Exogenous Methyl Jasmonate Acclimate Morpho-Physiological, Ionic and Gas Exchange Attributes of Wheat Genotypes (*Triticum aestivum* L.) under Salt Stress

Iftikhar Ahmed*, Ghulam Hassan Abbasi, Moazzam Jamil, Zaffar Malik

Faculty of Agriculture and Environment, Department of Soil Science, The Islamia University of Bahawalpur, 63100, Pakistan

Received: 15 June 2022
Accepted: 18 August 2022

Abstract

Salinity is a serious menace that has a significant influence on sustainability of agriculture and threatens food security of the world. Methyl jasmonate appeared to be an important modulator with different specific functions in plants and increase the resistance against different abiotic stresses. A hydroponic study was performed with three salt (control, 100 mM and 200 mM NaCl) and two methyl jasmonate concentrations (50 µM and 100 µM) applied in sole and integrate form. Methyl jasmonate treated plants exhibits improved growth mass and antioxidant safeguard. The imposition of salt in growth medium drastically reduced the plant growth, physiological, gas exchange, ionic and biochemical attributes. Application of methyl jasmonate significantly alleviated the deleterious effects of salinity by depicting the improvement in plant biomass, RWC, MSI, transpiration rate, photosynthetic rate, stomatal conductance, internal CO₂ concentration, chlorophyll contents, oxidative stress indicators, activity of antioxidant enzymes (POD, CAT, APX and SOD) and K⁺/Na⁺ ratio. The results also disclose that response of wheat genotypes against methyl jasmonate application under saline condition show a concentration effect and varietal diversity. Moreover, the application of 100µM methyl jasmonate under low and elevated salt concentration shows prominent response towards wheat genotype Faislabad-2008 while least response was observed in wheat genotype Victoria.

Keywords: antioxidant enzymes; K⁺/Na⁺ ratio, methyl jasmonate, photosynthetic rate, wheat, relative water contents

*e-mail: iftikharahmedifi@gmail.com*
Introduction

Soil salinization is a global issue that threatens crop growth and productivity, as well as the long-term viability of modern agriculture. Salinity affects more than one-third of the world’s irrigated land. Salinization is caused by rising groundwater levels with high salt content, as well as inefficient drainage and irrigation systems [1]. Plant growth and development are hampered by salinity stress, which imposes many primary restrictions. The first restriction is osmotic stress, which harms plants capacity to absorb water by reducing the external water potential [2]. Salt stress has a significant negative impact on crop performance, biochemical alterations and physiology, resulting in decreased seed germination, fresh and dry biomass, photosynthesis and mineral nutrient accumulation [3-6]. Biochemical alterations occur when plants are subjected to the detrimental effects of reactive oxygen species (ROS) in a saline environment which resulting in growth seizure and metabolic damage [7]. Antioxidant enzymes (CAT, SOD and POD) and nonenzymatic antioxidants (tocopherols, ascorbate and phenolic compounds) have boosted their activity, which protecting plants from salt-induced reactive oxygen species [8]. Wheat (Triticum aestivum L.) is a key staple food that is cultivated in ninety countries [9]. Wheat is the sole food available in many nutrient-deficient areas across the world [10]. Global food production has increased by several times in comparison to the past, yet the slow pace of agricultural progress is insufficient to meet the needs of the world fast-growing population. Wheat is responsible for 30% of world grain output and 45% of cereal nutrients [11]. It is grown all across the world and accounts for around one-sixth of all arable land. Among all the grains cultivated in Pakistan, it ranks top in terms of both acreage and output. In 2010-11, Pakistan produced 24214 thousand tonnes of wheat and had an area under cultivation of 8805 thousand hectares [12]. Soil characteristics and water availability have an impact on wheat growth [13]. Wheat is a moderately salt-resistant crop with large genotypic differences in salinity tolerance [14]. Wheat is one of the most important crops for provision of daily protein and calorie demands of the people [15]. Wheat productivity in Pakistan is poor in salt-affected regions, with yield losses as high as 65% in moderately saline-soils [16].

Methyl jasmonate (MeJA) is a cellular regulator that plays a role in a variety of developmental processes, including seed sprouting, root growth, fertilization, fruit maturing and senescence [17]. They stimulate plant protection mechanisms in response to insect-caused wounds, pathogens, and environmental challenges such as drought, chilling injuries and salt stress [18]. Under salinity stress, jasmonates restored salt restriction on maize dry mass production [19] and reduced the inhibitory impact of NaCl and improve antioxidant activities in strawberries plants [20]. MeJA has been shown to reduce the adverse effect of salt and water stress in a variety of agricultural plants, including cowpea, alfalfa, tomato, chilies and broccoli [21-25]. The objective of the current study was to better understand the morpho-physiological responses of salt-resistant and salt-sensitive wheat genotypes to a saline environment, as well as to alleviating the effects of methyl jasmonate on plant growth and physiology, improve nutrition, water relations, and gas exchange characteristics, and enhance antioxidant enzyme activities in wheat exposed to salinity stress. We want to know if these wheat genotypes have similar salinity adaptation mechanisms, and if so, what are the primary susceptible or tolerant features in these genotypes. Does methyl jasmonate help to improve these qualities in wheat genotypes that have been exposed to salt stress?

Material and Methods

Experimental Site and Growth Conditions

A Hydroponic experiment was conducted in a rain protected wire house at Soil Salinity Laboratory, The Islamia University of Bahawalpur, Pakistan. In moist sand culture, seed of two salt resistant wheat genotypes (Faisalabad-2008, Anaj-17) and two salt susceptible wheat genotypes (Gandum-09 and Victoria) were sown. Uniform seedlings at two leaf stage were transplanted to thermopole sheet in 50-liter capacity iron tubs having half strength Hoagland solution as a nutrient media [26]. The desired salinity levels (control, 100 and 200 mM) were attained by adding the appropriate quantity of NaCl, while methyl jasmonate was supplied at 50 and 100 µM L⁻¹. The study used a complete randomized design with split plot layouts, with each treatment being repeated four times. The following treatments were used: (T₁) control, (T₂) 100 mM NaCl L⁻¹, (T₃) 200 mM NaCl L⁻¹, (T₄) 100 mM NaCl + 50 µM L⁻¹ methyl jasmonate, (T₅) 100 mM NaCl + 100 µM L⁻¹ methyl jasmonate, (T₆) 200 mM NaCl + 50 µM L⁻¹ methyl jasmonate, (T₇) 200 mM NaCl + 100 µM L⁻¹ methyl jasmonate. Aeration pumps were used to deliver oxygen to the plants. The pH of the solution was regularly monitored and regulated at 6.0±0.5 every day.

