluble Sugars. In: 'Transactions of the Kansas Academy of Science'. Volume 62 (3), pp. 212-215.

Ogbaga, C.C., P. Stepien and G.N. Johnson (2014). Sorghum (*Sorghum bicolor*) varieties adopt strongly contrasting strategies in response to drought. Journal of Physiologia Plantarum, 152 (2): 389-401.

Păcularu-Burada, B., M. Turturică, J.M. Rocha and G.E. Bahrim (2021). Statistical approach to potentially enhance the postbiotication of gluten-free sourdough. Journal of Applied Sciences, 11 (11): 5306.

Palic, D., K. Moloto and O. Djuragic (2007). Critical assessment of laboratory methods for full-fat soybean quality control. In: International Feed Technology Symposium, 12, Novi Sad (Serbia), 13-15 Nov 2007. Institute for Food Technology.

Paterson, A.H., J.E. Bowers, R. Bruggmann, I. Dubchak, J. Grimwood, H. Gundlach, G. Haberer, U. Hellsten, T. Mitros and A. Poliakov (2009). The *Sorghum bicolor* genome and the diversification of grasses. Journal of Nature, 457 (7229): 551-556.

Paul, A., D.A. Southgate and J. Russell (1980). First supplement to McCance and Widdowson's the composition of foods. HMSO: London and Elsevier, New York.

Pontieri, P., G. Pepe, P. Campiglia, F. Merciai, M.G. Basilicata, D. Smolensky, M. Calcagnile, J. Troisi, R. Romano and F. Del Giudice (2021). Comparison of content in phenolic compounds and antioxidant capacity in grains of white, red, and black sorghum varieties grown in the mediterranean area. Journal of ACS Food Science and Technology, 1 (6): 1109-1119.

Punia, H., J. Tokas, A. Malik, A. Rani, P. Gupta, A. Kumari, V.S. Mor, A. Bhuker and S. Kumar (2020). Solar Radiation and Nitrogen Use Efficiency for Sustainable Agriculture. In: 'Resources Use Efficiency in Agriculture'. Springer, pp. 177-212.

Punia, H., J. Tokas, A. Malik and S. Sangwan (2021). Characterization of phenolic compounds and antioxidant activity in sorghum [*Sorghum*

bicolor (L.) Moench] grains. Journal of Cereal Research Communications, 49 (3): 343-353.

Rasper, V.F. and C.E. Walker (2000). Quality Evaluation of Cereals and Cereal Products. In: 'Handbook of Cereal Science and Technology'. Journal of CRC Press, pp. 505-537.

Rhodes, D. and A. Hanson (1993). Quaternary ammonium and tertiary sulfonium compounds in higher plants. Annual Review of Plant Biology, 44 (1): 357-384.

Salih, A., I. Ali, A. Lux, M. Luxova, Y. Cohen, Y. Sugimoto and S. Inanaga (1999). Rooting, water uptake, and xylem structure adaptation to drought of two sorghum cultivars. Journal of Crop Science, 39 (1): 168-173.

Shen, S., R. Huang, C. Li, W. Wu, H. Chen, J. Shi, S. Chen and X. Ye (2018). Phenolic compositions and antioxidant activities differ significantly among sorghum grains with different applications. Journal of Molecules, 23 (5): 1203-1209.

Southgate, D., A. Paul and J. Russell (1980). In: 'Supplement to McCance and Widdowson's The Composition of Foods'. HM Stationery Office.

Sun, Y., G. Niu, P. Osuna, L. Zhao, G. Ganjehunte, G. Peterson, J.R. Peralta-Videa and J.L. Gardea-Torresdey (2014). Variability in salt tolerance of *Sorghum bicolor* L. Journal of Agricultural Science, 2 (1): 9-21.

Taleon, V., L. Dykes, W. Rooney and L. Rooney (2012). Effect of genotype and environment on flavonoid concentration and profile of black sorghum grains. Journal of Cereal Science, 56 (2): 470-475.

