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Studies on the effect of salicylic acid on mitigating terminal heat stress in Indian mustard (*Brassica juncea* L. Czren & Coss)

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Abstract
Due to the extensive use of intensive cropping systems, especially in north-western India, late mustard planting is quite widespread, which poses an alarming danger to mustard globally. As a result, mustard crop has to face the problem of terminal heat stress. It alters the morpho-anatomical, physiological, and biochemical aspects of plants, affecting their growth and development and lowering their output. Nonetheless, there exist diverse approaches to enhance yield in mustard following anthesis when exposed to elevated temperatures. The study was conducted at the Students Instructional Farm at Acharya Narendra Deva University of Agriculture and Technology during rabi season 2021-22 and 2022-23. The Maya, NDR-8501, and RH-725 varieties of mustard were used in the experiment. Using chemicals that induce heat tolerance, seeds were sown on three separate dates: (D1) sown on October 15, (D2) sown on October 30, and (D3) sown on November 15. At regular intervals, information on various parameters was gathered. The optimum date of sowing for mustard was observed as October 30^{th} in the Ayodhya district of eastern Uttar Pradesh (North India). In the case of heat tolerance inducing chemicals, the higher growth components, seed yield, and contributing traits were recorded when applying salicylic acid (800 ppm), followed by salicylic acid (400 ppm), and the effect between the date of sowing and heat-inducing chemicals was also observed. Due to terminal heat stress, seed yield and its contributing qualities performed poorly since the planting was delayed. Therefore, the seed yield might be changed by using chemicals that cause heat, even postponing sowing until November, and vice versa.

Keywords: Salicylic acid, mitigating terminal heat stress, *Brassica juncea* L. Czren & Coss

Introduction

Mustard is an important oil seed crop in India and belongs to the family *Brassicaceae*. The mustard cultivated in India is known as Indian mustard or Rai (*Brassica juncea* L. Czern & Coss). According to Vavilov and Walknish, mustard originated in some parts of China, India, and Europe. In India, groundnuts are the most significant edible oilseed crop category after rapeseed and mustard. Of the entire area planted to these crops, around 85% is devoted to Indian mustard *(Brassica juncea* L.). Mustard is an often-cross-pollinated crop and is mostly pollinated by honey bees. Botanically, there are six species in the genus Brassica: *B. nigra*, B. oleracea, *B. rapa*, *B. carinata*, *B. juncea*, and *B. napus*. Among them, the first three species are elementary and diploid with 2n = 16, 18, and 20 chromosomes, respectively, and the other three are tetraploids with chromosome numbers 2n = 34, 36, and 38, respectively. These entire crops are grown under a wide range of agro-climatic conditions.

Most mustard crops are grown in regions with moderate temperatures. It is also cultivated in many tropical and subtropical regions as a crop for cold weather. Plant responses to high temperature stress are influenced by several factors, including genotype, stress intensity (SI), and duration of stress. Generally, Plants adapt their physiology, metabolism, and development in response to stress (Moradshahi *et al*., 2004) [18]. Heat stress at the flowering stage is a problem in several major mustard-growing countries, including Europe, Canada, Australia, and China; on the other hand, heat stress in the seedling and terminal phases is unique to India. The thermal tolerance of oilseed brassica during flowering has been extensively studied (Yadav *et al*., 1989 & 1990) [34, 33], but little is known about the plant's resistance to heat during the seedling and terminal phases. It is known that additional heat tolerance in agricultural plants is a stage-specific phenomena, meaning that tolerance in one developmental stage may not be related to tolerance in later stages. Additional heat tolerance is regulated during the developing process (Wahid *et al*., 2007) [30].

One of the main environmental stresses that affects crop growth, metabolism, and yield is high temperatures. Terminal heat stress is the phrase used to describe high temperature stress during reproductive development. According to Hall (1992) [8], the most vulnerable time for temperature stress damage is during blooming, most likely because of sensitivity during pollen formation, anthesis, and fertilisation, which lowers crop output. In the eastern part of Uttar Pradesh, mustard is planted after rice is harvested, hastening the crop's true maturity. The mustard crop suffers in the final stages of seed development and maturity as a result of such stress. Therefore, in order to deal with the high temperatures, these difficulties must be addressed immediately. In Brassica, high temperatures accelerate plant growth and result in blossom abortion, which significantly reduces seed output. Salicylic acid is a common phenolic molecule that influences several physiological and biochemical processes to improve photosynthesis during heat stress. It has been discovered that salicylic acid may activate the superoxide dismutase in a few different plant species (Rao *et al*. 1992) [22].

