**DROUGHT TOLERANCE OF COWPEA ENHANCED BY EXOGENOUS APPLICATION OF METHYL JASMONATE**

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**Abstract**

Drought stress limits crop productivity in many regions of the world. Methyl jasmonate (MeJA) a plant growth regulator is involved in many plant growth and developmental processes and tolerance to environmental stresses. This field experiment was conducted to investigate the role of exogenous application of MeJA (seed priming, foliar application at the vegetative or reproductive stages and the combination of them) in alleviating the adverse effects of drought stress in cowpea. Results showed that drought stress severely reduced growth attributes such as plant height, leaf area, biomass and seed yield as well as stomatal conductance, relative water content (RWC) and chlorophyll value. Drought also increased membrane lipid peroxidation (malondialdehyde "MDA" content), proline and total soluble sugars (TSS) contents. On the other hand, exogenously applied MeJA improved all growth attributes under drought stress conditions through stomata closure and improving RWC, enhancing chlorophyll value, proline and TSS contents and also reduction of membrane lipid peroxidation. Among MeJA treatments, foliar application at the reproductive stage was the most effective. These results suggest the involvement of MeJA in increasing drought tolerance of cowpea by improving water status and chlorophyll value, enhancing compatible solutes accumulation and reducing membrane lipid peroxidation.

**Keywords:** Foliar application; Jasmonates; Legumes; Seed priming; Water stress.

**Introduction**

Drought is a serious problem in many areas of the world, especially in arid and semi-arid regions. Drought stress affects a wide range of plant functions such as cell division and elongation, water and nutrients relations, photosynthesis, enzymes activity, stomata movement, assimilate partitioning, respiration, oxidative damage, growth, and productivity. Plants respond and adapt to drought stress by means of various morphological, biochemical and physiological changes (Farooq et al., 2009).

Plants produce various compounds including plant growth regulators that help them to adapt to environmental stresses. Jasmonic acid (JA) and its methyl ester, methyl jasmonate (MeJA) are important cellular regulators involved in many growth, developmental and physiological processes such as seed germination, root growth, gravitropism, trichome and tuber formation, embryo and seedling development, production of secondary compounds, carbon partitioning, accumulation of storage proteins, allelopathy, up-regulation of antioxidant enzymes, leaf movement and senescence, chlorosis, fertility, flowering, floral nectar synthesis, fruit ripening, and crop quality. These are also known to activate the plant defense responses to various biotic and abiotic stresses (Akash et al., 2009; Dar et al., 2015; Ahmad et al., 2016).

Application of plant growth regulators is one of the strategies to cope with the abiotic stresses in agriculture. It was found that exogenous application of MeJA improved tolerance to drought (Alam et al., 2014; Miranshahi and Sayyari, 2016), salinity (Sadeghipour, 2017; Ahmadi et al., 2018), chilling (Rehman et al., 2018) and heavy metal (Hanaka et al., 2016) stresses in different plant species. Foliar application of MeJA improved biological and grain yield of soybean under drought stress by enhancing antioxidant enzymes activity, proline accumulation and relative water content (RWC) as well as a decrease in membrane lipid peroxidation (Anjum et al., 2011a). Exogenously applied MeJA enhanced drought tolerance of cauliflower seedlings through increased chlorophyll, net photosynthetic rate, RWC, endogenous abscisic acid level, enzymatic and non-enzymatic antioxidant (proline and soluble sugar) systems activity, and also reduced lipid peroxidation and hydrogen peroxide levels (Wu et al., 2012). Foliar spray with MeJA via increasing total sugars, phenolic compounds, total fatty acids, peroxidase activity, photosynthetic pigments and...
RWC improved tolerance to drought and enhanced growth attributes of soybean genotypes under drought (Mohamed and Latif, 2017). Maize seed-treatment with MeJA improved growth by means of enhancing osmoprotectants accumulation, indole acetic acid level and oxidative enzymes activity under water stress conditions (Abdelgawad et al., 2014).

