IV. RESULTS

*Allium cepa* L. Var. *Aggregatum* (shallot), an economically important food crop, belong to family Amaryllidaceae, was selected for the present investigation. Experiments were conducted to study the effect of jasmonic acid (JA) and salicylic acid (SA) on *Allium cepa* under drought stress condition. The *Allium cepa* var. *Aggregatum* plants grown under eight treatments, normally irrigated control (C); 5 days interval drought, 5 DID (D); 5 DID+0.5 mM SA (DS1); 5 DID+1.0 mM SA (DS2); 5 DID+1.5 mM SA (DS3); 5 DID+25 μM JA (DJ1); 5 DID+50 μM JA (DJ2) and 5 DID+100 μM JA (DJ3) were analyzed on 50th, 65th, 80th and 95th DAS (days after sowing). Variation in growth, yield, water relations, photosynthetic pigments and biochemical constituents, proline metabolism enzyme activities, lipid peroxidation, non-enzymatic antioxidant contents and antioxidant enzyme activities were studied. The results obtained are presented below:

1. Growth parameters

1.1. Root length

Drought stress (5 DID) alone significantly decreased root length of *Allium cepa* plants on all growth stages and it was 74.1 per cent over control on 95th DAS (Table 1). However, application of SA and JA to drought stressed plants enhanced root length to a significant level as compared to drought stressed plants not treated with any one of these growth regulators (GRs), but it does not exceed the control. Among SA treated groups, DS3 exhibited highest root length followed
by DS2 and DS1 and it was 111.9, 106.6 and 102.6 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ2 showed maximum root length followed by DJ3 and DJ1 and it was 115.8, 113.9 and 111.2 per cent over control respectively on 95th DAS. The data indicate that among the two GRs used, JA proved more effective than SA in the enhancement of root growth of A. cepa under drought stress condition.

1.2. Shoot length

Drought stress caused a significant reduction in shoot length of A. cepa as compared to control on all growth stages and it was 72.2 per cent over control on 95th DAS (Table 1). The obtained data suggested that foliar application of two GRs significantly enhanced shoot length in drought stressed A. cepa plants as compared to those of untreated ones. Among the groups treated with SA, DS3 recorded highest shoot length followed by DS2 and DS1 and it was 91.4, 87.9 and 85.9 per cent over control respectively on 95th DAS. Similarly among JA treated groups DJ3 exhibited highest shoot length followed by DJ2 and DJ1 and it was 87.0, 86.1 and 82.1 Per cent over control respectively on 95th DAS (Table 1). Among the GRs used, SA showed better results in the improvement of shoot growth of A. cepa under drought stress condition.

1.3. Number of Leaves per plant

Total number of leaves per plant significantly decreased under drought stress condition in A. cepa as compared to control and it was 15.8 leaves per plant in 5 DID on 95th DAS (Table 2). On the other
hand, application of SA and JA increased total number of leaves per plant as compared to drought stress alone, but it does not exceed the control. There were found no significant differences in number of leaves per plant among groups treated with either SA or JA. Among these groups, the highest number of leaves per plant was recorded in DS2 and it was 26.2 leaves per plant on 95th DAS whereas, the lowest leaf number was recorded in DJ1 and it was 20.3 leaves per plant on 95th DAS.

1.4. Whole plant fresh weight

The whole plant fresh weight decreased significantly as compared to control in *A. cepa* plants under drought stress on all growth stages and it was 62.0, 59.5, 62.5 and 65.4 per cent over control on 50th, 65th, 80th and 95th DAS respectively (Table 3). In contrast to drought stress, application of SA and JA significantly increased whole plant fresh weight in drought stressed *A. cepa* plants, but this increase was lower as compared to control. Among the groups treated with two growth regulators, DS3 exhibited highest fresh weight followed by DJ3, DS2, DJ2, DS1, and DJ1 and it was 92.4, 88.4, 86.9, 84.9, 83.7 and 79.9 per cent over control respectively on 95th DAS.

1.5. Whole plant dry weight

Drought stress significantly declined the whole plant dry weight of *A. cepa* as compared to control on all growth stages and it was 60.5 per cent over control on 95th DAS. However, foliar spray of SA and JA significantly enhanced whole plant dry weight in drought stressed *A. cepa* when compared with those of untreated drought stressed plants,
but this enhancement was not above the control (Table 3). Among the SA treated groups, DS3 showed maximum dry weight followed by DS2 and DS1 and it was 91.3, 87.5 and 80.6 per cent over control respectively on 95th DAS. Among the JA treatments, DJ3 showed highest dry weight followed by DJ2 and DJ1 and it was 88.4, 82.6 and 76.1 per cent over control respectively on 95th DAS. In comparison, SA performed better than JA does in the enhancement of fresh and dry weight of *A. cepa* under drought stress condition.

2. Yield parameters

2.1. Number of bulb-lets (cloves) per plant

It is clear from the results that drought stress significantly decreased clove number in *A. cepa* as compared to control and it was 4.1 (mean of six replicates) cloves per plant in drought stress alone and 7.83 cloves in control at the time of harvest (Table 4). On the other hand, clove number per plant was found slightly increased upon application of SA and JA in presence of drought stress, but it does not exceed the control. There were found less significant differences in cloves number per plant among the groups treated with SA and JA and it was 6.3, 6.4, 7.3, 5.1, 6.2 and 6.3 in DS1, DS2, DS3, DJ1, DJ2 and DJ3 respectively at harvest time. Among the chemical treatments, DS3 exhibited highest (7.3) number of cloves per plant.