Plant Growth Measurement

The plants were harvested at vegetative stage and root and shoot lengths, as well as fresh and dry weight were measured according to standard procedures.

Root Traits

Root attributes (root surface area, root volume, root diameter and number of root tips) were determined by utilizing a root scanner by extract fresh roots from each plant (Win RHIZO Pro, STD, 2017, Netherland).
Leaf Area and Chlorophyll Content (SPAD)

The leaf area was determined by using a leaf area meter. Fully enlarged leaves from all treatments were used for this purpose. The leaf area was measured in cm² (Win FOLIA Pro, STD, 2016, Netherland). Using a SPAD meter, the chlorophyll contents (SPAD values) of fresh plant leaves were determined at vegetative stage (Minolta, Japan).

Measurements of Gas Exchange Characteristics

On a fully expanded youngest leaf, a portable LCA-4 ADC open system infrared gas analyzer was used to quantify net photosynthetic rate (A), transpiration rate (E), stomatal conductance (Gs) and sub-stomatal CO₂ concentration (Ci) at vegetative stage of plants. From 10 A.M. until 2 P.M., the following specifications/adjustments were utilized to collect these measurements: The leaf chamber temperature (Tch) ranged from 39.2 to 43.9ºC, the leaf chamber volume gas flow rate (v) 396 mL min⁻¹, the leaf chamber molar gas flow rate (U) 251 mol S⁻¹, the ambient pressure (P) 99.95 kPa, the molar flow of air per unit leaf area (Us) 221.06 mol m⁻² S⁻¹ and the PAR (Qleaf) at the leaf surface peaked at 918 µmol m⁻².

Relative Water Contents

After acquiring fresh, dry and turgid weight, RWC was measured using the technique of [27]; after selecting fully expanded youngest leaves of each treatment.

\[
\text{RWC (\%) = } \frac{(\text{Fresh weight- Dry weight})}{(\text{Turgid weight- Dry weight}) \times 100}
\]

Membrane Stability Index

The membrane stability index was calculated using Sairam’s approach [28]. In test tubes containing double distilled water, 0.1g leaf discs of all treatments were placed. They were maintained at 40ºC in a water bath. The EC was measured after 30 minutes of incubation (C₁). The identical leaf sample was subsequently held in a water bath at 100ºC for 10 minutes and the EC was measured once more (C₂). The formula used was:

\[
\text{Membrane Stability Index } = \left[1 - \frac{C_1}{C_2}\right] \times 100
\]

Estimation of Proline Content

To quantify proline from freeze-dried leaves, sulfosalicylic (3%) and extraction buffers ninhydrin [29] were used. 0.04 g dried leaves were extracted with sulfosalicylic acid (3% w/v). The extract was centrifuged at 3000 g for 10 minutes. A 200mL supernatant aliquot was combined with 400mL of the reagent combination (1.25 g ninhydrin, 20Ml phosphoric acid, and 30 mL glacial acetic acid) and heated in sealed test tubes at 100ºC for 1 hour. The mixture was then allowed to cool. To each sample’s combination, exactly 4 mL of toluene was added. At 520 nm, a Cecil Aquarius CE 7200 Double Beam Spectrophotometer was used to calculate proline content. The results were expressed as millimoles per gramme of dry weight (mmol g⁻¹ DW).

Determination of MDA and H₂O₂

Jambunathan’s approach was used to determine the levels of lipid peroxidation (MDA) [30]. The supernatant was removed by centrifuging for fifteen minutes at 10,000 r with 0.25 g fresh leaves and 0.1% trichloroacetic acid, TCA (5mL). Absorbance at 532 nm and 600nm were removed for non-specific turbidity adjustments. The researchers employed a 0.25% blank sample (TBA) and a specific activity coefficient of 155 mM⁻¹ cm⁻¹ respectively. The concentrations of hydrogen peroxide (H₂O₂) were determined using Velikova’s technique [31].

Ionic Attributes

In dried and crushed shoot material (0.01 g), sodium (Na⁺) and potassium (K⁺) concentrations were determined. Using a Flame Photometer (BWB-XP, UK), the samples were digested with hydrogen peroxide and sulfuric acid, then heated at 350ºC until fumes were produced and the compound was colorless, as described by Wolf [32].

Biochemical Attributes

A 10 ml extraction buffer containing 50 mM phosphate, pH 7.8, 1 mM EDTA, 1 g polyvinylpyrrolidon (PVP) and 0.5% Triton X-100 was used to homogenize fresh leaf segments weighing 0.5 g. The homogenate was centrifuged at 12,000 rpm for 20 minutes, and the supernatant was used to test for SOD, POD, CAT and APX. At a temperature of 0-4ºC, all procedures were carried out [33].

Statistical Analysis

The statistics package Statistics 8.1 (Statistics, IL, USA) was used to analyze the data in this study and the results are provided in tables and graphs. The graph bars represent the average value of four replicates while the error bars represent the standard deviations. The honest significant difference (HSD) test was used to assess and analyze the source of variance with a 5% probability [34].
Results

Plant Biomass

Salt stress has been shown to divide wheat genotypes into two groups. Wheat genotypes Faisalabad-2008 and Anaj-17 (salt resistant) are in the first group, whereas wheat genotypes Gandum-09 and Victoria are in the second (salt susceptible). Wheat genotypes in the first group have longer roots and shoots, as well as fresh and dry biomass than genotypes in the second group (Table 1, 2 and 3). Wheat genotypes Victoria demonstrates the greatest decline in growth (66% and 72% root and shoot length, 64% and 70% root and shoot fresh weight, 65% and 75% root and shoot dry weight) when exposed to extreme salt stress (200 mM NaCl). As indicated in this study, salinity has a substantial impact on all wheat genotypes with wheat genotype Faisalabad-2008 exhibiting the highest growth at both salt levels. Under high salt stress, visual signs such as leaf tip burn were observed in wheat genotype Victoria, which proved to be the most salt sensitive of all wheat genotypes. When a high dose of methyl jasmonate (100 µM) was combined with 100 mM salt stress, the growth of both categories of wheat genotypes was significantly altered. A notable effect was observed in wheat genotypes Faisalabad-2008, 13% and 12% improvement in root and shoot length, 20% and 21% increase in root and shoot fresh weight and 18% and 20% increase in root and shoot dry weight.

Root Traits

Increased salt in the growing environment has a considerable detrimental influence on both types of wheat genotypes root characteristics (Table 4 and 5). Wheat genotypes Victoria had the lowest values in root surface area and root volume (64% and 61%) when exposed to a high level of salinity (200mM NaCl) while root diameter and number of root tips were reduced by 43% and 61% respectively when compared to control. As revealed in the current study, wheat genotypes Faisalabad-2008 respond eminently to low and high doses of exogenously applied methyl jasmonate, manifesting improved plant root surface area and root volume (20% and 21%), root diameter and number of root tips (22% and 21%) when subjected to 100µM methyl jasmonate with low salt stress (100mM NaCl) revealing its better tolerance towards salt stress. Between these two wheat genotypes, other wheat genotypes exhibit a decline.