Cowpea [Vigna unguiculata L. (Walp.)] is an important grain legume which is rich in proteins, vitamins, minerals, fiber, and micronutrients. It is mainly cultivated in tropical and subtropical regions of Africa, Asia and America. The grains, fresh pods, and leaves as well as the foliage of cowpea are consumed by humans and animals, respectively. Furthermore, cowpea can increase soil fertility through nitrogen fixation (Da Silva et al., 2017; Horn et al., 2018). Although cowpea is considered as being more drought tolerant than other legumes, its productivity is negatively affected by prolonged droughts, especially at the reproductive growth stages. Moreover, there are variations among cowpea genotypes in their drought tolerance (Mwale et al., 2017; Oyewole et al., 2017). Little researches have been conducted on the comparison of various methods of MeJA application on the drought tolerance of crops especially cowpea. The aim of the present study, therefore, was to investigate the effects of different exogenous application methods of MeJA in improving drought tolerance of cowpea.

Materials and methods

Growth conditions, plant material, experimental design and treatments

This field experiment was conducted in spring and summer 2015 at the Islamshahr region (51° 12’ E, 35° 28’ N and 1050 m altitude), Tehran, Iran. This region is located in an arid climate. The mean annual rainfall and temperature are 218.1 mm and 16.4 °C, respectively. The meteorological data of the region for growing season of cowpea are presented in Table 1. The soil characteristics were as follows: pH, 7.71; EC, 2.33 dS m⁻¹; organic carbon, 2.7%; N, 0.23%; P and K, 18.9 and 383 mg kg⁻¹, respectively; and texture, clay loam.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean temperature (°C)</th>
<th>Precipitation (mm)</th>
<th>Mean humidity (%)</th>
<th>Sunshine duration (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June</td>
<td>31.2</td>
<td>0.4</td>
<td>20.5</td>
<td>329.6</td>
</tr>
<tr>
<td>July</td>
<td>31.8</td>
<td>0.4</td>
<td>21.5</td>
<td>353.2</td>
</tr>
<tr>
<td>August</td>
<td>30.1</td>
<td>0.0</td>
<td>21.0</td>
<td>370.6</td>
</tr>
<tr>
<td>September</td>
<td>25.0</td>
<td>8.7</td>
<td>32.5</td>
<td>319.3</td>
</tr>
<tr>
<td>October</td>
<td>20.1</td>
<td>15.7</td>
<td>33.0</td>
<td>267.5</td>
</tr>
</tbody>
</table>

This experiment was laid out in a randomized complete block design (RCBD) with 9 treatments and 4 replications. Experimental treatments were as follows: control; drought; drought+seed priming with MeJA (SP); drought+foliar application of MeJA at the vegetative stage (VS); drought+foliar application of MeJA at the reproductive stage (RS); drought+SP+VS; drought+SP+RS; drought+VS+RS; and drought+SP+VS+RS. Each replication consisted of 9 plots with 4 planting rows with length and distance of 5 and 0.5 m, respectively. Two irrigation regimes were used in this study including irrigation after 60 and 120 mm evaporation from a class A evaporation pan as normal and drought stress conditions, respectively. Seeds of cowpea (cv. Kamran) without visible defect, insect damage, and malformation were surface sterilized using 5% sodium hypochlorite solution for 5 min and then rinsed 3 times with sterile distilled water. For seed priming, the seeds were then soaked in water (control), or 30 µM aqueous solution of MeJA for 12 h. Afterward, air-dried seeds were sown on the planting rows by hand in 4 cm depth of soil on June 5, 2015. All plots were irrigated immediately after sowing, and subsequent irrigations were carried out according to the irrigation regimes. After thinning at the 3-leaf stage, the distance of seedlings on rows was 10 cm. Crop management practices such as hand weeding were done as required. For the foliar application of MeJA at the vegetative stage (5-leaf) and reproductive stage (early flowering), 30 µM aqueous solution of MeJA was sprayed by atomizer at the early morning. At the end of the flowering stage, some biochemical and physiological traits were estimated as follows:

Assessment of biochemical traits

Lipid peroxidation was estimated in terms of malondialdehyde (MDA) content according to the method of Heath and Packer (1968). Fresh leaf samples (500 mg) were homogenized in 10 mL of 0.1% (w/v) trichloroacetic acid (TCA). The homogenate was centrifuged at 15000 rpm for 5 min. Then, 4 mL (0.5%) of thiobarbituric acid in 20% TCA was added to a 1 mL aliquot of the supernatant. The mixture was heated at 95 °C for 30 min and then cooled rapidly in an ice bath. After centrifugation at 10000 rpm for 10 min, the
absorbance was recorded at 532 nm. The value for non-specific absorption at 600 nm was subtracted. The MDA content was calculated using the absorption coefficient of 155 mM$^{-1}$ cm$^{-1}$ and expressed as nmol g$^{-1}$ fresh weight.

