Effect of Different Levels of Zinc and Sulphur on Morpho-Physiological Parameters of Indian Mustard

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Abstract

A field experiment and laboratory experiment was conducted in Split Plot Design with three replications during 2011-12 & 2012-13 on Indian mustard variety Urvashi at New Dairy Farm, Kalyanpur, Kanpur and Seed Testing Laboratory of Department of Seed Science and Technology, respectively. Six doses of zinc and sulphur viz. 0.0, 2.5, 5.0, 7.5, 10.0, 12.5 Kg ha⁻¹ and 0, 10, 20, 30, 40, 50 Kg ha⁻¹, respectively were applied as basal dose. Observations were recorded on morpho-physiological characters. Results showed that the application of zinc and sulphur affected significantly to all parameters. The dose 10 Kg Zn ha⁻¹ & 50 Kg S ha⁻¹ recorded highest leaf area index at 30 DAS (0.65 & 0.68), 60 DAS (1.97 & 2.04) & 90 DAS (1.64 & 1.73), chlorophyll intensity at pre-flowering (47.19 & 48.75%). Like-wise, 12.5 kg Zn and 50 Kg S ha⁻¹ had registered maximum chlorophyll intensity at post-flowering (40.73 & 41.21%), canopy temperature depression at pre-flowering (4.93 & 5.07°C) and post-flowering (4.31 & 4.32°C), respectively. The interaction zinc and sulphur did not show significant effect on leaf area index at all stages. However, rest of the characters was affected by the application of zinc and sulphur.

Keywords: Mustard, Zinc, Sulphur, Effect, Morpho-Physiological

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Introduction

Mustrad (Brasica juncea, (L) Czem and cross) is important Rabi oilseed crop which belongs to family “Cruciferae”. India is first position in area and second position in production after China. India is the fourth largest oilseed economy in the world. Oilseed crops hold a sizeable share of the country’s gross cropped area (13%) and contribute around 3% of gross national product and 10% of the value of all agricultural commodities (Anonymous, 2014). The area, production and productivity of rapeseed-mustard is 6.70 and 34.19 million ha, 7.96 and 63.09 million tonnes and 1188 and 1850 kg ha⁻¹, respectively in India and world during 2013-2014 (Anonymous, 2014).
The average productivity of oilseeds in the country is only 1153 kg ha⁻¹. As soils of U.P. are deficient in zinc and sulphur, this study will facilitate in the improvement of yield and seed quality in our state. On an average oilseed crops absorb 11-12 kg sulphur to produce one tonne (1000 kg) of seed. Average sulphur content in seed of mustard is 1.1% as compared to 0.3% in pulses and 0.2% in cereals. Sulphur is a key nutrient for oilseed production, because in the plants, sulphur is directly involved in the formation of oil compounds. In rapeseed and mustard sulphur deficient plants have leaves which are more erect than normal and cupped inwards. Initially the underside of the leaves develops a red colour which can extend to the upper surface of leaves as well (Anonymous, 2004).

High crop yield in agriculturally progressive districts of India removed substantial amounts of micronutrients especially zinc from soil, causing yield reduction (Deb and Sakal, 2002). Sulphur increased the yield of mustard by 12 to 48% under irrigation, and by 17-124% under rainfed conditions (Aulakh and Pasricha, 1988). In terms of agronomic efficiency, each kilogram of sulphur increases the yield of mustard by 7.7 kg ha⁻¹ (Katyal et al., 1997).

Zinc is an essential micronutrient for plant growth and is absorbed by the plant roots in the form of Zn²⁺. It is involved in diverse metabolic activities, influences the activities of hydrogenase and carbonic anhydrase, synthesis of cytochrome and the stabilization of ribosomal fractions and auxin metabolism (Tisdale et al., 1984). Principle function of zinc in plants is as a metal activator of enzymes. Zinc entered into the constituents of enzyme system that regulate initial metabolic reactions in the plants body. Zinc catalyses the process of oxidation in plant cells and is vital for the transformation of carbohydrates. It regulates the consumption of sugars and increases the source of energy for the production of chlorophyll. Zinc also aids in the formation of auxin and synthesis of protein.

Zinc plays vital role in carbohydrate and proteins metabolism as well as it controls the plant growth hormone IAA. It is essential component of dehydrogenase, proteinase and promotes starch formation, seed maturation and production (Marschner, 1995).