Physiological Attributes

The results of the analysis (Fig. 1) of relative water contents, membrane stability index, chlorophyll contents (SPAD) and leaf area show that higher salt levels reduce plant water relations and membrane integrity in both groups of wheat genotypes, with wheat genotype Victoria showing the greatest reduction (45% RWC, 10.3±0.5% MFI, 11.1±0.7 SPAD, 23.2±1.5 leaf area) compared to control.
Table 2. Effect of exogenously applied methyl jasmonate on shoot and root fresh weight of four wheat genotypes under salt stress. Each value represents the average of four replicates and column not sharing the same letter differ significantly at 0.05 probability level.

| Treatments       | Shoot Fresh Weight (g plant⁻¹) | Root Fresh Weight (g plant⁻¹) |
|------------------|---------------------------------|-------------------------------|
|                  | FSD-2008 Anaj Gandum Victoria | FSD-2008 Anaj Gandum Victoria |
| Control          |                                |                               |
| 50±2.9 a         | 48±2.8 ab 45±2.7 cd 46±2.8 bc | 6.6±0.36 a 6.1±0.36 b 5.2±0.31 d 5.8±0.25 bc |
| S1 = 10 mM NaCl  |                                |                               |
| 36±2.1 gh        | 35.1±2.1 h 23.8±1.5 mn 23.1±1.3 n | 4.5±0.28 fg 4.45±0.27 g 3.38±0.20 k 3.45±0.21 k |
| S2 = 200 mM NaCl |                                |                               |
| 29±1.7 ij        | 28.8±1.7 jk 12.2±0.74 o 13.6±0.8 o | 3.82±0.22 hij 3.6±0.22 jk 1.8±0.10 m 2.05±0.13 lm |
| S1 + 50 µM MeJA  |                                |                               |
| 39.2±2.3 f       | 37.9±2.3 fg 25.4±1.5 lmn 24.4±1.4 lmn | 5.1±0.30 de 4.8±0.28 ef 3.6±0.21 jk 3.6±0.21 jk |
| S2 + 50 µM MeJA  |                                |                               |
| 30.4±1.8 ij      | 30.2±1.8 ij 12.5±0.8 o 14.1±0.8 o | 4.0±0.25 hi 3.7±0.22 ijk 1.82±0.11 m 2.1±0.13 lm |
| S2 + 100 µM MeJA |                                |                               |
| 31.3±1.9 i       | 31.1±1.9 ij 12.9±0.8 o 14.4±0.9 o | 4.1±0.25 h 3.8±0.23 hi 1.9±0.13 lm 2.2±0.15 l |

Table 3. Effect of exogenously applied methyl jasmonate on shoot and root dry weight of four wheat genotypes under salt stress. Each value represents the average of four replicates and column not sharing the same letter differ significantly at 0.05 probability level.

| Treatments       | Shoot Dry Weight (g plant⁻¹) | Root Dry Weight (g plant⁻¹) |
|------------------|------------------------------|------------------------------|
|                  | FSD-2008 Anaj Gandum Victoria | FSD-2008 Anaj Gandum Victoria |
| Control          |                                |                               |
| 6.9±0.40 a       | 6.1±0.35 b 5.3±0.28 d 5.9±0.24 e | 1.51±0.11 ab 1.57±0.12 a 1.4±0.09 c 1.44±0.1 bc |
| S1 = 100 mM NaCl |                                |                               |
| 4.9±0.24 f       | 4.4±0.24 h 2.7±0.13 o 2.4±0.12 d | 1.1±0.06 fg 1.14±0.07 fg 0.78±0.05 p 0.79±0.05 op |
| S2 = 200 mM NaCl |                                |                               |
| 4.1±0.21 j       | 3.6±0.18 l 1.5±0.08 qp 1.4±0.07 r | 0.87±0.05 mn 0.94±0.06 klm 0.42±0.02 q 0.47±0.04 q |
| S1 + 50 µM MeA   |                                |                               |
| 5.3±0.27 d       | 4.7±0.23 g 2.9±0.15 n 2.5±0.12 p | 1.19±0.07 ef 1.23±0.07 f 0.83±0.05 nop 1.02±0.06 hij |
| S2 + 50 µM MeA   |                                |                               |
| 5.8±0.29 c       | 5.3±0.28 d 3.1±0.17 m 2.7±0.13 o | 1.32±0.08 d 1.37±0.08 cd 0.87±0.05 mn 1.09±0.07 ghi |
| S2 + 100 µM MeA  |                                |                               |
| 4.2±0.22 ij      | 3.7±0.19 k 1.54±0.09 qr 1.44±0.08 qr | 0.91±0.06 lmn 0.98±0.05 jkl 0.43±0.03 q 0.48±0.05 q |
| S2 + 100 µM MeJA |                                |                               |
| 4.3±0.24 hi      | 3.8±0.24 k 1.59±0.10 q 1.48±0.09 qr | 0.93±0.06 klm 1.01±0.06 ijk 0.44±0.03 q 0.49±0.05 q |
### Table 4. Effect of exogenously applied methyl jasmonate on root surface area and root volume of four wheat genotypes under salt stress. Each value represents the average of four replicates and column not sharing the same letter differ significantly at 0.05 probability level.