Proline content was determined according to the method described by Bates et al. (1973). Fresh leaf samples (500 mg) were homogenized in 10 mL of 3% aqueous sulfosalicylic acid and the homogenate solution was filtered through filter paper. Two mL of the filtrate was then added to 2 mL acid ninhydrin reagent and 2 mL glacial acetic acid in a test tube and placed in a water bath at 100 °C for 1 h. The reaction was terminated in an ice bath. Then, 4 mL of toluene was added to the reaction mixture and mixed vigorously for 30 s. The chromophore containing toluene was aspirated from the aqueous phase and the absorbance read at 520 nm. The proline concentration was determined using a standard curve and expressed as μmol g$^{-1}$ fresh weight.

Total soluble sugars (TSS) were extracted by overnight submersion of 200 mg fresh leaves in 10 mL of 80% (v/v) ethanol at 25 °C with periodic shaking and centrifuged at 600 rpm. The supernatant was evaporated until completely dried, then dissolved in a known volume of distilled water to be ready for determination of soluble sugars (Hommel et al., 1992). TSS was analyzed by reacting of 0.1 mL of ethanolic extract with 3 mL freshly prepared anthrone (150 mg anthrone + 100 mL of 72% H$_2$SO$_4$) in boiling water bath for 10 min and reading the cooled samples at 625 nm using Spekol Spectrocolourimeter (Yemm and Willis, 1954).

**Measurement of physiological traits**

Stomatal conductance was measured on a sunny day between 10:00 and 11:00 h on the youngest fully expanded leaves using a Portable Leaf Porometer, SC-1, Decagon Devices, USA. To determine the RWC; 10 disks (1 cm in diameter) from the middle portion of the youngest fully expanded leaves were collected, immediately weighed to record the fresh weight (FW), then rehydrated in Petri dishes containing distilled water for 24 h under dim light and room temperature to get the turgid weight (TW) and subsequently the discs were oven dried at 70 °C for 48 h to record the dry weight (DW). RWC was calculated as: RWC (%) = (FW - DW) / (TW - DW) × 100. Chlorophyll value of the youngest fully expanded leaves was measured using a Chlorophyll Content Meter, CL-01, Hansatech Instruments Ltd. England.

**Determination of growth attributes**

At the late flowering stage, for estimation of leaf area index (LAI), leaf area of the plants in 1 m$^2$ was calculated using Leaf Area Meter, CI-202, CID, Bio-Science, USA. At the physiological maturity (early October), plants height was recorded. Also, plants in 2 m$^2$ of each plot were harvested, sun-dried and then seed yield per unit area was determined (with 13% moisture). Afterward, above ground plant parts were oven-dried at 80 °C for 48 h and biomass per unit area was calculated.

**Statistical analysis**

All data were analyzed using the MSTAT-C statistical software (Version 2.1; Michigan State University, USA) and means were compared by the Duncan Multiple Range Test (DMRT) at $P \leq 0.05$.

**Results**

**Growth variables**

All growth attributes examined in this study, including plant height, LAI, biomass and seed yield, were significantly decreased due to drought stress by 32%, 42%, 44% and 57%, respectively, compared with the control. However, exogenously applied MeJA increased all growth traits under drought conditions. The maximum increases in plant height and LAI were obtained by foliar application of MeJA at the vegetative stage, but the highest increases in biomass and seed yield were recorded by foliar application of MeJA at the reproductive stage (Table 2).