Material and Method

The field experiment was conducted at the Students Instructional Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) during Rabi 2021–22 and 2022–23. Geographically, the farm is situated in the Gangetic Plains of eastern Uttar Pradesh, between latitudes 24.470 and 26.560 N and longitudes 82.120 and 83.980 E. It is 113 metres above mean sea level. This region has a subtropical climate. The region receives 762 mm of rainfall per year, with the majority falling between the final week of June and the middle of October. Occasional showers also happen during the winter. The experimental site's characteristics were an electrical conductivity (EC) of 0.96 ds/m, 8.8 pH, 180 kg available N/ha, 11.80 kg available P2O5/ha, 180 kg available K2O/ha, and 0.31 percent organic carbon. Following thinning, the distances between rows and plants inside a row were kept at 30 and 15 cm, respectively. The studies were set up in a factorial RBD with three replications at three sowing dates and heat-mitigating chemical induction at the vegetative and anthesis stages with three varieties of Indian mustard: NDR-8501 (V1), Maya (V2), and RH-725 (V3). All possible treatment combinations consisting of three dates of showing, *viz*., October 30 (D1), October 30 (D2), and November 15 (D3), and foliar sprays of salicylic acid at 800 ppm and foliar sprays of salicylic acid at 400 ppm as a treatment. Immediately following crop sowing, standard irrigation was administered to ensure enough seed germination and healthy crop establishment. Other agronomic practices were carried out in accordance with suggestions offered for the region's mustard. The five plants were randomly selected from each plot. Each selected plant was labelled for easy identification. The means of five observation plants were used for calculating the sampling values of growth parameters, yield attributes, and yield. The degree of significance of the experimental data was determined statistically, and the sowing date was determined using pooled analysis.

Plant height

The plant height was measured at maturity from the base of the plant (From ground level) to the main shoot length at the maturity stage.

Number of total branches per plant

This was determined by counting all of the mature plants' branches, including their tertiary branches.

1000-seed weight (g)

An electronic balance was used to count and weigh one thousand sun-dried seeds from the yield of each chosen plant in grammes.

Seed yield per plant

Weighing the total seed collected after each plant was threshed individually allowed us to calculate the seed yield per plant in grammes.

Biological yield per plant

Before threshing, the weight of each fully sun-dried harvested plant was measured individually and represented as the biological yield in grammes per plant.

Harvest index

Grain recovery from total dry matter was taken into consideration for the harvest index, which was given as a percentage. It was computed using the accompanying formula:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Germination

In germination test three replications of 50 seeds were kept in two layers of moist filter or blotter paper in Petri dish. The sample was kept in seed germinator maintained at 20 ± 1^{0}C.The germination percentage was calculated as below:

$$\text{Germination (\%)} = \frac{\text{Number of germinated seed}}{\text{Total number of seed}} \times 100$$

Vigour index I

Using the methodology outlined by Abdul-Baki and Anderson (1973) [35], the Vigor index I was computed and reported as a whole number:

Vigour index was calculated by the multiplication of germination percentage with that of seedling length on the day of final count.

Vigour index I = Germination (%) X Seedling length (cm)

Result and Discussion

The table illustrates that of the varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November), the plant height of D2 was 186.04 cm, followed by D1 183.24 cm and D3 169.65 cm, respectively. Among the varieties, the NDR-8501 variety of Indian mustard displays a significant plant height of 1186.55 cm, followed by Maya (V2) at 185.43 cm and RH-785 (V3) at 1182.94 cm, respectively. The greatest plant height seen when heat-tolerance-inducing compounds were sprayed was 800 ppm (186.82 cm) of salicylic acid, which had a substantial impact. Salicylic acid at 400 ppm (183.07 cm) was next in line.