Materials and Methods

The experiment was conducted at the New Dairy Research Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kalyanpur, Kanpur UP during 2011-12 and 2012-13 on Indian mustard variety Urvashi under Split Plot Design with three replications having plant distance 45 cm and 5 cm respectively. Five rows were sown in each plot of 4 × 2.25 m². The recommended fertilizer was applied at the rate of 120 Kg N, 60 Kg P₂O₅ and 40 Kg K₂O ha⁻¹ uniformly in all plots as feeder dose and plant protection measure were Spraying of Malathion 50 EC @ 1 liter dissolved in 1000 liters of water ha⁻¹ for the control of hairy caterpillar. Spraying of Imidachloroprid 17.8 EC @ 375 ml in 1000 liters of water ha⁻¹ was applied as per requirement for the control of aphids. The study was consisted of two factors viz. zinc and sulphur with Six doses of zinc and sulphur viz. 0.0, 2.5, 5.0, 7.5, 10.0, 12.5 Kg ha⁻¹ and 0, 10, 20, 30, 40, 50 Kg ha⁻¹, respectively were applied as basal dose. The composition of soil of the experimental plot is alluvial in nature. The soil samples were drawn and analyzed in the Soil Testing Laboratory Chandra Shekhar Azad University of Agriculture and Technology, Kanpur for different physical and chemical composition following the standard procedure.

Data were Recorded Leaf Area Index was calculated by formula given by Watson (1947). Chlorophyll Intensity was determine
by chlorophyll meter SPAD 502 and expressed as per cent. Canopy Temperature Depression was measured by Infrared Thermometer (Teletamp AG, USA) and expressed as °C.

**Results and Discussion**

**Effect of zinc and sulphur on leaf area index (30 DAS)**

Data related to (LAI) leaf area index of Indian mustard at 30 days after sowing as influenced by different levels of zinc and sulphur have been presented in Table 1 and Fig. 5 and their respective mean sum of squares are shown in Appendix I.

It is clear from the appendix I that the zinc application had significant effect on leaf area index (LAI) at 30 DAS. It is perceptible from the table 41 that all treatments Zn0 and Zn1, Zn2 and Zn3 and Zn4 and Zn5 which showed non-significant difference to each other. Maximum leaf area index was recorded in the treatment Zn5 (0.65) while minimum was found in control (0.63). Fig. 5 reveals that leaf area index was increased with increasing level of zinc.

It is obvious from the Appendix I that different doses of sulphur applied had significant effect on leaf area index at 30 DAS. It is perceptible from the Table 1 that all treatments differed significantly to each other except S4 and S5, which showed non-significant difference to each other. Every increasing dose of sulphur significantly increased leaf area index at 30 days after sowing during experimentation (Fig. 5). Highest leaf area index was observed in S5 (0.68) while lowest (0.60) was found in control.

The data pertaining to leaf area index at 30 DAS with different levels of zinc and sulphur application was found non-significant during experimentation (Appendix I). The maximum leaf area index was recorded maximum (0.70) with the treatment combination of Zn4 × S5 while minimum (0.59) was obtained with Zn0 × S0 (Table 1).

**Effect of zinc and sulphur on leaf area index (60 DAS)**

The results obtained on leaf area index of Indian mustard at 60 days after sowing as influenced by different levels of zinc and sulphur have been presented in Table 1 and Fig. 6 and their respective mean sum of squares are shown in Appendix I.

It is evident from the appendix I that the zinc application had significant effect on leaf area index at 60 DAS. Table 1 shows that the treatment has exhibited significant variations. Though, non-significant difference was observed between the treatments Zn0 and Zn1 and Zn4 and Zn5, however, Zn2 and Zn3 showed significant difference. Enhancement in the leaf area index was accompanied by increase in the doses applied (Fig. 6). Maximum LAI (1.97) was recorded in the treatment Zn4 which showed at par with Zn5 while minimum (1.91) was found in control.

Appendix I showed significant effect on leaf area index at 60 DAS. Various levels of sulphur differed significantly with respect to Leaf Area Index at 60 DAS (Table 1). The treatments S0 and S1, S2 and S3 and S4 and S5 exhibited non-significant difference. Every increasing dose of sulphur significantly increased leaf area index at 60 days after sowing during experimentation (Fig. 6). The maximum leaf area index (2.04) was noticed in S5 and minimum (1.83) was reported in control.

Interaction of zinc and sulphur showed non-significant effect with respect to LAI at 60 DAS.
DAS during experimentation (Appendix I). The maximum leaf area index (2.09) was observed with the treatment combination of Zn$_5$ × S$_5$ while the lowest (1.81) was recorded in Zn$_0$ × S$_0$ (Table 1).

**Effect of zinc and sulphur on leaf area index (90 DAS)**

Data pertaining to leaf area index at 90 days after sowing of mustard as influenced by different levels of zinc and sulphur are presented in Table 4.1, 4.4 and Fig. 7 and their respective mean sum of square have been shown in Appendix I. It is clear from the Appendix I that different doses of zinc applied showed significant effect on leaf area index at 90 DAS. Table 4.1 indicates that the treatment Zn$_0$ and Zn$_1$, Zn$_2$ and Zn$_3$ and Zn$_4$ and Zn$_5$ did not show significant difference. Maximum LAI (1.64) was recorded in Zn$_4$ while minimum (1.57) was found in control (Fig. 7).