| Treatments                  | FSD-2008 Root Surface Area (cm²) | Anaj Root Surface Area (cm²) | Gandum Root Surface Area (cm²) | Victoria Root Surface Area (cm²) | FSD-2008 Root Volume (cm³) | Anaj Root Volume (cm³) | Gandum Root Volume (cm³) | Victoria Root Volume (cm³) |
|-----------------------------|----------------------------------|------------------------------|-------------------------------|---------------------------------|---------------------------|------------------------|-------------------------|--------------------------|
| Control                     | 245±12.4 a                       | 237±10.4 a                   | 232±11.7 b                    | 230±10.3 b                      | 18.3±1.1 b                | 19.1±1 a               | 16.9±0.8                | 17.1±0.9 c               |
| S1 = 100 mM NaCl            | 174±8.5 ef                       | 171±8.1 fg                   | 148±7.3 ijk                   | 145±7.4 jk                      | 12.6±0.7 g                | 13.4±0.6 f              | 10.6±0.6                | 10.6±0.5 lm              |
| S2 = 200 mM NaCl            | 140±7.1 k                        | 141±7.1 k                    | 79±3.9 l                      | 85±4.3 l                        | 10.1±0.6 m                | 11.1±0.6 jkl            | 5.5±0.3                 | 6.1±0.3 nop              |
| S1 + 50 µM MeJA             | 189±9.5 d                        | 184±9.5 de                   | 159±8.2 hi                    | 153±7.8 hij                      | 13.8±0.6 f                | 14.6±0.7 e              | 11.4±0.6                | 11.3±0.6 ijk             |
| S1 + 100 µM MeJA            | 208±10.5 c                       | 206±10.2 c                   | 163±8.5 gh                    | 164±8.8 fgh                      | 15.2±0.8 e                | 16.3±0.8 d              | 11.9±0.6                | 12.1±0.6 gh              |
| S2 + 50 µM MeJA             | 146±7.7 jk                       | 142±7.2 k                    | 88±4.7 l                      | 81±4.2 l                        | 10.6±0.5 lm               | 11.6±0.6 hij            | 5.6±0.3                 | 6.2±0.3 no               |
| S2 + 100 µM MeJA            | 150±7.1 ijk                      | 143±7.7 k                    | 90±5.11                       | 83±4.3 l                        | 10.9±0.6 kl               | 11.9±0.6 gh             | 5.8±0.4                 | 6.4±0.3 n                |

### Table 5. Effect of exogenously applied methyl jasmonate on root diameter and number of root tips of four wheat genotypes under salt stress. Each value represents the average of four replicates and column not sharing the same letter differ significantly at 0.05 probability level.

| Treatments                  | FSD-2008 Root Diameter (mm) | Anaj Root Diameter (mm) | Gandum Root Diameter (mm) | Victoria Root Diameter (mm) | FSD-2008 Number of Root Tips | Anaj Number of Root Tips | Gandum Number of Root Tips | Victoria Number of Root Tips |
|-----------------------------|-----------------------------|-------------------------|---------------------------|----------------------------|-----------------------------|-------------------------|--------------------------|-----------------------------|
| Control                     | 3.92±0.20 a                 | 3.73±0.17 b             | 3.45±0.13                 | 3.51±0.18 a                 | 4620±226 a                 | 4570±218 a              | 4350±217 b               | 4310±215 b                 |
| S1 = 100 mM NaCl            | 2.74±0.14 f                 | 2.76±0.14 fg             | 2.27±0.12                 | 2.28±0.12 f                 | 3230±164 e                | 3199±157 ef            | 2827±136 ij              | 2758±138 jk               |
| S2 = 200 mM NaCl            | 2.23±0.12 k                 | 2.31±0.12 jk             | 1.29±0.07                 | 1.33±0.07 k                 | 2587±130 mm               | 2513±126 n            | 1609±79 q              | 1680±85 pq               |
| S1 + 50 µM MeJA             | 2.98±0.15 e                 | 2.99±0.15 e              | 2.42±0.12                 | 2.41±0.13 e                 | 3488±164 d                | 3422±167 d            | 2968±134 gh             | 2895±140 hi              |
| S1 + 100 µM MeJA            | 3.34±0.16 cd                | 3.33±0.16 d              | 2.54±0.13                 | 2.57±0.14 cd                | 3908±190 c                | 3870±185 c            | 3110±157 f              | 3006±157 g               |
| S2 + 50 µM MeJA             | 2.34±0.12 ijk               | 2.42±0.13 hij            | 1.32±0.07                 | 1.36±0.08 ijk               | 2715±135 kl               | 2638±135 lm            | 1657±79 pq              | 1730±86 op               |
| S2 + 100 µM MeJA            | 2.40±0.13 hij               | 2.49±0.13 hi             | 1.36±0.08                 | 1.40±0.07 hij               | 2793±142 jk               | 2715±134 kl            | 1689±85 opq             | 1780±89 o                |
In terms of chlorophyll concentration and leaf area, all wheat genotypes follow a parallel pattern, with lower values as salt level increases. When compared to other wheat genotypes described in this trial, Faislabad-2008 reacts admirably to methyl jasmonate and exhibits enhanced RWC, MSI, chlorophyll and leaf area contents.

**Gas Exchange Attributes**

Salt stress in the growth medium has a significant detrimental influence on the gas exchange characteristics of both wheat genotypes (Fig. 2). Wheat genotypes Victoria had the lowest photosynthetic rate and transpiration rate (69% and 67%) when exposed to a high level of salinity (200 mM NaCl), while stomatal conductance and internal CO₂ concentration were reduced by 56 and 54% respectively when compared to control. Wheat genotypes Faislabad-2008 respond prominently to low and high doses of exogenously applied methyl jasmonate, as showed in the current study and exhibit enhanced plant photosynthetic and transpiration rate (15 and 17%) and other gas exchange characteristics when exposed to 100 µM methyl jasmonate with low salt stress (100 mM NaCl), revealing its better tolerance towards salinity stress. Between these two wheat genotypes, other wheat genotypes exhibit a decline.

**Oxidative Stress Indicators**

Effects of NaCl and methyl jasmonate on MDA, H₂O₂ and proline levels in four wheat genotypes shown in Fig. 3. When compared to control, salinity treatment resulted in significant increases in MDA, H₂O₂ and proline contents in all four Wheat genotypes, but this pattern is reduced at low salt stress (100mM NaCl) in both salt resistant wheat genotypes (Faislabad-2008 and Anaj-17) and more prominent at high salinity stress in both salt susceptible wheat genotypes (Gandum-09 and Victoria). In comparison to plants grown in low salinity level at 100 mM, high level of methyl jasmonate (100 µM) application reduced the concentration of MDA, H₂O₂ and proline in the plants by 11%, 13% and 18% in the wheat genotype Faislabad-2008 plants and by 7%, 6% and 9% in the wheat genotype Victoria plants when exposed to salinity level at 100 mM.
The result depicts plant exposure to salt stress and methyl jasmonate as well as their interaction on potassium and sodium concentrations and the K+/Na+ ratio as shown in Fig. 4. The K+/Na+ ratio of all wheat genotypes was strongly altered by increasing salinity stress, and wheat genotypes Victoria with the greatest Na+ content was found. Victoria appears to be the most sensitive wheat genotypes to salinity at both levels of salinity. Wheat genotypes Faisalabad-2008 and Anaj-17 exhibited the highest tendency to retain K+ in the leaves across all treatments and the highest K+ levels were seen in these genotypes. Methyl jasmonate supply at 100 µM in the presence of 100mM salt stress highlighted a critical mechanism governing Na+ and K+ concentrations, resulting in an enhanced K+/Na+ ratio in wheat genotypes Faisalabad-2008 compared to all other genotypes.