Among the varieties, the Maya variety of Indian mustard shows a significant total number of branches (20.83), followed by NDR-8501 (V1) (20.41), and RH-785 (V3) (19.46). The total branches of the varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November) were significant total branches in D2 23.31, followed by D1 19.66 and D3 14.27, respectively. When it came to chemical spraying, the greatest number of branches overall was noted. Salicylic acid at 800 ppm (20.66) and 400 ppm (19.80), respectively, had substantial effects. The varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November) showed the highest 1000-seed weights, with D2 coming in at 6.23 g, D1 at 5.99 g, and D3 at 4.16 g. The Maya variety of Indian mustard showed the highest 1000-seed weight of 5.74 g, followed by NDR-8501 (V1) at 5.65 g and RH-785 (V3) at 5.52 g. When chemicals were sprayed, salicylic acid 800 ppm (5.68 g) and salicylic acid 400 ppm (5.60 g) had the greatest seed weights, respectively. The germination percentage of the mustard varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November) was highest in D2 (90.74%), followed by D1 (89.15%), and D3 (88.51%), and among the varieties, the Maya variety of Indian mustard shows a significant germination percentage of 91.23%, followed by NDR-8501 (V1) (90.45%), and RH-785 (V3) (90.03%), respectively. In the case of the spraying of heat-inducing chemicals, the germination percentage was highest in salicylic acid at 800 ppm (90.91%), followed by salicylic acid at 400 ppm (90.23%), respectively. The harvest index of varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November) was highest in D2 (606.67), followed by D1 (404.70), and D3 (289.57). Among the varieties, the Maya variety of Indian mustard shows a significant harvest index of 499.65, followed by NDR-8501 (V2) (473.96), and RH-785 (V3) (461.66), respectively. In the case of the spraying of heat-inducing chemicals, the harvest index was highest in salicylic acid at 800 ppm (493.43), followed by salicylic acid at 400 ppm (493.43%).The Maya variety of Indian mustard shows a significant seed yield per plant of 15.36 gm, followed by NDR-8501 (V2) at 14.82 gm and RH-785 (V3) at 14.54 gm, respectively. The seed yield/plant of varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November) were highest in D2 (18.29 gm), followed by D1 (14.59 gm) and D3 (11.83 gm). Salicylic acid 800 ppm (15.20 g) and salicylic acid 400 ppm (114.61 g), respectively, had the maximum seed yield per plant when chemicals were sprayed. Among the varieties sown on D1 (15 October), D2 (30 October), and D3 (15 November), the Maya variety of Indian Mustard exhibits significant Vigor Index I (1523.15), followed by NDR-8501 (V1) 1456.60 and RH-785 (V3) 1404.56, respectively. The highest Vigor Index I was recorded in D2 1609.28, followed by D1 1390.41, and D3 1088.93. When it came to chemical spraying, salicylic acid 800 ppm (1504.11) and salicylic acid 400 ppm (1419.02) had the highest Vigor Index I, respectively.

Observations are the mean of two-year data with three replications

Table 1: Effect of date of sowing, varieties, and heat mitigating chemicals on plant height, total branches, 1000 seed weight, germination%, harvest index, seed yield per plant, and vegetation index

Treatments	Plant Height	Total no of brunches	1000- Seed weight (gm)	Germination (%)	Harvest Index (%)	Seed Yield/Plant (gm)	Vigour Index I (%)
Varieties							
V1	186.55	20.41	5.65	90.45	473.96	14.82	1456.60
V2	185.43	20.83	5.74	91.23	499.65	15.36	1523.15
V3	182.85	19.46	5.52	90.03	461.66	14.54	1404.93
Mean	184.94	20.23	5.64	90.57	478.42	14.91	1461.56
S. E	0.89	0.33	0.05	0.29	9.14	0.20	27.94
Date Of Sowing							
D1	183.24	19.66	5.99	89.15	404.70	14.59	1390.41
D2	186.04	23.31	6.23	90.74	606.67	18.29	1609.28
D3	169.65	14.27	4.16	88.51	289.57	11.83	1088.93
Mean	179.64	19.08	5.46	89.47	433.64	14.90	1362.87
S. E	4.13	2.14	0.53	0.54	75.67	1.53	123.16
Treatments							
T1	186.82	20.66	5.68	90.91	493.43	15.20	1504.11
T2	183.07	19.80	5.60	90.23	463.41	14.61	1419.02
Mean	184.94	20.23	5.64	90.57	478.42	14.91	1461.56
S. E	1.33	0.30	0.03	0.24	10.61	0.21	30.08
C.V	2.67	2.14	2.59	2.63	3.80	2.63	3.86