2.2. Bulb weight per plant

The data revealed that there was a significant decrease in bulb weight of *A. cepa* under drought stress as compared to control when harvested and it was 12.6 g per plant in drought stressed plants and
24.4 g in control plants (Table 4). However, application of SA and JA significantly enhanced bulb weight under drought stress but it does not exceed the control. Among the SA treatments, DS3 showed highest bulb weight followed by DS2 and DS1 and it was 20.8, 18.3 and 17.5 g per plant respectively. Similarly, among the JA treatments, DJ3 showed highest bulb weight followed by DJ2 and DJ1 and it was 18.1, 17.3 and 15.1 g per plant respectively. Among the two GRs, SA proved very effective than JA in the enhancement of total bulb yield of *A. cepa* under drought stress.

Table 4: Ameliorative effects SA and JA on Number of cloves per plant and total bulb weight (g/plant) of *Allium cepa* var *Aggregatum* under drought stress (Values are the mean ±SE of six replicates).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Number of cloves</td>
<td>7.8±0.75</td>
</tr>
<tr>
<td>Total bulb weight</td>
<td>24.4±1.3</td>
</tr>
</tbody>
</table>

3. Relative water content

The relative water content (RWC) in the leaves of *A. cepa* was significantly declined under drought stress alone when compared with control on all growth stages and it was 91.3% in control and 57.8% in drought stress on 95th DAS (Table 2). However, foliar application of SA
and JA in presence of drought stress increased RWC of leaves of A. *cepa* to a significant level, but it does not surpass the control. Among the SA treatments, DS3 exhibited highest RWC followed by DS2 and DS1 and it was 81.2, 73.5 and 68.8 per cent respectively on 95\textsuperscript{th} DAS. Similarly, among JA treatments, DJ3 showed highest RWC followed by DJ2 and DJ1 and it was 75.6, 69.2 and 64.0 per cent respectively on 95\textsuperscript{th} DAS. When comparing the two GRs, SA proved more prominent as compared to JA in improving the RWC of leaves of drought stressed *A. cepa*.

4. Mineral content

4.1. Potassium

**Root**

Drought stress alone markedly decreased root potassium content as compared to control on all growth stages and it was 56.6 per cent over control on 95\textsuperscript{th} DAS (Fig. 1). However, foliar application of SA and JA to drought stressed *A. cepa* plants, increased root potassium content noticeably in comparison to drought stress alone. Among SA treated groups, DS3 exhibited higher potassium content followed by DS2 and DS1 and it was 98.0, 88.9 and 75.1 per cent over control respectively on 95\textsuperscript{th} DAS and similarly among JA treated groups, DJ3 showed maximum potassium content followed by DJ2 and DJ1 and it was 94.9, 82.0 and 66.2 per cent over control respectively on 95\textsuperscript{th} DAS. Among the two GRs, SA was found more effective than JA under drought stress condition.
Shoot

The data revealed that potassium content decreased significantly under drought stress in shoot of *Allium cepa* as compared to control on all growth stages and it was 54.3 per cent over control on 95th DAS (Fig. 1). On the other hand, foliar application of SA and JA enhanced potassium content of drought stressed *A. cepa* plants when compared with those received only drought stress. Among the SA treated groups, DS3 showed highest potassium content followed by DS2 and DS1 and it was 96.4, 87.4 and 73.1 per cent over control respectively on 95th DAS, whereas, among JA treated groups, potassium content was found highest in DJ3 followed by DJ2 and DJ1 and it was 92.5, 79.7 and 67.3 per cent over control respectively on 95th DAS. Among the GRs used, SA showed more positive effects as compared to JA does by enhancing the potassium content in *A. cepa* under drought stress condition.

4.2. Calcium content

Root

The observations revealed that calcium content in roots of *A. cepa* decreased with drought stress alone as compared to control on all growth stages and it was 58.5 over control on 95th DAS (Fig. 2). However, calcium content in roots was enhanced by application of different concentrations of SA and JA under drought stress but it does not exceed the control. Among SA treatments, DS3 exhibited maximum calcium content followed by DS1 and DJ2 and it was 91.2, 78.8 and 70.1 per cent over control respectively on 95th DAS. Likewise
among the JA treatments, DJ3 showed highest calcium content followed by DS2 and DJ1 and it was 88.3, 73.0 and 68.0 per cent over control respectively on 95th DAS (Table 13).

**Shoot**

Calcium content in shoot of *A. cepa* was decreased significantly under drought stress treatment as compared to control on all growth stages and it was 58.0 per cent over control on 95th DAS (Fig. 2). On the other hand, foliar application of SA and JA improved shoot calcium content significantly under drought stress. Among the SA treated groups, DS3 exhibited highest calcium content followed by DS2 and DS1 and it was 93.2, 80.4 and 71.6 per cent control respectively on 95th DAS. Similarly, among JA treatments, DJ3 showed highest calcium content followed by DJ2 and DJ1 and it was 89.5, 79.0 and 68.2 per cent over control respectively on 95th DAS. Among the two chemicals, SA performed better than JA in ameliorating the effects of drought stress in *A. cepa* by enhancing potassium and calcium uptake.