**Antioxidant Enzymes**

Salinity stress decreased antioxidant enzyme activity compared to the control, notably in salt susceptible wheat genotypes compared to salt resistant wheat genotypes (Fig. 5). Wheat genotypes at high saline level (200mM NaCl) showed a 58% decrease in POD, which functions as a first barrier for the removal of ROS, which resulted in a 57% drop in APX and 55 and 61% reductions in SOD and CAT respectively which successfully resist hydrogen peroxide buildup in plants. Under both levels of salt stress, exogenously provided methyl jasmonate (100µM) enhanced plant growth and physiology while also increasing the biochemical activities and reducing the impairment caused by oxidative stress in wheat. A distinguished increase in these protective enzyme's concentration was found in wheat genotypes Faisalabad-2008 and Anaj-17.

**Discussion**

Agricultural plant productivity is dramatically declined by increased salt stress in the growth medium causes a drop in plant growth attributes such as physiological features, biochemical and gas exchange properties and ion hemostasis [35, 36]. Methyl jasmonate provision considerably reduces the
harmful effects of salt because of its acclimating role in modifying morpho-physiological features, mineral nutrition and antioxidant defense mechanisms, methyl jasmonate provision considerably reduces the harmful effects of salt [37, 38]. The greater concentrations of Na$^+$ and Cl$^-\$ in the growth medium affect membrane stability, interrupt photosynthetic action and assemble toxic ions at the tissue level resulting in an imbalance in nutrient uptake, suspend cell division and produce reactive oxygen species (ROS) all of which significantly reduce plant biomass [39]. Plant physiological properties such as photosynthetic rate, transpiration rate and stomatal opening and shutting are all affected by high levels of Na$^+$ ions in the soil [40]. Under some stresses,
a decreased in photosynthetic activity and a restriction in the intake of necessary nutrients leads to a shortage of critical metabolites [41]. Provision of methyl jasmonate improves plant physiology in a salt-stressed environment by reducing Na$^+$ inflow, up-regulating the antioxidant defense system, enhancing photosynthetic rate-related leaf ultra-structure and increasing ribulose biphosphate carboxylase activity [42]. Furthermore, by modifying the efflux flow of Na$^+$ in the roots of salt treated plants, methyl jasmonate leads to improved agricultural plant development by regulating increased salt concentrations [43]. According to a previous study done by Avalbaev methyl jasmonate supplementation can ameliorate the negative effects of salt toxicity on wheat cultivar development [44]. As shown in the current study, salt stress modifies plant cell physiology by disrupting plant water relations, deteriorating membrane stability and lowering chlorophyll concentration. When comparing wheat genotypes Victoria and Faislabad-2008, this decline is more pronounced. Plant water potential and ion toxicity are intimately linked to plant water content and membrane stability. They are the most important indication for evaluating genotype performance under various forms of abiotic stress. The rising trend of NaCl in the growth medium significantly lowers the RWC and MSI resulting in decreased water absorption by the plant, leaf succulence and cell membrane damage due to scratched membrane-associated fatty acids [45]. Under high salt stress, because of metabolic changes, disruption in hormonal balance at the molecular level, stomata closing and changes in the creation of pigments involved in plant life sustenance such as chlorophyll, leaves develop chlorosis and eventually fall resulting in lower chlorophyll contents [46]. Methyl jasmonate nourishment significantly increased plant water content by improving plant root growth and ability absorb more water from the growth channel and flow from bottom to top, stable osmotic alteration, regulating transpiration rate with stomatal conductance and regulating plant water potential [47]. By functioning as a scavenger against H$_2$O$_2$ and O$_2^-$, methyl jasmonate improved antioxidant machinery and maintained ROS balance at the cellular level, promoting membrane integrity and permeability [48]. Provision of methyl jasmonate not only improves the absorption of certain plant nutrients but also promotes the translocation of magnesium (Mg) which is the primary component of chlorophyll synthesis in plant shoots [49].

Fig. 5. Effect of exogenously applied methyl jasmonate on biochemical attributes such as a) Superoxide dismutase activity, b) Peroxidase activity, c) Catalase activity and d) Ascorbate peroxidase activity of four wheat genotypes under salt stress. The bar values depict the average of three replications and the bars not sharing the same lowercase letters differ significantly from each other according to the HSD test at $P < 0.05$ probability level.
Salt-induced oxidative damage in wheat (Fig. 3), may be responsible for plasma membrane rupture, electrolyte leakage, lipid peroxidation and nutrient uptake inhibition as seen by higher oxidative stress markers (MDA and H$_2$O$_2$) under salinity stress [50]. These findings are consistent with those of [51], who found oxidative stress in wheat in a saline environment. Lower Na$^+$ absorption greater plasma membrane stability and decreased exposure of wheat plant roots to a salty environment might all contribute to a considerable drop in MDA and H$_2$O$_2$ following methyl jasmonate treatment. Under the influence of salt stress, a variety of physiological indicators can reveal information on the lowering of gas exchange properties. The decreased in photosynthetic and transpiration rate, as well as stomatal conductance was seen in our experiment with an increasing trend of Na$^+$, with wheat genotypes Victoria showing the greatest drop when compared to wheat genotype Faislabad-2008. It might be owing to the plant response to altered water contents and low water availability in the rhizosphere due to salt which was triggered by changing stomata packing [52]. The administration of methyl jasmonate under saline circumstances had no significant effect on internal CO$_2$ content, which might be related to differences in stress duration and severity, plant development stage and plant species. Exogenously provision of methyl jasmonate improved chlorophyll activity and water availability by adjusting osmotic pressure, stopping chlorophyll breakdown and lowering H$_2$O$_2$ production in leaves [53].

Due to its role in nutrient availability, feasible absorption and transport within the plants, soil salinity causes a nutritional imbalance in wheat [54]. The plasma membrane's existence of Na$^+$ transport channels allow it to enter the cell [55]. The plant cell's ability to retain K$^+$ is a key aspect in improving plant stress tolerance. Reduced K$^+$ uptake in a saline environment might be related to nutritional imbalance and competitive uptake of Na$^+$ and Cl$^-$ with specific nutrients like K$^+$, Mn$^{2+}$ and Ca$^{2+}$ [56]. In plants, a lower Na$^+/K^+$ ratio aids salt-tolerant genotypes in performing well in saline environments and sustaining cellular metabolism by boosting protein synthesis, controlling enzyme activation, photosynthetic activity, osmoregulation and enhanced cell turgor [57]. In the current study, wheat plants treated with methyl jasmonate had higher K$^+$ levels in their shoots than those not treated with methyl jasmonate, as previously reported [58]. This elevated K$^+$ concentration can be attributable to a rise in root plasma membrane H-ATPase pumps when methyl jasmonate is applied. Under salt stress, methyl jasmonate might reduce Na$^+$ loading in roots, while increased Na$^+$ retrieval from shoots resulted in higher K$^+$ accumulation, osmotic balance and ionic ratio, as well as a decline in Na$^+/K^+$ ratio [59]. Excessive production of reactive oxygen species (ROS) in plants is toxic and damages subcellular apparatuses and DNA, resulting in cell death [60]. By efficient destruction induced by O$_3$ and H$_2$O$_2$ in the chloroplast and cytoplasm of the plant cell, salinity affected the quantity and activity of antioxidant enzymes in scavenging ROS [61]. Methyl jasmonate has also been shown to operate as an antioxidant, enhancing the activities of superoxide dismutase (SOD), ascorbate peroxidase (APX) and peroxidase (POD) in the leaves of various agricultural plants, which act as the primary line of defense in the photosystem I to decrease ROS generation [62]. Our data imply that the addition of methyl jasmonate to all wheat genotypes influences the facilitation of antioxidant enzyme activities, perhaps protecting plant tissues from oxidative membrane damage and modifiable ROS scavenging enzymes in a salt medium.