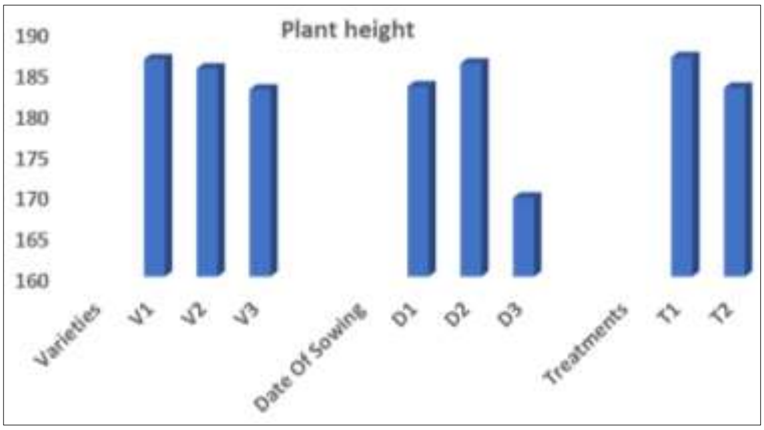

Fig 1: The plant height of varieties in relation to the date of sowing and chemicals

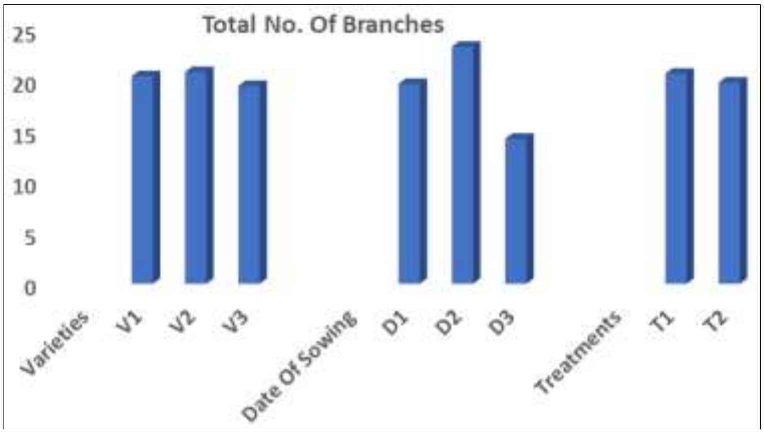

Fig 2: The number of total branches of varieties in relation to the date of sowing and chemicals

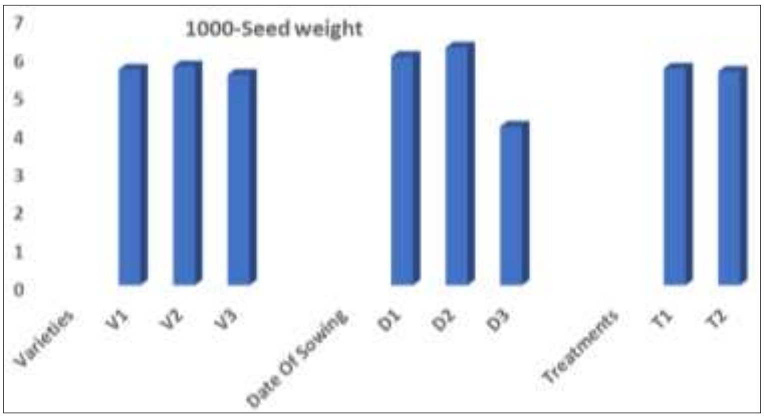

Fig 3: The 1000-seed weight of varieties in relation to the date of sowing and chemicals