**5. Photosynthetic pigments**

**5.1. Chlorophyll content**

**5.1.1. Chlorophyll-a**

It is clear from data that drought stress significantly decreased chlorophyll-a content in leaves of *A. cepa* as compared to control on all growth stages and it was 52.6 per cent over control on 95th DAS. However, foliar spray of SA and JA significantly increased chlorophyll-a content in drought stressed *A. cepa* when compared with those of
untreated drought stressed plants (Table 5). Among the SA treated groups, DS3 showed highest chlorophyll-a content followed by DS2 and DS1 and it was 87.0, 73.4 and 62.2 per cent over control respectively on 95\textsuperscript{th} DAS. Among the JA treated groups, DJ3 exhibited highest chlorophyll-a content followed by DJ2 and DJ1 and it was 80.4, 71.1 and 60.6 per cent over control respectively on 95\textsuperscript{th} DAS. SA performed better than JA does in the enhancement of chlorophyll-a in the leaves of \textit{A. cepa} under drought stress condition.

\subsection*{5.1.2. Chlorophyll-b}

The data suggest that drought stress significantly declined chlorophyll-b content in leaves of \textit{Allium cepa} on all growth stages as compared to control and it was 50.2 per cent over control on 95\textsuperscript{th} DAS (Table 5). In contrast to drought stress, application of SA and JA significantly increased chlorophyll-b content in drought stressed \textit{A. cepa} plants, but it does not exceed the control. Among the SA treatments, DS3 showed highest chlorophyll-b content followed by DS2 and DS1 and it was 85.0, 72.8 and 60.5 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among the JA treatments, DJ3 exhibited highest chlorophyll-b content followed by DJ2 and DJ1 and it was 79.0, 69.2 and 58.4 per cent over control respectively on 95\textsuperscript{th} DAS.

\subsection*{5.1.3. Total chlorophyll content}

Drought stress significantly decreased total chlorophyll content in leaves of \textit{A. cepa} as compared to control on all growth stages and it was 51.7 per cent over control on 95\textsuperscript{th} DAS (Fig. 3). However, foliar
application of SA and JA significantly increased total chlorophyll content in drought stressed *A. cepa* when compared with those of untreated drought stressed plants. Among the SA treated groups, DS3 showed highest total chlorophyll content followed by DS2 and DS1 and it was 86.2, 73.1 and 61.5 per cent over control respectively on 95th DAS. Among the JA treated groups, DJ3 exhibited highest total chlorophyll content followed by DJ2 and DJ1 and it was 79.8, 70.4 and 59.7 per cent over control respectively on 95th DAS. Among the two GRs, SA performed better than JA does in the enhancement of total chlorophyll content in *A. cepa* under drought stress condition.

### 5.2. Carotenoid content

The data revealed that carotenoid content decreased significantly under drought stress in leaves of *Allium cepa* as compared to control on all growth stages and it was 70.2 per cent over control on 95th DAS (Fig. 3). On the other hand, foliar application of SA and JA enhanced carotenoid content of drought stressed *A. cepa* plants when compared with those received only drought stress. Among the SA treated groups, DS3 showed highest carotenoid content followed by DS2 and DS1 and it was 93.1, 87.3 and 83.1 per cent over control respectively on 95th DAS, whereas, among JA treated groups, carotenoid content was found highest in DJ3 followed by DJ2 and DJ1 and it was 90.0, 85.2 and 78.3 per cent over control respectively on 95th DAS. SA showed more positive effects as compared to JA by enhancing the carotenoid content in the leaves of *A. cepa* under drought stress condition.
6. Biochemical constituents

6.1. Protein content

Root

Our data suggest that drought stress alone significantly decreased root protein content of *A. cepa* as compared to control on all growth stages and it was 53.8, 53.2, 52.2 and 50.1 per cent over control on 50\textsuperscript{th}, 65\textsuperscript{th}, 80\textsuperscript{th} and 95\textsuperscript{th} DAS (Table 6). However, foliar application of SA and JA enhanced root protein content to a large extent in presence of drought stress, but this increase does not exceed the control. Among SA treatments, DS3 showed highest root protein content followed by DS2 and DS1 and it was 90.7, 77.2 and 65.8 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly, among JA treatments, DJ3 recorded maximum root protein content followed by DJ2 and DJ1 and it was 85.9, 73.9 and 62.8 per cent over control respectively on 95\textsuperscript{th} DAS.

Shoot

Drought stress alone markedly decreased shoot protein content as compared to control on all growth stages and it was 50.9 per cent over control on 95\textsuperscript{th} DAS (Table 6). On the other hand, foliar application of SA and JA to drought stressed *A. cepa* plants, increased shoot protein content noticeably in comparison to drought stress alone. Among SA treated groups, DS3 exhibited highest shoot protein content followed by DS2 and DS1 and it was 91.1, 77.9 and 64.2 per cent over control respectively on 95\textsuperscript{th} DAS and similarly among JA treated groups, DJ3 showed maximum shoot protein content followed
by DJ2 and DJ1 and it was 85.9, 72.9 and 62.9 per cent over control respectively on 95\textsuperscript{th} DAS. Among the two GRs, SA was found more effective than JA under drought stress condition.