**Conclusions**

Wheat genotypes that are subjected to salt stress exhibit interrupted growth, poor plant water relations, membrane destabilization, excessive cellular Na$^+$ levels, decreased photosynthetic activity, as well as oxidative damage. Exogenous treatment of methyl jasmonate performed a multifunctional effect in enhancing salt tolerance in wheat genotypes, according to an increase in plant biomass, increased water contents, higher K$^+$/Na$^+$ ratio, gas exchange characteristics, and antioxidant enzyme activity. Wheat genotype Faislabad-2008 has the greatest K$^+$/Na$^+$ ratio and maximum stress-resistance antioxidant enzyme activities, as well as enhanced morpho-physiological properties, allowing for the designation of salt tolerance when subjected to methyl jasmonate at a concentration of 100 µM. Contrarily, among all the wheat genotypes tested in saline environment, Victoria responds the least favorably to the treatment of methyl jasmonate. Our findings can aid scientists investigating saline agriculture by illuminating the efficacy of methyl jasmonate in preventing salt stress and presenting fresh opportunities for its use in farming.

**Acknowledgments**

Authors are highly thankful to Soil Salinity Laboratory, Department of Soil Science, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur, 63100, Pakistan for providing research facilities for a part of doctoral study and also thankful to reviewers for the improvement of the manuscript. The authors are also highly thankful to Higher Education Commission (HEC) for providing funding under the PhD Fellowship for 5000 Scholars, Phase II, Batch VI (Pin No. 520-148726-2AV6-045).

**Conflict of Interest**

The authors declare no conflict of interest.
References

1. HAFEZ E.M., OMARA A.E.D., ALHUMAYDHI F.A., EL-ESAWI, M.A. Minimizing hazard impacts of soil salinity and water stress on wheat plants by soil application of vermicompost and biochar. Physiologia Plantarum, 172 (2), 587, 2021.

2. ZAMAN M., SHAHID S.A., HENG L. Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques. Springer Nature, Cham, Switzerland, 1, 164, 2018.

3. LUO R., LI M., WANG C., ZHANG M., NASIR KHAN M.A., SUN X., LI J. Singlet oxygen-dominated non-radical oxidation process for efficient degradation of bisphenol A under high salinity condition. Water Research, 148, 416, 2019.

4. GARCIA-PASTOR M.E., SERRANO M., GUILLEN F., GMENEZ M.I., MARTINEZ-ROMERO D., VALERO D., ZAPATA P.I. Preharvest application of methyl jasmonate increases crop yield, fruit quality and bioactive compounds in pomegranate ‘Mollar de Elche’ at harvest and during postharvest storage. Journal of the Science of Food and Agriculture, 100 (1), 145, 2020.

5. HESSINI K., ISSAOUI K., FERCHICHI S., SAIF T., ABDELLY C., SIDIQI K.H.M., CRUZ C. Interactive effects of salinity and nitrogen forms on plant growth, photosynthesis and osmotic adjustment in maize. Plant Physiology and Biochemistry, 139 (March), 171, 2019.

6. GHORBANI A., OMIRAN V.O.G., RAZAVI S.M., PIRDASHTI H., RANJBAR M. Piriformospora indica confers salinity tolerance on tomato (Lycopersicon esculentum Mill.) through amelioration of nutrient accumulation, K/Na homeostasis and water status. Plant Cell Reports, 38 (9), 1151, 2019.

7. KHAN A., BILAL S., KHAN A.L., IMRAN M., AL-HARRASI A., AL-RAWAHI A., LEE I.J. Silicon-mediated alleviation of combined salinity and cadmium stress in date palm (Phoenix dactylifera L.) by regulating physio-hormonal alteration. Ecotoxicology and Environmental Safety, 188 (October 2019), 109885, 2020.

8. BHARTI N., BARNAWAL D. Amelioration of Salinity Stress by PGPR: ACC Deaminase and ROS Scavenging Enzymes Activity. PGPR Amelioration in Sustainable Agriculture, Amit Kishore Singh, Ajay Kumar and Pawan Kumar Singh, Elsevier, Amsterdam, Netherlands, 1, 85, 2019.

9. KOUSAR P., ALI L., RAZA A., MAQBOOL A., MAQBOOL S., IRUM N. Effect of different levels of nitrogen on the economic yield of Wheat (Triticum aestivum L.) variety Aas-11 Department of Botany, Govt. Sadiq College Women University Bahawalpur , Pakistan, 6 (3), 7, 2015.

10. JANGIR H., BHARADWAJ A., SRIVASTAVA G., DAS M. Fertilizer-free cultivation of wheat in nutrient-deficient soil by treating the seeds with nanopyrite. Nanotechnology for Environmental Engineering, 5 (1), 1, 2020.

11. CHARMET G. Wheat domestication: Lessons for the future. Comptes Rendus - Biologies, 334 (3), 212, 2011.

12. ALI S., LIU Y., ISHAQ M., SHAH T., ABDULLAH ILYAS A., DIN I.U. Climate change and its impact on the yield of major food crops: Evidence from pakistan. Foods, 6 (6), 1, 2017.

13. IQBAL J., HAYAT K., HUSSAIN S., ALI A., BAKHSH M.A.A.H.A. Effect of seeding rates and nitrogen levels on yield and yield components of wheat (Triticum aestivum L.). Pakistan Journal of Nutrition, 11 (7), 531, 2012.

14. AHMAD M., MUNIR M., SHAHZAD A., SHAHID MASOOD M., IQBAL M. Evaluation of bread wheat genotypes for salinity tolerance under saline field conditions. African Journal of Biotechnology, 10 (20), 4086, 2011.