**Table 2. Mean comparison of growth attributes of cowpea as affected by drought stress and MeJA application.**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (cm)</th>
<th>LAI</th>
<th>Biomass (g m$^{-2}$)</th>
<th>Seed yield (g m$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>128.17±6.41$^{a}$</td>
<td>5.05±0.31$^{a}$</td>
<td>1636.13±49.08$^{a}$</td>
<td>436.21±17.44$^{a}$</td>
</tr>
<tr>
<td>Drought</td>
<td>86.50±4.32$^{c}$</td>
<td>2.90±0.17$^{c}$</td>
<td>916.13±27.48$^{c}$</td>
<td>187.55±7.48$^{c}$</td>
</tr>
<tr>
<td>D+SP</td>
<td>104.83±5.24$^{b}$</td>
<td>4.19±0.25$^{bc}$</td>
<td>1143.14±34.29$^{bc}$</td>
<td>326.91±13.08$^{bc}$</td>
</tr>
<tr>
<td>D+VS</td>
<td>107.91±5.42$^{a}$</td>
<td>4.86±0.29$^{a}$</td>
<td>1324.87±39.72$^{a}$</td>
<td>354.46±14.16$^{a}$</td>
</tr>
<tr>
<td>D+RS</td>
<td>104.00±5.20$^{a}$</td>
<td>4.17±0.25$^{bc}$</td>
<td>1483.27±44.49$^{bc}$</td>
<td>368.91±14.76$^{bc}$</td>
</tr>
<tr>
<td>D+SP+VS</td>
<td>89.50±4.47$^{c}$</td>
<td>3.52±0.21$^{c}$</td>
<td>1049.67±31.47$^{c}$</td>
<td>289.98±11.60$^{c}$</td>
</tr>
<tr>
<td>D+SP+RS</td>
<td>99.73±4.99$^{a}$</td>
<td>3.38±0.20$^{a}$</td>
<td>1076.60±32.28$^{a}$</td>
<td>303.69±12.16$^{a}$</td>
</tr>
<tr>
<td>D+VS+RS</td>
<td>1089.87±32.67$^{bc}$</td>
<td>3.64±0.22$^{cd}$</td>
<td>1089.87±32.67$^{bc}$</td>
<td>252.60±10.10$^{bc}$</td>
</tr>
<tr>
<td>D+SP+VS+RS</td>
<td>88.33±4.42$^{c}$</td>
<td>3.35±0.20$^{c}$</td>
<td>1098.27±32.94$^{c}$</td>
<td>247.22±9.88$^{c}$</td>
</tr>
</tbody>
</table>
Means within a column followed by the same letter (s) are not significantly different at $P \leq 0.05$ level using DMRT. Data are mean $\pm$ SE ($n=4$).

D: Drought; SP: Seed priming with MeJA; VS: Foliar application of MeJA at the vegetative stage; RS: Foliar application of MeJA at the reproductive stage; LAI: Leaf Area Index.

**Biochemical variables**
In this experiment, lipid peroxidation was measured by estimating the MDA content, a product of lipid peroxidation. Drought stress raised the level of MDA by 144%, compared to normal conditions. Nonetheless, exogenous application of MeJA significantly decreased the MDA content under drought conditions. Among the MeJA treatments, foliar application at the reproductive stage was the most effective (Table 3).

The content of proline in the leaf of cowpea plants is presented in Table 3. With drought treatment, the level of proline increased by 9% as compared to control. Under drought stress, proline content was also drastically more increased by MeJA application, especially, foliar application at the reproductive stage. Drought stress resulted in a slightly increase in TSS contents by 5% compared with the control. During drought stress, TSS content was markedly elevated in MeJA-treated plants. The most effective treatment was the foliar application of MeJA at the reproductive stage (Table 3).

**Physiological variables**
Drought stress led to a significant decline in the stomatal conductance by 3% when compared with the control. Exogenous application of MeJA led to further reduction in the stomatal conductance of the water-stressed cowpea plants. Among MeJA treatments, foliar application at the reproductive stage was the most effective (Table 3).

Drought stress caused a considerable reduction in RWC by 21% relative to control. Nonetheless, MeJA treatment enhanced the RWC in drought-stressed cowpea plants. Foliar application of MeJA at the reproductive stage showed the best enhancement as compared to other treatments (Table 3).

Chlorophyll value of cowpea leaves was decreased significantly under drought stress by 44% as compared to control. However, exogenously applied MeJA improved chlorophyll value under drought stress conditions. Foliar application of MeJA at the reproductive stage was the best treatment (Table 3).