Appendix I showed significant effect on leaf area index at 90 days after sowing. Various levels of sulphur expressed significant effect with respect on LAI at 90 DAS. The treatments showed significant difference to each other. Significantly highest leaf area index (1.73) in the treatment S$_5$ was obtained while minimum (1.49) was reported in control (Table 1).

The interaction of zinc and sulphur did not show significant effect with leaf area index at 90 DAS in Appendix IX. However, numerically maximum leaf area index was found in the treatment combination of Zn$_5$ × S$_5$ while lowest recorded in Zn$_0$ × S$_0$ (Table 4.4).

**Effect of zinc and sulphur on chlorophyll intensity pre-flowering stage**

Data on chlorophyll intensity at pre-flowering of Indian mustard as influenced by various levels of zinc and sulphur have been presented in Table 4.5 and 4.6 and their mean sum of square are given in Appendix I. It is apparent from the Appendix I that the application of different levels of zinc significantly influenced the chlorophyll intensity at pre-flowering of Indian mustard. Treatment Zn$_0$ to Zn$_3$ differed significantly to one another while the treatment Zn$_4$ and Zn$_5$ did not show significant difference (Table 2). Application of highest tested dose of Zn$_5$ significantly recorded highest chlorophyll intensity at pre-flowering (47.23%) as compared to rest of the doses of zinc while it was at par with Zn$_4$. It was also observed that the application of Zn$_4$ produced more chlorophyll intensity at pre-flowering (47.19%) followed by Zn$_3$ (46.58%), Zn$_2$ (45.46%) and Zn$_1$ (44.78%), respectively. The minimum chlorophyll intensity at pre-flowering (43.78%) of Indian mustard was obtained with control plots (Fig. 8).

It is obvious from the Appendix I that the application of different doses of sulphur significantly improved the chlorophyll intensity at pre-flowering of Indian mustard. Every increasing dose of sulphur significantly increased the chlorophyll intensity at pre-flowering stage during experimentation. Table 2 shows that all treatment differed significantly to each other. Significantly highest chlorophyll intensity at pre-flowering (48.75%) stage was obtained with the application of S$_5$ as compared to rest of the doses of sulphur. Without sulphur applied plots (control) recorded minimum chlorophyll intensity at pre-flowering (42.70%) of Indian mustard (Fig. 8).

Interaction effect of various levels of zinc and sulphur was significant on chlorophyll intensity at pre-flowering in Table 4.6. Maximum chlorophyll intensity at pre-flowering (51.30%) was obtained with the combined application of Zn$_4$ × S$_5$ and the second best treatment (50.58%) found in Zn$_5$ × S$_5$ while minimum chlorophyll intensity at pre-flowering (41.45%) was obtained in absolute control plot (Fig.9)
Effect of zinc and sulphur on chlorophyll intensity at post-flowering stage

The pertained data on chlorophyll intensity at post-flowering of Indian mustard as influenced by various levels of zinc and sulphur have been presented in Table 4.5 and 4.7 and their mean sum of square are given in Appendix I.

It is clear from the Appendix I that the application of different levels of zinc significantly influenced chlorophyll intensity at post-flowering of Indian mustard. All treatments differed significantly to one another. Application of highest tested dose of Zn$_5$ significantly recorded highest chlorophyll intensity at post-flowering (40.73%) as compared to rest of the doses of zinc. The minimum chlorophyll intensity at post-flowering (35.63%) of Indian mustard was obtained with control plot (Fig. 10).

It is obvious from the Appendix I that the application of different doses of sulphur significantly improved the chlorophyll intensity at post-flowering stage during experimentation. Table 4.5 shows that all treatments differed significantly to one other. The highest chlorophyll intensity at post-flowering (41.21%) stage was obtained with the application of S$_5$ as compared to rest of the doses of sulphur. Without sulphur applied plots (control) recorded minimum chlorophyll intensity at post-flowering stage (35.82%) of Indian mustard (Fig. 10).

The interaction effect of various levels of zinc and sulphur was significant on chlorophyll intensity at post-flowering in Table 2. Maximum chlorophyll intensity at post-flowering (44.60%) was obtained with the combined application of Zn$_5$ $\times$ S$_4$ and statistically to be at par with Zn$_4$ $\times$ S$_4$ while minimum chlorophyll intensity at post-flowering (34.05%) was obtained in absolute control plot (Fig. 11).