15. HENCHION M., HAYES M., MULLEN A.M., FENELON M., TIWARI B. Future protein supply and demand: Strategies and factors influencing a sustainable equilibrium. Foods, 6 (7), 1, 2017.

16. SHAFI M., BAKHT J., KHAN M.J., KHAN M.A., ANWAR S. Effect of salinity on yield and ion accumulation of wheat genotypes. Pakistan Journal of Botany, 42 (6), 4113, 2010.

17. SHAFI M., BAKHT J., KHAN M.J., KHAN M.A., ANWAR S. Effect of salinity on yield and ion accumulation of wheat genotypes. Pakistan Journal of Botany, 42 (6), 4113, 2010.

18. YU X., ZHANG W., ZHANG Y., LANG D., ZHANG X. The roles of methyl jasmonate to stress in plants. Functional Plant Biology, 46 (3), 197, 2019.

19. TAYYAB N., NAZ R., YASMIN H., NASHEEN A., KEYANI R., SAJJAD M., ROBERTS T.H. Combined seed and foliar pre-treatments with exogenous methyl jasmonate and salicylic acid mitigate drought-induced stress in maize. PLoS ONE, 15 (5), 1, 2020.

20. KUMAR A., SINGH S., GAURAV A.K., SRIVASTAVA S., VERMA J.P. Plant Growth-Promoting Bacteria: Biological Tools for the Mitigation of Salinity Stress in Plants. Frontiers in Microbiology, 11 (July), 1, 2020.

21. SADEGHIPOUR O. Amelioration of salinity tolerance in cowpea plants by seed treatment with methyl jasmonate. Legume Research, 40 (6), 1100, 2017.

22. GHASEM F., POUSTINI K., BEHSHARATI H., MOHAMMADI V.A., ABOOEI M.F., GOETTFERT M. Pre-incubation of sino rhizobium meliloti with luteolin, methyl jasmonate and genistein affecting alfalfa (Medicago sativa L.) Growth, nodulation and nitrogen fixation under salt stress conditions. Journal of Agricultural Science and Technology, 14 (6), 1255, 2012.

23. MANAN A., AYYUB C.M., PERVEZ M.A., AHMAD R. Methyl jasmonate brings about resistance against salinity stressed tomato plants by altering biochemical and physiological processes. Pakistan Journal of Agricultural Sciences, 53 (1), 35, 2016.

24. TZORTZAKIS N., CHRYSA GYRIS A., SIVAKUMAR D., LOULAKAKIS K. Vapour or dipping applications of methyl jasmonate, vinegar and sage oil for pepper fruit sanitization towards grey mould. Postharvest Biology and Technology, 118, 120, 2016.

25. LUO F., CAI J.H., ZHANG X., TAO D.B., ZHOU X., ZHOU Q., JI S.J. Effects of methyl jasmonate and melatonin treatments on the sensory quality and bioactive compounds of harvested broccoli. RSC Advances, 8 (72), 41422, 2018.

26. HOAGLAND D.R., ARNON D.I. The water-culture method for growing plants without soil. Circular. California Agricultural Experiment Station, 347 (2), 32, 1950.

27. LAZCANO-FERRAT I., LOVATT C.J. Relationship between relative water content, nitrogen pools, and growth of Phaseolus vulgaris L. and P. acutifolius A. Gray during water deficit. Crop Science, 39 (2), 467, 1999.