6.2. Amino acid content

Root

Drought stress caused a significant increase in root amino acid content of \textit{A. cepa} as compared to control on all growth stages and it was 151.3 per cent over control on 95\textsuperscript{th} DAS. However, treatment with SA and JA to drought stressed \textit{A. cepa} plants further increased root amino acid content to a significant level (Fig. 4). Among SA treated groups, DS3 exhibited higher root amino acid content followed by DS2 and DS1 and it was 170.6, 165.9 and 162.8 per cent over control respectively on 95\textsuperscript{th} DAS and similarly among JA treated groups, DJ3 showed maximum root amino acid content followed by DJ2 and DJ1 and it was 168.0, 163.8 and 158.6 per cent over control respectively on 95\textsuperscript{th} DAS. SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

Shoot

Under drought stress condition, shoot amino acid content of \textit{A. cepa} increased to a large extent as compared to control on all growth stages and it was 154.5 per cent over control on 95\textsuperscript{th} DAS (Fig. 4). Foliar application of SA and JA to drought stressed \textit{A. cepa}, further enhanced shoot amino acid content to a marked level. Among SA treated groups, DS3 showed highest shoot amino acid content followed by DS2 and DS1 and it was 175.2, 168.5 and 163.7 per cent
over control respectively on 95th DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot amino acid content followed by DJ2 and DJ1 and it was 172.5, 166.5 and 162.1 per cent over control respectively on 95th DAS.

6.3. Proline content

Root

Drought stress significantly increased root proline content of *A. cepa* as compared to control on all growth stages and it was 140.1 per cent over control on 95th DAS (Table 7). Likewise, foliar application of SA and JA in presence of drought stress further increased root proline content to more significant level. Among the SA treated groups, DS3 recorded highest proline accumulation followed by DS2 and DS1 and it was 167.3, 159.2 and 151.4 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 exhibited highest proline content followed by DJ2 and DJ1 and it was 162.4, 156.4 and 148.8 per cent over control respectively on 95th DAS.

Shoot

Proline content increased significantly under drought stress condition in shoots of *A. cepa* as compared to control on all growth stages and it was 140.5 per cent over control on 95th DAS (Table 7). However, treatment with SA and JA to drought stressed *A. cepa* plants further increased shoot proline content to a significant level. Among SA treated groups, DS3 exhibited higher proline content followed by DS2 and DS1 and it was 169.8, 160.5 and 152.7 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DJ3
showed maximum shoot proline content followed by DJ2 and DJ1 and it was 165.4, 157.3 and 150.6 per cent over control respectively on 95th DAS. SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

6.4. Glycine betaine content

**Root**

Drought stress caused a significant increase in glycine betaine content of roots of *A. cepa* as compared to control on all growth stages and it was 157.8 per cent over control on 95th DAS (Fig. 5). However, treatment with SA and JA to drought stressed *A. cepa* plants further enhanced root glycine betaine content to a significant level. Among SA treated groups, DS3 exhibited higher glycine betaine content followed by DS2 and DS1 and it was 188.9, 182.5 and 174.8 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 showed maximum root glycine betaine content followed by DJ2 and DJ1 and it was 184.5, 174.6 and 167.2 per cent over control respectively on 95th DAS. Among the two chemical treatments, SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

**Shoot**

Under drought stress condition, shoot glycine betaine content of *A. cepa* increased to a large extent as compared to control on all growth stages and it was 161.3 per cent over control on 95th DAS (Fig. 5). Foliar application of SA and JA to drought stressed *A. cepa*, further enhanced shoot glycine betaine content to a marked level. Among SA
treated groups, DS3 showed highest glycine betaine accumulation followed by DS2 and DS1 and it was 194.3, 186.3 and 179.2 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot glycine betaine content followed by DJ2 and DJ1 and it was 191.6, 183.9 and 174.9 per cent over control respectively on 95\textsuperscript{th} DAS.

6.5. Total soluble sugar content

Root

Drought stress significantly increased total soluble sugar content in roots of \textit{A. cepa} as compared to control on all growth stages and it was 123.3 per cent over control on 95\textsuperscript{th} DAS (Table 8). Likewise, foliar application of SA and JA in presence of drought stress further increased total soluble sugar content to more significant level. Among the SA treated groups, DS3 recorded highest total soluble sugar accumulation followed by DS2 and DS1 and it was 138.9, 135.1 and 132.1 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among JA treated groups, DJ3 exhibited highest total soluble sugar content followed by DJ2 and DJ1 and it was 134.4, 131.3 and 127.9 per cent over control respectively on 95\textsuperscript{th} DAS.