Effect of zinc and sulphur on canopy temperature depression ($^\circ$C) at pre-flowering stage

Data pertaining to canopy temperature depression ($^\circ$C) at pre-flowering of Indian mustard as influenced by different doses of zinc and sulphur have been presented in Table 4.8 and 4.9 and their respective mean sum of square are given in Appendix I.

Appendix I expressed the significant effect on canopy temperature depression ($^\circ$C) at pre-flowering stage of Indian mustard. Table 3 indicates that the treatment Zn$_0$, Zn$_1$, Zn$_2$, Zn$_3$, Zn$_4$ and Zn$_5$ exhibited significant difference to each other. The highest canopy temperature depression ($^\circ$C) at pre-flowering (4.93$^\circ$C) of Indian mustard was recorded with the application of Zn$_5$ as compared to rest of the doses of zinc. The minimum canopy temperature depression ($^\circ$C) at pre-flowering (4.19$^\circ$C) was obtained in control (Fig. 12).

It is evident from the Appendix I that the application of various doses of sulphur significantly increased the canopy temperature depression ($^\circ$C) at pre-flowering stage of Indian mustard. Table 4.8 reveals that every increasing dose of sulphur significantly increased canopy temperature depression at pre-flowering of Indian mustard. Application of highest tested dose of sulphur i.e. S$_5$ recorded significant highest canopy temperature depression at pre-flowering (5.06$^\circ$C) stage of Indian mustard than the other levels of sulphur application. Minimum canopy temperature depression at pre-flowering (4.09$^\circ$C) was obtained in control plot (Fig. 12).
The interaction effect on canopy temperature depression at pre-flowering stage was significantly influenced due to various levels of sulphur and zinc (Appendix X). Highest canopy temperature depression (5.47°C) at pre-flowering was observed in Zn5 × S5 and it was statistically at par to the interaction of Zn4 × S5 and Zn5 × S4. Lowest (3.85°C) was reported in the treatment combination of without sulphur and zinc applied plot (Zn0S0), (Fig. 13 and Table 3).

Effect of zinc and sulphur on canopy temperature depression (°C) at post-flowering stage

The results obtained on canopy temperature depression (°C) at post-flowering stage of Indian mustard as influenced by different doses of zinc and sulphur have been presented in Table 4.8 and 4.10 and their respective mean sum of square are given in Appendix I.

It is clear from the Appendix I that the application of various doses of zinc had influence the canopy temperature depression at post-flowering. Table 4.8 reveals that the treatment Zn0, Zn1, Zn2, Zn3, Zn4 and Zn5 showed significant difference to each other. The treatment Zn5 showed highest canopy temperature depression (4.31°C) followed by Zn4 (Fig. 14). The minimum canopy temperature depression (3.74°C) of Indian mustard was recorded in control. Increasing trends in canopy temperature depression at post-flowering stage due to zinc application were observed as dose increased.

It is evident from the Appendix X that the application of various doses of sulphur significantly increased the canopy temperature depression (°C) at post-flowering stage of Indian mustard. Table 4.8 shows that the treatment S5 recorded significantly higher canopy temperature depression at post-flowering (4.32°C) of Indian mustard than rest of doses applied except S4. The treatment S4 and S5 was found to be differed non-significantly. The progressive increase in canopy temperature depression at post-flowering of Indian mustard was accompanied by increase in sulphur levels. Minimum canopy temperature depression at post-flowering (3.74°C) was observed in control plot, respectively (Fig. 14).

Appendix X depicted canopy temperature depression at post-flowering stage was significantly influenced due to various levels of sulphur and zinc. Most of the treatment combination differed significantly to each other. Table 4.10 reveals that interaction of Zn5 × S5 recorded significantly highest canopy temperature depression at post-flowering (4.63°C) and it was statistically at par to the interaction of Zn4 × S5 and Zn5 × S4. While minimum (3.27°C) was reported in the treatment combination of without zinc and sulphur applied plot (Zn0 × S0) (Fig. 15).
Fig. 8: Effect of Zinc and Sulphur on Chlorophyll Intensity (%) at Pre-flowering in Indian Mustard Variety Urvashi

Fig. 9: Interaction Effect of Zinc and Sulphur on Chlorophyll Intensity (%) at Pre-flowering in Indian Mustard Variety Urvashi (Pooled)

Fig. 10: Effect of Zinc and Sulphur on Chlorophyll intensity (%) at Post-flowering in Indian Mustard Variety Urvashi
Fig. 13: Interaction Effect of Zinc and Sulphur and on Canopy Temperature Depression (°C) at Pre-flowering in Indian Mustard Variety Urvashi (Pooled)