Van Hung, P. (2016). Phenolic compounds of cereals and their antioxidant capacity. Critical Reviews in Food Science and Nutrition, 56 (1): 25-35.

Velikova, V., I. Yordanov and A. Edreva (2000). Oxidative stress and some antioxidant systems in acid rain-treated bean plants: protective role of exogenous polyamines. Journal of Plant Science, 151 (1): 59-66.

Verbruggen, M., G. Beldman and A. Voragen (1995). Barium and potassium hydroxide as a tool to extract pure glucuronoarabinoxylans from water unextractable cell wall material of sorghum. Journal of Cereal Science, 21: 271-282.

Vietor, D. and F. Miller (1990). Assimilation, partitioning, and nonstructural carbohydrates in sweet compared with grain sorghum. Journal of Crop Science, 30 (5): 1109-1115.

WHO, World Health Organization (1985). Protein requirements (WHO technical report series, No. 724). Report of a joint FAO/WHO/UNU expert consultation. World Health Organization, Geneva.

Yang, L., L. Dykes and J.M. Awika (2014). Thermal stability of 3-deoxyanthocyanidin pigments. Journal of Food chemistry, 160: 246-254.

Yobi, A., B.W. Wone, W. Xu, D.C. Alexander, L. Guo, J.A. Ryals, M.J. Oliver and J.C. Cushman (2012). Comparative metabolic profiling between desiccation-sensitive and desiccation-tolerant species of *Selaginella* reveals insights into the resurrection trait. The Plant Journal, 72 (6): 983-999.

Zhang, J. and M. Kirkham (1996). Lipid peroxidation in sorghum and sunflower seedlings as affected by ascorbic acid, benzoic acid, and propyl gallate. Journal of Plant Physiology, 149 (5): 489-493.

Zhao, S., C.C. Xu, Q. Zou and Q. Meng (1994). Improvements of method for measurement of malondialdehyde in plant tissues. J. Plant Physiol. Commun., 30 (3): 207-210.

الدلائل الكيميائية الحيوية لمقاومة الملوحة وعلاقتها بمركبات التغذية في السورجم تحت ظروف رأس سدر، جنوب سيناء

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على الرغم من أنها تنتمي لـ C4، إلا أن نباتات الذرة الرفيعة ثنائية اللون مقاومة بشكل معتدل للملوحة. يتأثر نمو وتطور النباتات في مرحلة البادرات سلبًا بمستويات الملوحة العالية، مثل تلك الموجودة في منطقة الدراسة قيد الدراسة (أكثر من ٨٠٠٠ جزء في المليون). بالإضافة إلى ذلك، لها تأثير على إنتاج الحبوب، وتطور الأزهار، والتخصيب، وعملية العقد. نتيجة لذلك، تبحث الدراسة في متغيرات الإجهاد في المؤشرات الكيميائية الحيوية لتقييم كيفية ازدهار سبعة أنواع من الذرة الرفيعة ثنائية اللون (Roma, MN2756, Shandaweel-1, Shandaweel-15, Rex, Ramada, Cukorcirok) عند التعرض لملوحة عالية وكيف يؤثر ذلك على محصول الحبوب والدلائل الكيميائية الحيوية والمكونات الغذائية. أوضحت الدراسة أن الصنف Rex يتميز عن سائر أصناف الذرة الرفيعة بقصر طول الساق حيث لا يزيد عن ١.٥ متر عند الحصاد والوزن المتوسط لمحصول القش ومحصول الحبوب الجيد. أشارت النتائج إلى أن نسبة إنتاجية الحبوب في الصنف Rex بلغت ٣٢.١٤٪ من وزن النبات. تتميز حبوب Rex بمحتواها الغذائي العالي، مع المركبات الفينولية عند ٦٩٢.٣ (ميكروجرام / جم) والأحماض الأمينية عند ٢٩٧.١٢ ملجم / جم في دقيق الذرة. نتيجة لذلك، يُعتقد أن صنف Rex هو أفضل أنواع الذرة الرفيعة التي تمت زراعتها في رأس سدر تحت ظروف الإجهاد الملحي.