**Table 3.** Mean comparison of biochemical and physiological traits of cowpea as affected by drought stress and MeJA application

<table>
<thead>
<tr>
<th>Treatments</th>
<th>MDA (nmol g⁻¹ F.W.)</th>
<th>Proline (µmol g⁻¹ F.W.)</th>
<th>TSS (mg g⁻¹ F.W.)</th>
<th>gₛ (mmol m⁻² s⁻¹)</th>
<th>RWC (%)</th>
<th>Chl. V. (Spad Unit)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>109.27±5.45</td>
<td>55.11±2.75</td>
<td>2.53±0.18</td>
<td>7.59±0.38</td>
<td>87.17±4.84</td>
<td>49.19±1.96</td>
</tr>
<tr>
<td>Drought</td>
<td>266.40±13.30</td>
<td>60.1±3.0</td>
<td>2.66±0.19</td>
<td>7.32±0.37</td>
<td>68.23±2.72</td>
<td>27.89±1.11</td>
</tr>
<tr>
<td>D+SP</td>
<td>187.78±9.40</td>
<td>80.39±4.02</td>
<td>5.50±0.38</td>
<td>6.88±0.34</td>
<td>77.11±3.09</td>
<td>45.33±1.81</td>
</tr>
<tr>
<td>D+VS</td>
<td>186.76±9.35</td>
<td>90.41±4.52</td>
<td>5.84±0.41</td>
<td>6.85±0.34</td>
<td>80.68±3.22</td>
<td>47.84±1.91</td>
</tr>
<tr>
<td>D+RS</td>
<td>193.66±9.70</td>
<td>67.54±3.37</td>
<td>3.67±0.26</td>
<td>6.95±0.35</td>
<td>74.89±3.01</td>
<td>44.33±1.77</td>
</tr>
<tr>
<td>D+SP+VS</td>
<td>190.13±9.50</td>
<td>64.01±3.21</td>
<td>3.01±0.21</td>
<td>7.21±0.36</td>
<td>74.39±2.98</td>
<td>42.91±1.72</td>
</tr>
<tr>
<td>D+VS+RS</td>
<td>198.04±9.91</td>
<td>71.92±3.61</td>
<td>3.75±0.26</td>
<td>6.93±0.35</td>
<td>75.10±3.01</td>
<td>44.60±1.78</td>
</tr>
<tr>
<td>D+SP+VS+RS</td>
<td>205.40±10.25</td>
<td>63.51±3.17</td>
<td>2.87±0.20</td>
<td>7.27±0.36</td>
<td>73.77±2.95</td>
<td>37.51±1.50</td>
</tr>
</tbody>
</table>

Means within a column followed by the same letter (s) are not significantly different at $P \leq 0.05$ level using DMRT. Data are mean ± SE ($n=4$).

D: Drought; SP: Seed priming with MeJA; VS: Foliar application of MeJA at the vegetative stage; RS: Foliar application of MeJA at the reproductive stage.

MDA: Malondialdehyde; TSS: Total Soluble Sugars; gₛ: Stomatal Conductance; RWC: Relative Water Content; Chl. V.: Chlorophyll Value.

**Discussion**
In the present study, drought stress through inducing the membrane lipid peroxidation, closure of stomata, reducing the RWC and chlorophyll value, severely decreased growth parameters of cowpea plants including plant height, LAI, biomass and seed yield. These results are in agreement with the previous findings (Silva et al., 2016; Ndiso et al., 2016). Nonetheless, foliar application of MeJA diminished the unfavorable effects of drought and improved all growth attributes. Similarly, the advantageous impacts of exogenously applied MeJA on the growth traits and tolerance to drought stress have been reported by others in different conditions.
plant species (Alam et al., 2014; Ahmad and Murali, 2015; Miranshahi and Sayyari, 2016; Mohamed and Latif, 2017; Sheteiwy et al., 2018). Water stress induces the overproduction of reactive oxygen species (ROS) which cause the membrane lipid peroxidation. MDA, as a final product of membrane lipid peroxidation, is a reliable indicator of oxidative damage. Usually, the low MDA level in the cell indicates a higher tolerance to drought (Toscano et al., 2016). In the current study, drought stress noticeably increased MDA content; however, exogenously applied MeJA decreased MDA content under drought stress conditions. Similar beneficial role of MeJA on reducing oxidative damage (MDA content) under drought stress conditions have been observed in many plant species (Mahmood et al., 2012; Wu et al., 2012; Alam et al., 2014; Nazarli et al., 2014). These results suggest that under drought stress, MeJA can stimulate antioxidant defense systems (enzymatic and non-enzymatic) in plants for ROS scavenging which ultimately improves drought tolerance (Wang, 1999; Anjum et al., 2011a).