Fig. 14: Effect of Zinc and Sulphur on Canopy Temperature Depression (°C) at Post-flowering in Indian Mustard Variety Urvashi
Table 1 Interaction Effect of Zinc and Sulphur on Leaf Area Index at 30, 60 and 90 DAS in Indian Mustard Variety Urvashi (Pooled).

| Zinc          | Sulphur | 0 Kg S ha\(^{-1}\) (S\(_0\)) | 10 Kg S ha\(^{-1}\) (S\(_1\)) | 20 Kg S ha\(^{-1}\) (S\(_2\)) | 30 Kg S ha\(^{-1}\) (S\(_3\)) | 40 Kg S ha\(^{-1}\) (S\(_4\)) | 50 Kg S ha\(^{-1}\) (S\(_5\)) | 0 Kg S ha\(^{-1}\) (S\(_0\)) | 10 Kg S ha\(^{-1}\) (S\(_1\)) | 20 Kg S ha\(^{-1}\) (S\(_2\)) | 30 Kg S ha\(^{-1}\) (S\(_3\)) | 40 Kg S ha\(^{-1}\) (S\(_4\)) | 50 Kg S ha\(^{-1}\) (S\(_5\)) | 0 Kg S ha\(^{-1}\) (S\(_0\)) | 10 Kg S ha\(^{-1}\) (S\(_1\)) | 20 Kg S ha\(^{-1}\) (S\(_2\)) | 30 Kg S ha\(^{-1}\) (S\(_3\)) | 40 Kg S ha\(^{-1}\) (S\(_4\)) | 50 Kg S ha\(^{-1}\) (S\(_5\)) |
|---------------|---------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| 0.0 Kg Zn ha\(^{-1}\) (Zn\(_0\)) | 0.59    | 0.61                          | 0.62                          | 0.63                          | 0.65                          | 0.67                          | 1.81                          | 1.85                          | 1.89                          | 1.92                          | 1.96                          | 2.00                          | 1.46                          | 1.50                          | 1.54                          | 1.60                          | 1.64                          | 1.69                          |
| 2.5 Kg Zn ha\(^{-1}\) (Zn\(_1\)) | 0.59    | 0.60                          | 0.62                          | 0.64                          | 0.66                          | 0.68                          | 1.82                          | 1.86                          | 1.90                          | 1.93                          | 1.96                          | 2.01                          | 1.47                          | 1.50                          | 1.56                          | 1.61                          | 1.66                          | 1.71                          |
| 5.0 Kg Zn ha\(^{-1}\) (Zn\(_2\)) | 0.60    | 0.62                          | 0.63                          | 0.65                          | 0.67                          | 0.68                          | 1.83                          | 1.87                          | 1.91                          | 1.95                          | 1.99                          | 2.04                          | 1.48                          | 1.52                          | 1.58                          | 1.62                          | 1.68                          | 1.72                          |
| 7.5 Kg Zn ha\(^{-1}\) (Zn\(_3\)) | 0.61    | 0.62                          | 0.64                          | 0.65                          | 0.68                          | 0.69                          | 1.84                          | 1.88                          | 1.92                          | 1.97                          | 2.02                          | 2.05                          | 1.50                          | 1.53                          | 1.60                          | 1.64                          | 1.69                          | 1.74                          |
| 10.0 Kg Zn ha\(^{-1}\) (Zn\(_4\)) | 0.61    | 0.63                          | 0.64                          | 0.66                          | 0.68                          | 0.70                          | 1.85                          | 1.90                          | 1.95                          | 2.00                          | 2.05                          | 2.09                          | 1.52                          | 1.56                          | 1.62                          | 1.67                          | 1.73                          | 1.77                          |
| 12.5 Kg Zn ha\(^{-1}\) (Zn\(_5\)) | 0.61    | 0.63                          | 0.64                          | 0.66                          | 0.68                          | 0.69                          | 1.85                          | 1.89                          | 1.94                          | 1.99                          | 2.04                          | 2.07                          | 1.51                          | 1.55                          | 1.61                          | 1.66                          | 1.72                          | 1.75                          |
| SE (d)        |         | 0.09                          |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |
| CD (p = 0.05) |         | N.S.                          |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               |                               | N.S.                          |
**Table 2** Interaction Effect of Zinc and Sulphur on Chlorophyll Intensity (%) at Pre-flowering and Post-flowering in Indian Mustard Variety