Shoot

Total soluble sugar content increased significantly under drought stress condition in shoots of \textit{A. cepa} as compared to control on all growth stages and it was 126.3 per cent over control on 95\textsuperscript{th} DAS (Table 8). However, treatment with SA and JA to drought stressed \textit{A. cepa} plants, further increased total soluble sugar content
to a significant level. Among SA treated groups, DS3 exhibited highest total soluble sugar content followed by DS2 and DS1 and it was 143.9, 139.7 and 135.4 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot total soluble sugar content followed by DJ2 and DJ1 and it was 138.3, 134.7 and 132.1 per cent over control respectively on 95th DAS. SA proved more effective as compared to JA by increasing total soluble sugar content under drought stress condition.

6.6. Sucrose content

Root

Drought stress caused a significant increase in root sucrose content of *A. cepa* as compared to control on all growth stages and it was 119.5 per cent over control on 95th DAS (Fig. 6). However, treatment with SA and JA to drought stressed *A. cepa* plants further enhanced root sucrose content to a more significant level. Among SA treated groups, DS3 exhibited higher sucrose content followed by DS2 and DS1 and it was 140.2, 135.2 and 128.8 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 showed maximum root sucrose content followed by DJ2 and DJ1 and it was 138.1, 130.9 and 126.2 per cent over control respectively on 95th DAS.

Shoot

Under drought stress condition, shoot sucrose content of *A. cepa* increased significantly as compared to control on all growth stages and it was 122.0 per cent over control on 95th DAS (Fig. 6).
Foliar application of SA and JA to drought stressed *A. cepa*, further enhanced shoot sucrose content to a marked level. Among SA treated groups, DS3 showed highest sucrose accumulation followed by DS2 and DS1 and it was 144.4, 139.4 and 134.3 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot sucrose content followed by DJ2 and DJ1 and it was 140.4, 135.3 and 129.4 per cent over control respectively on 95\textsuperscript{th} DAS. Among the two chemical treatments, SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

6.7. Starch content

**Root**

The observations revealed that root starch content of *A. cepa* was decreased with drought stress alone as compared to control on all growth stages and it was 77.2 over control on 95\textsuperscript{th} DAS (Fig. 7). However, starch content in roots was enhanced by application of different concentrations of SA and JA under drought stress but it does not exceed the control. Among the SA treated groups, maximum starch content was observed in DS3 group followed by DS2, DS1 and it was 92.6, 85.7 and 83.7 per cent over control respectively on 95\textsuperscript{th} DAS. Likewise, among JA treatments, DJ3 exhibited highest starch content followed by DJ2 and DJ1 and it was 89.4, 82.5 and 78.8 per cent over control respectively on 95\textsuperscript{th} DAS.
**Shoot**

Starch content in the shoots of *A. cepa* decreased significantly under drought stress treatment as compared to control on all growth stages and it was 78.7 per cent over control on 95th DAS (Fig. 7). On the other hand, foliar application of SA and JA improved shoot starch content significantly under drought stress. Among the SA treated groups, DS3 exhibited highest starch content followed by DS2 and DS1 and it was 96.5, 90.6 and 86.4 per cent control respectively on 95th DAS. Similarly, among JA treated groups, DJ3 showed highest starch content followed by DJ2 and DJ1 and it was 92.1, 87.5 and 84.2 per cent over control respectively on 95th DAS. Among the two chemical treatments, SA showed better results as compared to JA.

7. **Proline metabolism enzymes**

7.1. **γ-glutamyl kinase activity**

**Root**

Drought stress significantly increased γ-glutamyl kinase activity in roots of *A. cepa* as compared to control on all growth stages and it was 174.4 per cent over control on 95th DAS (Table 9). Likewise, foliar application of SA and JA in presence of drought stress further increased γ-glutamyl kinase activity to a marked level. Among the SA treated groups, DS3 recorded highest γ-glutamyl kinase activity followed by DS2 and DS1 and it was 190.9, 186.5 and 183.9 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 exhibited highest γ-glutamyl kinase activity followed by
DJ2 and DJ1 and it was 189.7, 183.3 and 178.5 per cent over control respectively on 95th DAS.

**Shoot**

The rate of $\gamma$-glutamyl kinase activity increased significantly under drought stress condition in shoots of *A. cepa* as compared to control on all growth stages and it was 175.9 per cent over control on 95th DAS. However, treatment with SA and JA to drought stressed *A. cepa* plants, further increased $\gamma$-glutamyl kinase activity to a significant level (Table 9). Among SA treated groups, DS3 exhibited highest $\gamma$-glutamyl kinase activity followed by DS2 and DS1 and it was 194.4, 188.4 and 185.9 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot $\gamma$-glutamyl kinase activity followed by DJ2 and DJ1 and it was 191.8, 185.4 and 180.4 per cent over control respectively on 95th DAS. Among the two chemical treatments, SA proved more effective as compared to JA by improving $\gamma$-glutamyl kinase activity of *A. cepa* under drought stress condition.

**7.2. Proline oxidase activity**

**Root**

The data suggested that root proline oxidase activity of *A. cepa* was decreased with drought stress alone as compared to control on all growth stages and it was 61.9 over control on 95th DAS (Fig. 8). However, proline oxidase activity in roots was enhanced by application of different concentrations of SA and JA under drought stress but it does not exceed the control. Among SA treated groups, maximum
proline oxidase activity was observed in DS3 group followed by DS2 and DS1 and it was 96.0, 85.5 and 76.1 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DS3 possessed highest proline oxidase activity followed by DJ2 and DJ1 and it was 85.7, 74.6 and 69.5 per cent over control respectively on 95th DAS.