28. SAIRAM RK., SAXENA D.C. Oxidative stress and antioxidative mechanisms in wheat genotypes: possible mechanism of
water stress tolerance. Journal of Agronomy and Crop Science, 184, 55, 2000.
29. BATES R.P., WALDREN I.D., PLANT S., AUGUST N. Rapid determination of free proline for water-stress studies Author Teare Published by: Springer Stable, 39 (1), 205, 2016.
30. JAMBUNATHAN N. Determination and detection of reactive oxygen species (ROS), lipid peroxidation, and electrolyte leakage in plants. In Plant Stress Tolerance, 639, 291, 2010.
31. VELIKOVA V., YORDANOV I.A. Oxidative stress and some antioxidant systems in acid rain treated bean plants: protective roles of exogenous polyamines. Plant Science, 151 (1), 59, 2000.
32. WOLF B.A. Comprehensive system of leaf analyses and its use for diagnosing crop nutrient status. Communications in Soil Science and Plant Analysis, 13 (12), 1035, 1982.
33. NAHAR K., HASANUZZAMAN M., ALAM M.M., FUJITA M. Exogenous glutathione confers high temperature stress tolerance in mung bean (Vigna radiata L.) by modulating antioxidant defense and methylglyoxal detoxification system. Environmental and Experimental Botany, 112, 44, 2015.
34. STEEL R.G.D., TORRIE J.H.P. Principles and procedures of statistics. 1960.
35. KHAN M.A., SAHILE A.A., JAN R., ASAIF S., HAMAYUN M., IMRAN M., LEE I.J. Halotolerant bacteria mitigate the effects of salinity stress on soybean growth by regulating secondary metabolites and molecular responses. BMC Plant Biology, 21 (1), 1, 2021.
36. SAPRE S., GONTIA-MISHRA I., TIWARI S. Plant Growth-Promoting Rhizobacteria Ameliorates Salinity Stress in Banaba (Pithecolobium dulce) seedlings. Journal of Plant Growth Regulation, 41 (2), 647, 2022.
37. LIU R., WANG Z., ZHENG J., XU Z., TANG X., HUANG Z., LI T. The effects of methyl jasmonate on growth, gene expression and metabolite accumulation in Isatis indigotica Fort. Industrial Crops and Products, 177 (November 2021), 114482, 2022.
38. GHORBANI A., PISHKAR L., ROODBARI N., TAVAKOLI S.A., JAHROMI E.M., WU C. Nitrate Reductase is Needed for Methyl Jasmonate-Mediated Arsenic Tolerance of Rice by Modulating the Antioxidant Defense System, Glyoxalase System and Arsenic Sequestration Mechanism. Journal of Plant Growth Regulation, 3, 1, 2022.
39. RAHIMI E., NAZARI F., JAVADI T., SAMADI S., TEIXEIRA DA SILV, J.A. Potassium-enriched clinopodiumite zeolite mitigates the adverse impacts of salinity stress in perennial ryegrass (Lolium perenne L.) by increasing silicon absorption and improving the K/Na ratio. Journal of Environmental Management, 285 (October 2020), 112142, 2021.
40. TAO R., DING J., LI C., ZHU X., GUO W., ZHU M. Evaluating and Screening of Agro-Physiological Indices for Salinity Stress Tolerance in Wheat at the Seedling Stage. Frontiers in Plant Science, 12 (March), 1, 2021.
41. WANG Y., CHEN S., DENG C., SHI X., COTA-RUIZ K., WHITE J. C., GARDEA-TORRESDEY J.L. Metabolomic analysis reveals dose-dependent alteration of maize (Zea mays L.) metabolites and mineral nutrient profiles upon exposure to zerovalent iron nanoparticles. NanoImpact, 23 (March), 100036, 2021.
42. SALIMI F., SHEKARI F., HAMZEI J. Methyl jasmonate improves salinity resistance in German chamomile (Matricaria chamomilla L.) by increasing activity of antioxidant enzymes. Acta Physiologiae Plantarum, 38 (1), 2016.
43. TALEBI M., MOGHADDAM M., PIRBALOUTI A.G. Methyl jasmonate effects on volatile oil compounds and antioxidant activity of leaf extract of two basil cultivars under salinity stress. Acta Physiologiae Plantarum, 40 (2), 1, 2018.
44. AVALBAEV A., ALLAGULOVA C., MASLENNIKOVA D., FEDOROVA K., SHAKIROVA F. Methyl Jasmonate and Cytokinin Mitigate the Salinity-Induced Oxidative Injury in Wheat Seedlings. Journal of Plant Growth Regulation, 40 (4), 747, 2021.
45. SHAHZAD H., ULLAH S., IQBAL M., BILAL H.M., SHAH G.M., AHMAD S., AHMAD I. Salinity types and level-based effects on the growth, physiology and nutrient contents of maize (Zea mays). Italian Journal of Agronomy, 14 (4), 199, 2019.
46. WIBOWO F. Prediction of gene action content of Na, K, and Chlorophyll for Soybean Crop Adaptation to Salinity. JERAMI Indonesian Journal of Crop Science, 2 (1), 21, 2019.
47. TAVALLALIV., KARIMI S. Methyl jasmonate enhances salt tolerance of almond rootstocks by regulating endogenous phytohormones, antioxidant activity and gas-exchange. Journal of Plant Physiology, 234 (February), 98, 2019.
48. WANG H., WU Y., YU R., WU C., FAN G., LI T. Effects of postharvest application of methyl jasmonate on physicochemical characteristics and antioxidant system of the blueberry fruit. Scientia Horticulturae, 258 (June), 108785, 2019.
49. ESMAIELZADEH S., FALLAH H., NIKNEJAD Y., MAHMOUDI M., TARI D.B. Methyl jasmonate increases aluminum tolerance in rice by augmenting the antioxidant defense system, maintaining ion homeostasis, and increasing nonprotein thiol compounds. Environmental Science and Pollution Research, 29, 46708, 2022.
50. MOHSIN S.M., HASANUZZAMAN M., PARVIN K., FUJITA M. Pretreatment of wheat (Triticum aestivum L.) seedlings with 2,4-D improves tolerance to salinity-induced oxidative stress and methylglyoxal toxicity by modulating ion homeostasis, antioxidant defenses, and glyoxalase systems. Plant Physiology and Biochemistry, 152 (April), 221, 2020.
51. SELEIMAN M.F., ASLAM M.T., ALHAMMAD B.A., HASSAN M.U., MAQBOOL R., CHATTHA M.U., BATTAGLIA M.L. Salinity Stress in Wheat: Effects, Mechanisms and Management Strategies. Phytotransport-International Journal of Experimental Botany, 91 (4), 667, 2022.
52. PARVEZ S., ABBAS G., SHAHID M., AMJAD M., HUSSAIN M., ASAD S.A., NAEME M.A. Effect of salinity on physiological, biochemical and photosynthetic attributes of two genotypes of quinoa (Chenopodium quinoa Willd.) exposed to arsenic stress. Ecotoxicology and Environmental Safety, 187 (October), 109814, 2020.
53. KARIMI R., GAVILI-KILANEH K., KHADIIVI A. Methyl jasmonate promotes salinity adaptation responses in two grapevine (Vitis vinifera L.) cultivars differing in salt tolerance. Food Chemistry, 375 (October), 131667, 2022.
54. SONI S., KUMAR A., SEHRAWAT N., KUMAR A., KUMAR N., LATA C., MANN A. Effect of saline irrigation on plant water traits, photosynthesis and ionic balance in durum wheat genotypes. Saudi Journal of Biological Sciences, 28 (4), 2510, 2021.
55. AMINI HAJIABADI A., MOSLEH ARANI A., GHASEMI S., RAD M.H., ETESAMI H., SHABAZI MANSHADI S., DOLATI A. Mining the rhizosphere of halophytic rangeland plants for halotolerant bacteria to improve growth and yield of salinity-stressed wheat. Plant Physiology and Biochemistry, 163 (January), 139, 2021.

56. GOLKAR P., TAGHIZADEH M. In vitro evaluation of phenolic and osmolite compounds, ionic content, and antioxidant activity in safflower (*Carthamus tinctorius* L.) under salinity stress. Plant Cell, Tissue and Organ Culture, 134 (3), 357, 2018.

57. IMRAN M., BOELT B., MUHLING K.H. Zinc seed priming improves salt resistance in maize. Journal of Agronomy and Crop Science, 204 (4), 390, 2018.

58. SHAMLOO-DASHTPAGERDI R., ALIAKBARI M., LINDLOF A., TAHMASEBI S. A systems biology study unveils the association between a melatonin biosynthesis gene, O-methyl transferase 1 (OMT1) and wheat (*Triticum aestivum* L.) combined drought and salinity stress tolerance. Planta, 255 (5), 1, 2022.

59. AHMADI F.I., KARIMI K., STRUIK P.C. Effect of exogenous application of methyl jasmonate on physiological and biochemical characteristics of *Brassica napus* L. cv. Talaye under salinity stress. South African Journal of Botany, 115, 5, 2018.

60. KHALVANDI M., AMERIAN M., PIRDASHTI H., KERAMATI S., HOSSEINI J. Essential oil of peppermint in symbiotic relationship with *Piriformospora indica* and methyl jasmonate application under saline condition. Industrial Crops and Products, 127 (June), 195, 2019.

61. LI J., MENG B., CHAI H., YANG X., SONG W., LI S., SUN W. Arbuscular mycorrhizal fungi alleviate drought stress in *C3* (*Leymus chinensis*) and *C4* (*hemarthria altissima*) grasses via altering antioxidant enzyme activities and photosynthesis. Frontiers in Plant Science, 10 (April), 1, 2019.

62. SHOJA A.A., CIRAK C., GANJEALI A., CHENJANY M. Stimulation of phenolic compounds accumulation and antioxidant activity in in vitro culture of *Salvia tebesana* Bunge in response to nano-TiO, and methyl jasmonate elicitors. Plant Cell, Tissue and Organ Culture, 149 (1), 423, 2022.