| Zinc          | Sulphur | Chlorophyll Intensity (%) Pre-flowering | Chlorophyll Intensity (%) Post-flowering |
|--------------|---------|----------------------------------------|------------------------------------------|
|              | 0 Kg S ha⁻¹ (S₀) | 10 Kg S ha⁻¹ (S₁) | 20 Kg S ha⁻¹ (S₂) | 30 Kg S ha⁻¹ (S₃) | 40 Kg S ha⁻¹ (S₄) | 50 Kg S ha⁻¹ (S₅) | 0 Kg S ha⁻¹ (S₀) | 10 Kg S ha⁻¹ (S₁) | 20 Kg S ha⁻¹ (S₂) | 30 Kg S ha⁻¹ (S₃) | 40 Kg S ha⁻¹ (S₄) | 50 Kg S ha⁻¹ (S₅) |
| 0.0 Kg Zn ha⁻¹ (Zn₀) | 41.45 | 42.55 | 43.40 | 44.40 | 45.10 | 45.80 | 34.05 | 34.60 | 35.30 | 35.85 | 36.45 | 36.50 |
| 2.5 Kg Zn ha⁻¹ (Zn₁) | 41.93 | 43.70 | 44.65 | 45.60 | 45.95 | 46.85 | 34.57 | 35.75 | 36.95 | 36.80 | 37.80 | 37.85 |
| 5.0 kg Zn ha⁻¹ (Zn₂) | 42.43 | 44.23 | 45.23 | 45.85 | 46.88 | 48.13 | 36.00 | 36.50 | 36.70 | 38.00 | 39.95 | 39.40 |
| 7.5 Kg Zn ha⁻¹ (Zn₃) | 42.98 | 44.63 | 45.50 | 46.83 | 49.68 | 49.83 | 36.20 | 37.30 | 38.05 | 39.05 | 41.38 | 41.15 |
| 10.0 kg Zn ha⁻¹ (Zn₄) | 43.45 | 44.85 | 45.82 | 47.27 | 50.48 | 51.30 | 37.10 | 38.05 | 39.05 | 40.42 | 44.10 | 43.35 |
| 12.5 Kg Zn ha⁻¹ (Zn₅) | 43.95 | 44.87 | 46.30 | 47.60 | 50.05 | 50.58 | 37.98 | 38.25 | 39.30 | 41.40 | 44.60 | 43.85 |

SE (d) 0.33
CD (p = 0.05) 0.66
Table 3 Interaction Effect of Zinc and Sulphur on Canopy Temperature Depression (°C) at Pre-flowering and Post-flowering in Indian Mustard Variety Urvashi (Pooled)

| Zinc       | Sulphur | Depression (°C) at Pre-flowering | Depression (°C) at Post-flowering |
|------------|---------|---------------------------------|----------------------------------|
|            | 0 Kg S ha⁻¹ (S₀) | 10 Kg S ha⁻¹ (S₁) | 20 Kg S ha⁻¹ (S₂) | 30 Kg S ha⁻¹ (S₃) | 40 Kg S ha⁻¹ (S₄) | 50 Kg S ha⁻¹ (S₅) | 0 Kg S ha⁻¹ (S₀) | 10 Kg S ha⁻¹ (S₁) | 20 Kg S ha⁻¹ (S₂) | 30 Kg S ha⁻¹ (S₃) | 40 Kg S ha⁻¹ (S₄) | 50 Kg S ha⁻¹ (S₅) |
| 0.0 Kg Zn ha⁻¹ (Zn₀) | 3.85 | 3.96 | 4.20 | 4.26 | 4.37 | 4.52 | 3.27 | 3.65 | 3.78 | 3.87 | 3.92 | 3.97 |
| 2.5 Kg Zn ha⁻¹ (Zn₁) | 4.00 | 4.06 | 4.33 | 4.45 | 4.62 | 4.78 | 3.70 | 3.77 | 3.95 | 4.05 | 4.07 | 4.12 |
| 5.0 Kg Zn ha⁻¹ (Zn₂) | 4.03 | 4.22 | 4.48 | 4.72 | 4.93 | 5.07 | 3.78 | 3.88 | 4.03 | 4.13 | 4.22 | 4.27 |
| 7.5 Kg Zn ha⁻¹ (Zn₃) | 4.12 | 4.28 | 4.56 | 4.80 | 5.05 | 5.23 | 3.85 | 3.97 | 4.13 | 4.15 | 4.30 | 4.40 |
| 10.0 Kg Zn ha⁻¹ (Zn₄) | 4.23 | 4.42 | 4.57 | 5.02 | 5.25 | 5.32 | 3.90 | 4.08 | 4.17 | 4.22 | 4.45 | 4.55 |
| 12.5 Kg Zn ha⁻¹ (Zn₅) | 4.28 | 4.58 | 4.83 | 5.12 | 5.31 | 5.47 | 3.97 | 4.17 | 4.22 | 4.33 | 4.57 | 4.63 |
| SE (d)     | 0.09               |               |               |               |               |               | 0.09 |               |               |               |               |               |
| CD (p = 0.05) | **0.18**         |               |               |               |               |               | 0.17 |               |               |               |               |               |
Appendix I Data for the year 2011-12 and 2012-12 for the character, Chlorophyll Intensity (%) and Canopy Temperature Depression (°C) at Pre and Post-Flowering Stage