**Shoot**

Proline oxidase activity in the shoots of *A. cepa* decreased significantly under drought stress treatment as compared to control on all growth stages and it was 56.0 per cent over control on 95th DAS (Fig. 8). On the other hand, foliar application of SA and JA improved shoot proline oxidase activity significantly under drought stress. Among the SA treated groups, DS3 exhibited highest proline oxidase activity followed by DS2 and DS1 and it was 96.8, 87.8 and 77.9 per cent control respectively on 95th DAS. Similarly, among JA treated groups, DJ3 showed highest proline oxidase activity followed by DJ2 and DJ1 and it was 88.7, 76.5 and 69.4 per cent over control respectively on 95th DAS (Table). SA proved more effective than JA by increasing the rate of proline oxidase activity of *A. cepa* under drought stress condition.

**8. Non-enzymatic antioxidants**

**8.1. α-tocopherol content**

**Root**

Drought stress significantly increased root α-tocopherol content of *A. cepa* as compared to control on all growth stages and it was
143.2 per cent over control on 95\textsuperscript{th} DAS (Table 10). Foliar application of SA and JA in presence of drought stress further increased \( \alpha \)-tocopherol content of \textit{A. cepa} to a marked level. Among the SA treated groups, DS3 recorded highest \( \alpha \)-tocopherol content followed by DS2 and DS1 and it was 172.4, 164.3 and 157.8 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among JA treated groups, DJ3 exhibited highest \( \alpha \)-tocopherol content followed by DJ2 and DJ1 and it was 167.0, 160.0 and 155.1 per cent over control respectively on 95\textsuperscript{th} DAS.

**Shoot**

The data obtained revealed that \( \alpha \)-tocopherol content increased significantly under drought stress condition in shoots of \textit{A. cepa} as compared to control on all growth stages and it was 151.0 per cent over control on 95\textsuperscript{th} DAS (Table 10). However, treatment with SA and JA to drought stressed \textit{A. cepa} plants, further increased \( \alpha \)-tocopherol content to a significant level. Among SA treated groups, DS3 exhibited highest \( \alpha \)-tocopherol content followed by DS2 and DS1 and it was 175.5, 169.8 and 164.1 per cent over control respectively on 95\textsuperscript{th} DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot \( \alpha \)-tocopherol content followed by DJ2 and DJ1 and it was 171.1, 164.6 and 157.6 per cent over control respectively on 95\textsuperscript{th} DAS. Among the two chemical treatments, SA proved more effective as compared to JA by enhancing \( \alpha \)-tocopherol content of \textit{A. cepa} under drought stress condition.
8.2. Ascorbic acid content

**Root**

From the data it is evident that drought stress caused a significant increase in root ascorbic acid content of *A. cepa* as compared to control on all growth stages and it was 144.7 per cent over control on 95\textsuperscript{th} DAS (Fig. 9). However, treatment with SA and JA to drought stressed *A. cepa* plants further enhanced root ascorbic acid content to a more significant level. Among SA treated groups, DS3 exhibited highest ascorbic acid content followed by DS2 and DS1 and it was 168.1, 161.1 and 156.9 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among JA treated groups, DJ3 showed maximum root ascorbic acid content followed by DJ2 and DJ1 and it was 162.6, 157.9 and 153.7 per cent over control respectively on 95\textsuperscript{th} DAS.

**Shoot**

Under drought stress condition, shoot ascorbic acid content of *A. cepa* increased significantly as compared to control on all growth stages and it was 140.3 per cent over control on 95\textsuperscript{th} DAS (Fig. 9). Foliar application of SA and JA to drought stressed *A. cepa*, further enhanced shoot ascorbic acid content to a marked level. Among SA treated groups, DS3 showed highest ascorbic acid content followed by DS2 and DS1 and it was 162.1, 157.1 and 152.7 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot ascorbic acid content followed by DJ2 and DJ1 and it was 160.4, 153.8 and 148.3 per cent over control.
respectively on 95th DAS. SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

8.3. Reduced glutathione content

**Root**

It is clear from data obtained that drought stress significantly increased reduced glutathione content in roots of *A. cepa* as compared to control on all growth stages and it was 150.0 per cent over control on 95th DAS (Table 11). However, foliar application of SA and JA in presence of drought stress further increased reduced glutathione content of *A. cepa* to a marked level. Among the SA treated groups, DS3 showed highest reduced glutathione content followed by DS2 and DS1 and it was 207.9, 197.8 and 185.5 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 exhibited highest reduced glutathione content followed by DJ2 and DJ1 and it was 193.9, 184.3 and 176.1 per cent over control respectively on 95th DAS.