In many plant species, proline concentration increases normally in the cytosol in response to environmental stresses which improves stress tolerance. Proline plays a key role in osmotic adjustment, membranes and proteins stability, free radicals scavenger and buffering cellular redox potential under stress conditions (Ashraf and Foolad, 2007). In the present study, the proline content of cowpea leaves was higher in drought conditions and it was the highest in the drought stress combined with MeJA. These findings are in accordance with those of Anjum et al. (2011a), Wu et al. (2012), Nazarli et al. (2014) and Pazirandeh et al. (2015), who reported that water stress increased proline content and MeJA application further enhanced proline concentration in different plant species. In the current experiment, increased proline concentration by MeJA application helped to maintain the tissue water and improved water status in terms of RWC under drought stress conditions.

In this study, TSS contents in cowpea leaves were slightly increased by drought stress. Nonetheless, exogenous application of MeJA significantly elevated the TSS levels under drought conditions. The increase in TSS contents under drought stress conditions may be due to starch degradation. TSS can act as osmotic regulators or metabolic signaling molecules which cause drought tolerance (Mohamed and Latif, 2017). In accordance with the present findings, exogenous application of MeJA enhanced TSS contents in cauliflower (Wu et al., 2012), maize (Abdelgawad et al., 2014), chamomile (Nazarli et al., 2014), onion (Ahmad and Murali, 2015) and soybean (Mohamed and Latif, 2017) under drought stress conditions.

Stomata closure is one of the first responses of the plant to water stress for preventing water loss which is more closely related to soil moisture content than leaf water status, and it is mainly controlled by ABA produced in dehydrating roots (Chaves et al., 2002). In the current study, drought decreased stomatal conductance in cowpea, however, application of MeJA led to a further reduction. These results are in harmony with the findings of Wang (1999) and Anjum et al. (2011b), who found that MeJA application reduced stomatal conductance and transpiration rate of strawberry and soybean plants under drought stress conditions. Stomata closure due to the application of MeJA is attributed to its role in stimulating the ABA accumulation (Bandurska et al., 2003; Pazirandeh et al., 2015). Based on these results, closure of stomata and prevention of water losses is one of the mechanisms of drought tolerance due to MeJA application.

RWC is one of the most important indicators of water status in plants which is related to water uptake from the roots and transpiration rate from the leaves. RWC has been indicated as an important marker of water stress in plants which is directly related to soil water content (Mohamed and Latif, 2017). Reduction of RWC under water stress conditions has been reported in different plant species (Anjum et al., 2011a; Miranshahi and Sayyari, 2016). The results of this study showed that water status of cowpea leaves in terms of RWC was decreased in response to drought stress and markedly enhanced by MeJA application. The positive effect of exogenously applied MeJA on the RWC in different plant species has been reported by others (Mahmood et al., 2012; Wu et al., 2012; Alam et al., 2014; Ahmad and Murali, 2015; Pazirandeh et al., 2015; Mohamed and Latif, 2017; Sheteiwy et al., 2018). In this experiment, exogenously applied MeJA via stomata closure and accumulation of osmolytes improved tissue water content and RWC under drought conditions. Moreover, MeJA enhances root hydraulic conductivity through calcium and ABA-dependent and independent signaling pathways which can facilitate water uptake and improves water status of the plant under restricted moisture (Sanchez-Romera et al., 2014).

In many plant species, water stress caused a reduction in the chlorophyll content through the chlorophyll degradation by chlorophyllase activity, reducing chlorophyll biosynthesis and overproduction of ROS (Mohamed and Latif, 2017; Sheteiwy et al., 2018). In the current study, drought stress severely reduced chlorophyll value, but the exogenous application of MeJA enhanced this
physiological trait. This ameliorator role of exogenous application of MeJA on the chlorophyll content under drought conditions have been observed in cauliflower (Wu et al., 2012), maize (Abdelgawad et al., 2014), Brassica species (Alam et al., 2014), and soybean (Mohamed and Latif, 2017). Moreover, Kovac and Ravinkar (1994) reported that the positive effects of jasmonic acid treatment on the photosynthetic pigment levels might be more indirect through enhanced water and nutrient absorption.

In conclusion, exogenous application of 30 μM MeJA ameliorated drought tolerance of cowpea and led to increased growth and seed yield under drought stress conditions. Among MeJA treatments, foliar application at the reproductive stage was the most effective. The beneficial role of MeJA in increasing drought tolerance of cowpea was related to improving water status and chlorophyll value, enhancing osmolytes (proline and soluble sugars) accumulation and reducing membrane lipid peroxidation.

References