| Treatments | Chlorophyll Intensity (%) | Canopy Temperature Depression (°C) |
|------------|---------------------------|-----------------------------------|
|            | Pre-flowering | Post-flowering | Pre-flowering | Post-flowering |
|            | 2011-12   | 2012-13   | 2011-12   | 2012-13   | 2011-12   | 2012-13   |
| **S₀Zn₀**  | 42.4       | 40.5       | 35.4       | 32.7       | 3.8       | 3.9       | 3.3       | 3.3       |
| **S₀Zn₁**  | 42.6       | 41.3       | 35.6       | 33.5       | 4.0       | 3.9       | 3.7       | 3.7       |
| **S₀Zn₂**  | 43.0       | 41.9       | 37.2       | 34.8       | 4.1       | 4.0       | 3.8       | 3.8       |
| **S₀Zn₃**  | 43.5       | 42.5       | 37.2       | 35.2       | 4.2       | 4.0       | 3.8       | 3.9       |
| **S₀Zn₄**  | 43.9       | 43.0       | 37.7       | 36.5       | 4.2       | 4.3       | 3.9       | 3.9       |
| **S₀Zn₅**  | 44.1       | 43.8       | 37.9       | 36.1       | 4.3       | 4.3       | 4.0       | 4.0       |
| **S₁Zn₀**  | 43.0       | 42.1       | 36.0       | 33.2       | 3.9       | 4.2       | 3.7       | 3.6       |
| **S₁Zn₁**  | 43.6       | 43.8       | 36.7       | 34.8       | 4.0       | 4.1       | 3.8       | 3.8       |
| **S₁Zn₂**  | 44.3       | 44.2       | 37.5       | 35.5       | 4.2       | 4.2       | 3.9       | 3.9       |
| **S₁Zn₃**  | 44.6       | 44.7       | 38.2       | 36.4       | 4.3       | 4.3       | 4.0       | 4.0       |
| **S₁Zn₄**  | 44.7       | 45.0       | 38.8       | 37.3       | 4.4       | 5.4       | 4.0       | 4.1       |
| **S₁Zn₅**  | 44.5       | 45.2       | 39.4       | 37.1       | 4.6       | 4.6       | 4.1       | 4.2       |
| **S₂Zn₀**  | 43.5       | 43.3       | 36.6       | 34.3       | 4.2       | 4.2       | 3.8       | 3.8       |
| **S₂Zn₁**  | 44.8       | 44.5       | 37.1       | 34.9       | 4.3       | 4.3       | 3.9       | 4.0       |
| **S₂Zn₂**  | 45.3       | 45.2       | 37.7       | 35.7       | 4.6       | 4.4       | 4.0       | 4.1       |
| **S₂Zn₃**  | 45.4       | 45.6       | 38.3       | 37.5       | 4.7       | 4.6       | 4.1       | 4.2       |
| **S₂Zn₄**  | 45.7       | 45.9       | 39.2       | 38.9       | 4.8       | 4.7       | 4.1       | 4.2       |
| **S₂Zn₅**  | 46.1       | 46.5       | 40.0       | 38.6       | 4.9       | 4.7       | 4.2       | 4.2       |
| **S₃Zn₀**  | 44.0       | 44.8       | 37.6       | 34.8       | 4.2       | 4.3       | 3.9       | 3.9       |
| **S₃Zn₁**  | 45.3       | 45.9       | 38.1       | 35.5       | 4.5       | 4.3       | 4.0       | 4.1       |
| **S₃Zn₂**  | 45.3       | 46.4       | 39.3       | 36.7       | 4.9       | 4.6       | 4.1       | 4.1       |
| **S₃Zn₃**  | 46.2       | 47.5       | 40.5       | 31.6       | 4.9       | 4.6       | 4.1       | 4.2       |
| **S₃Zn₄**  | 46.6       | 47.9       | 41.3       | 40.2       | 5.1       | 4.9       | 4.2       | 4.2       |
| **S₃Zn₅**  | 46.7       | 48.5       | 42.7       | 40.1       | 5.3       | 4.9       | 4.4       | 4.3       |
| **S₄Zn₀**  | 44.7       | 45.5       | 37.7       | 35.3       | 4.3       | 4.4       | 3.9       | 3.9       |
| **S₄Zn₁**  | 45.8       | 46.1       | 38.9       | 36.8       | 4.7       | 4.5       | 4.0       | 4.1       |
| **S₄Zn₂**  | 46.5       | 47.3       | 40.2       | 38.6       | 4.8       | 4.7       | 4.2       | 4.2       |
| **S₄Zn₃**  | 50.6       | 48.8       | 41.8       | 40.5       | 5.1       | 4.9       | 4.3       | 4.3       |
| **S₄Zn₄**  | 47.9       | 51.5       | 43.0       | 43.7       | 5.3       | 5.2       | 4.4       | 4.5       |
| **S₄Zn₅**  | 48.8       | 51.3       | 43.5       | 43.5       | 5.3       | 5.3       | 4.6       | 4.5       |
| **S₅Zn₀**  | 45.4       | 46.2       | 38.1       | 36.4       | 4.5       | 4.5       | 4.0       | 4.0       |
| **S₅Zn₁**  | 47.2       | 46.5       | 39.7       | 37.9       | 4.7       | 4.8       | 4.1       | 4.1       |
| **S₅Zn₂**  | 48.5       | 47.8       | 40.4       | 39.5       | 5.1       | 5.0       | 4.3       | 4.3       |
| **S₅Zn₃**  | 50.3       | 49.4       | 42.2       | 42.6       | 5.2       | 5.2       | 4.4       | 4.4       |
| **S₅Zn₄**  | 50.1       | 52.5       | 43.2       | 44.7       | 5.3       | 5.3       | 4.5       | 4.6       |
| **S₅Zn₅**  | 49.0       | 52.2       | 45.3       | 43.9       | 5.5       | 5.4       | 4.6       | 4.6       |
| **SE (d)** | 0.07       | 0.25       | 0.07       | 0.25       | 0.04      | 0.05      | 0.06      | 0.03      |