**Shoot**

The data obtained shown that reduced glutathione content increased significantly under drought stress condition in shoots of *A. cepa* as compared to control on all growth stages and it was 154.2 per cent over control on 95th DAS (Table 11). However, treatment with SA and JA to drought stressed *A. cepa* plants, further increased reduced glutathione content to a significant level when compared to control and alone drought stressed plants. Among SA treated groups, DS3 exhibited highest reduced glutathione content followed by DS2 and
DS1 and it was 217.7, 204.7 and 191.5 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot reduced glutathione content followed by DJ2 and DJ1 and it was 202.7, 192.4 and 183.3 per cent over control respectively on 95th DAS. SA proved more effective as compared to JA by augmenting reduced glutathione content of *A. cepa* under drought stress condition.

9. **Enzymatic antioxidants**

9.1. **Superoxide dismutase activity**

**Root**

Our data suggested that superoxide dismutase (SOD) activity in roots of *Allium cepa* was significantly increased under drought stress as compared to control on all growth stages and it was 153.0 per cent over control on 95th DAS (Fig. 10). The foliar application of SA and JA to drought stressed *A. cepa* further enhanced rate of SOD activity to a more significant level when compared with control and drought stressed plants alone. Among the SA treated groups, DS3 exhibited highest root SOD activity followed by DS2 and DS1 and it was 195.9, 185.9 and 174.9 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 possessed highest SOD activity followed by DJ2 and DJ1 and it was 190.2, 177.0 and 165.7 per cent over control respectively on 95th DAS.

**Shoot**

Under drought stress condition, shoot SOD activity of *A. cepa* increased significantly as compared to control on all growth stages
and it was 162.9 per cent over control on 95th DAS (Fig. 10). Foliar application of SA and JA to drought stressed \textit{A. cepa}, further enhanced shoot SOD activity to a marked level as compared to control and drought stressed plants. Among SA treated groups, DS3 showed highest SOD activity followed by DS2 and DS1 and it was 224.2, 205.8 and 191.9 per cent over control respectively on 95th DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot SOD activity followed by DJ2 and DJ1 and it was 208.7, 195.0 and 182.9 per cent over control respectively on 95th DAS. SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

\textbf{9.2. Peroxidase activity}

\textbf{Root}

There was a significant increase in peroxidase (POD) activity in roots of \textit{A. cepa} as compared to control on all growth stages and it was 163.8 per cent over control on 95th DAS (Table 12). However, foliar application of SA and JA to drought stressed \textit{A. cepa}, increased root POD activity noticeably when compared with that of control and alone drought stress. Among the SA treated groups, DS3 showed highest root POD activity followed by DS2 and DS1 and it was 201.5, 194.9 and 186.5 per cent over control respectively on 95th DAS. Similarly among JA treated groups, DJ3 exhibited highest POD activity followed by DJ2 and DJ1 and it was 198.6, 192.3 and 184.1 per cent over control respectively on 95th DAS.
**Shoot**

The data revealed that POD activity increased significantly under drought stress condition in shoots of *A. cepa* as compared to control on all growth stages and it was 162.4 per cent over control on 95th DAS. However, treatment with SA and JA to drought stressed *A. cepa* plants, further increased POD activity to a significant level when compared to control and alone drought stress (Table 12). Among SA treated groups, DS3 exhibited highest POD activity followed by DS2 and DS1 and it was 199.1, 191.4 and 185.3 per cent over control respectively on 95th DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot POD activity followed by DJ2 and DJ1 and it was 196.4, 187.9 and 180.3 per cent over control respectively on 95th DAS. Among the two chemical treatments, SA proved more effective as compared to JA by augmenting POD activity of *A. cepa* under drought stress condition.

**9.3. Catalase activity**

**Root**

The data suggested that catalase (CAT) activity in roots of *Allium cepa* was significantly increased under drought stress as compared to control on all growth stages and it was 150.3 per cent over control on 95th DAS (Fig. 11). The foliar application of SA and JA to drought stressed *A. cepa* further enhanced rate of CAT activity to a more significant level when compared with control and drought stress alone. Among the SA treated groups, DS3 exhibited highest root CAT activity followed by DS2 and DS1 and it was 176.6, 171.1 and 162.8
per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among JA treated groups, DJ3 possessed highest CAT activity followed by DJ2 and DJ1 and it was 172.1, 166.4 and 160.2 per cent over control respectively on 95\textsuperscript{th} DAS.

**Shoot**

Under drought stress condition, shoot CAT activity of *A. cepa* increased significantly as compared to control on all growth stages and it was 154.9 per cent over control on 95\textsuperscript{th} DAS (Fig. 11). Foliar application of SA and JA to drought stressed *A. cepa*, further enhanced shoot CAT activity to a marked level as compared to control and drought stressed plants. Among SA treated groups, DS3 showed highest CAT activity followed by DS2 and DS1 and it was 183.4, 174.9 and 167.0 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly, among JA treated groups, DJ3 recorded maximum shoot CAT activity followed by DJ2 and DJ1 and it was 179.5, 170.3 and 164.0 per cent over control respectively on 95\textsuperscript{th} DAS. SA proved more effective as compared to JA by showing more prominent results under drought stress condition.