CD (p=0.05) 0.17 0.55 0.16 0.55 0.09 0.11 0.13 0.13

Note: Pooled data has already been presented under the chapter (IV) Experimental Finding.
In the present investigation, all morpho-physiological parameters were affected significantly due to application of various doses of zinc and sulphur. The linear increase in values related to morpho-physiological parameters due to application of zinc and sulphur was observed. The dose 10 Kg ha\(^{-1}\) zinc and 50 Kg ha\(^{-1}\) sulphur exhibited profound effect at 90 DAS with respect to leaf area index. Though the same dose has also shown increasing results 60 DAS. At 30 DAS least effect of zinc and sulphur doses were recorded as compared to 60 and 90 DAS. No interaction effect of zinc and sulphur was recorded at any stages of days after sowing. As far as concerned with chlorophyll intensity at pre-flowering and post-flowering stages, 10 (Zn\({}_{4}\)) and 12.5 (Zn\({}_{5}\)) Kg ha\(^{-1}\) zinc recorded highest chlorophyll intensity per cent, respectively. However, application of 50 Kg S ha\(^{-1}\) recorded highest chlorophyll intensity per cent that is 48.47\% and 41.21\% at pre-flowering and post-flowering stages, respectively. It has also been visualized that all treatments of zinc and sulphur expressed significant difference to one another. Significant interaction of zinc and sulphur were recorded with respect to chlorophyll intensity at pre-flowering and post-flowering stages, a combination of 10 Kg Zn ha\(^{-1}\) + 50 Kg S ha\(^{-1}\) (Zn\(_4\) × S\(_5\)) produced maximum chlorophyll intensity that is 51.30\%. However, at post-flowering stage a combined effect of 10 Kg Zn ha\(^{-1}\) + 40 Kg S ha\(^{-1}\) (Zn\(_4\) × S\(_4\)) were found to be beneficial by scoring 44.10\% as compared to rest of the combinations. As far as concerned to canopy temperature depression at pre-flowering and post-flowering stage, upto the application of 12.5 Kg Zn and 50 Kg S had produced highest canopy temperature depression recorded with 4.93 and 4.31\(^{0}\)C and 5.06 and 4.32\(^{0}\)C, respectively. Linear increased in canopy temperature depression was recorded with every increasing dose of zinc and sulphur. Interaction of zinc and sulphur exhibited significant effect of canopy temperature depression at pre-flowering stage. An application of 10 Kg Zn ha\(^{-1}\) + 50 Kg S ha\(^{-1}\) (Zn\(_4\) × S\(_3\)) was found to be best among all combination applied during the investigation. It seems that the application of zinc and sulphur interacts with physiological activities of the plant that helps better in growth of the plants. The increase in leaf area index of Indian mustard due to Zinc and sulphur application have also been reported by Upasani and Sharma (1986), Khanpara et al. (1993), Patel and Sheeke (1998), Upadhyay et al. (2000), Chandel et al. (2003), Mankar et al. (2004), Raut et al. (2004), Husain et al. (2004), Sahu et al. (2004), Kumar (2005), Singh et al. (2007), Jain et al. (2008), Verma et al. (2012), Sharifi (2012), Singh et al. (2012).

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