**9.4. Ascorbate peroxidase activity**

**Root**

There was a significant increase in ascorbate peroxidase (APX) activity in roots of *A. cepa* as compared to control on all growth stages and it was 163.8 per cent over control on 95\textsuperscript{th} DAS (Fig. 12). However, foliar application of SA and JA to drought stressed *A. cepa*, increased root APX activity noticeably when compared with that of control and
alone drought stress. Among the SA treated groups, DS3 showed highest root APX activity followed by DS2 and DS1 and it was 182.3, 177.2 and 170.5 per cent over control respectively on 95\textsuperscript{th} DAS. Similarly among JA treated groups, DJ3 exhibited highest APX activity followed by DJ2 and DJ1 and it was 176.6, 171.5 and 168.6 per cent over control respectively on 95\textsuperscript{th} DAS.

**Shoot**

The data shown that APX activity increased significantly under drought stress condition in shoots of \textit{A. cepa} as compared to control on all growth stages and it was 169.7 per cent over control on 95\textsuperscript{th} DAS (Fig. 12). However, treatment with SA and JA to drought stressed \textit{A. cepa} plants, further increased APX activity to a significant level when compared to control and alone drought stress. Among SA treated groups, DS3 exhibited highest APX activity followed by DS2 and DS1 and it was 203.5, 195.3 and 188.2 per cent over control respectively on 95\textsuperscript{th} DAS. Whereas, among JA treated groups, DJ3 showed maximum shoot APX activity followed by DJ2 and DJ1 and it was 198.3, 192.7 and 186.2 per cent over control respectively on 95\textsuperscript{th} DAS. SA showed better results as compared to JA in the enhancement of APX activity in both root and shoot of drought stressed \textit{A. cepa} plants.

**10. Lipid peroxidation (MDA content)**

**Root**

The data revealed that drought stress caused a significant increase in lipid peroxidation by increasing malondialdehyde (MDA)
content, the end product of lipid peroxidation, in roots of *Allium cepa* as compared to control on all growth stages and it was 210.3 per cent over control on 95\(^{th}\) DAS (Table 13). However, foliar application of SA and JA to drought stressed *A. cepa* significantly reduced lipid peroxidation by decreasing MDA content when compared with alone drought stress. Among the SA treated groups, DS3 exhibited lowest root MDA content followed by DS2 and DS1 and it was 118.6, 125.1 and 138.4 per cent over control respectively on 95\(^{th}\) DAS. Similarly among JA treated groups, DJ3 possessed lowest MDA content followed by DJ2 and DJ1 and it was 123.4, 135.7 and 144.9 per cent over control respectively on 95\(^{th}\) DAS. SA proved more effective as compared to JA.

**Shoot**

Under drought stress condition, there was two-fold increase in lipid peroxidation by the means of MDA content in shoots of *A. cepa* as compared to control on all growth stages and it was 214.8 per cent over control on 95\(^{th}\) DAS (Table 13). On the other hand, foliar application of SA and JA to drought stressed *A. cepa*, significantly decreased lipid peroxidation by decreasing MDA content as compared to drought stress alone. Among SA treated groups, DS3 showed lowest MDA content followed by DS2 and DS1 and it was 122.6, 131.5 and 145.1 per cent over control respectively on 95\(^{th}\) DAS. Similarly, among JA treated groups, DJ3 recorded minimum MDA content followed by DJ2 and DJ1 and it was 131.4, 141.9 and 152.5 per cent over control respectively on 95\(^{th}\) DAS. SA proved more effective as compared to JA.
by decreasing MDA content, hence reducing rate of lipid peroxidation in *A. cepa* under drought stress condition.

11. **Hydrogen peroxide content**

**Root**

The data suggested that there was near about 2.3 fold increase the production of hydrogen peroxide (H$_2$O$_2$) in roots of *A. cepa* as compared to control on all growth stages and it was 224.6 per cent over control on 95$^{\text{th}}$ DAS (Table 14). However, foliar application of SA and JA to drought stressed *A. cepa*, decreased H$_2$O$_2$ content noticeably when compared with that of drought stress alone. Among the SA treated groups, DS3 showed lowest root H$_2$O$_2$ content followed by DS2 and DS1 and it was 133.4, 138.9 and 146.5 per cent over control respectively on 95$^{\text{th}}$ DAS. Similarly among JA treated groups, DJ3 exhibited lowest root H$_2$O$_2$ content followed by DJ2 and DJ1 and it was 140.6, 144.2 and 151.4 per cent over control respectively on 95$^{\text{th}}$ DAS.

**Shoot**

The data shown that generation of H$_2$O$_2$ increased significantly under drought stress condition in shoots of *A. cepa* as compared to control on all growth stages and it was 232.8 per cent over control on 95$^{\text{th}}$ DAS (Table 14). However, treatment with SA and JA to drought stressed *A. cepa* plants, lowered the production of H$_2$O$_2$ when compared with that of drought stress alone. Among SA treated groups, DS3 exhibited lowest H$_2$O$_2$ content followed by DS2 and DS1 and it was 147.3, 145.3 and 156.2 per cent over control respectively on 95$^{\text{th}}$
DAS. Whereas, among JA treated groups, DJ3 showed lowest shoot 
H$_2$O$_2$ content followed by DJ2 and DJ1 and it was 151.5, 159.4 and 162.4 per cent over control respectively on 95$^{th}$ DAS. Among the two chemicals, SA proved more effective as compared to JA by preventing the excessive H$_2$O$_2$ production in A. cepa under drought stress condition.