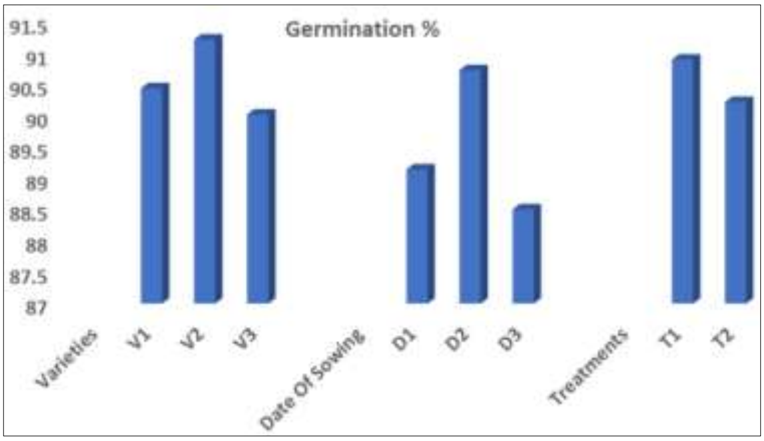

Fig 4: The Germination% of Varieties in Relation to Date of Sowing and Chemicals

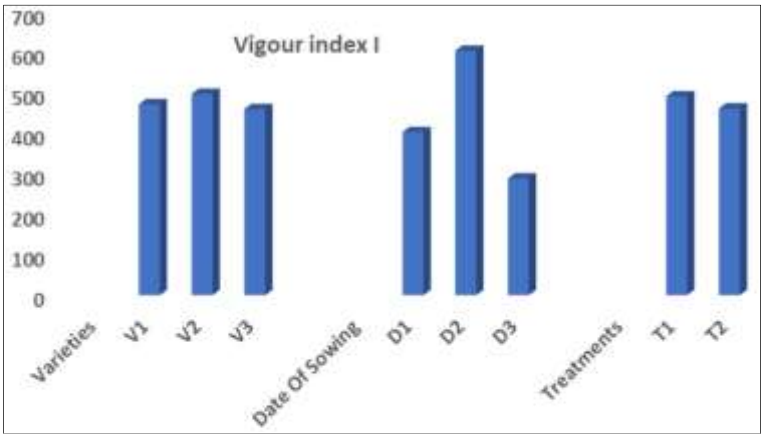

Fig 5: The Vigor Index I of Varieties in Relation to Date of Sowing and Chemicals

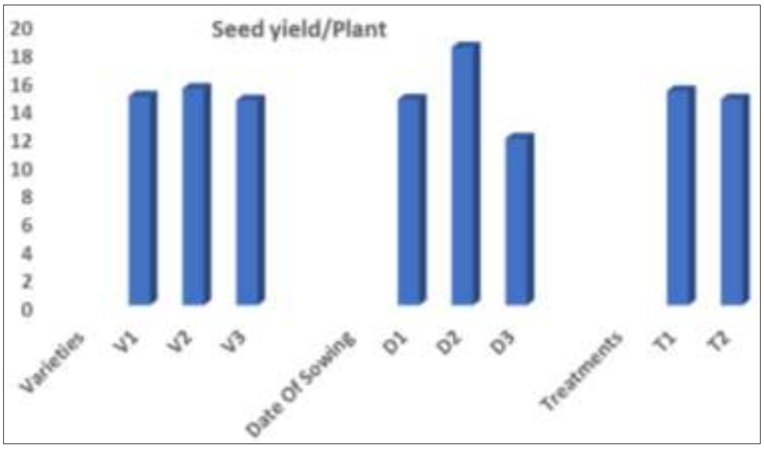

Fig 6: The seed yield/plant of Varieties in relation to date of sowing and chemicals

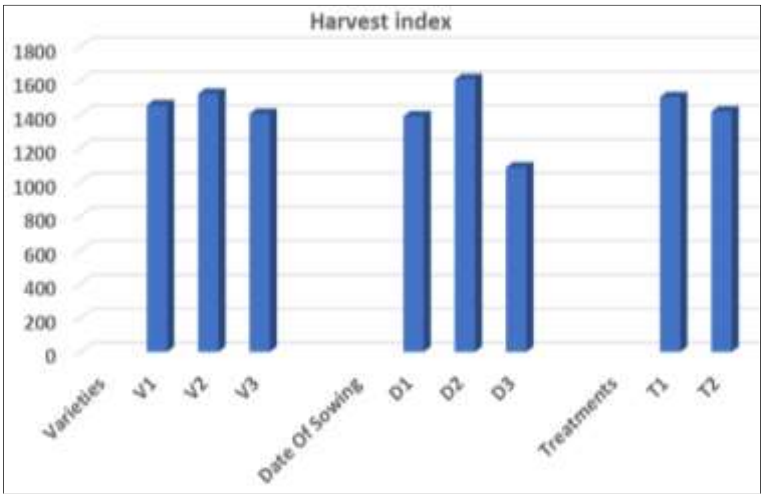

Fig 7: The Harvest Index of Varieties in Relation to Date of Sowing and Chemicals

Conclusion

The effects of heat tolerance inducing compounds on the contributing characteristics and seed output of NDR-8501, Maya, and RH-725 mustard varieties were detected. Specifically, the application of salicylic acid at 800 ppm showed the most significant effect, followed by salicylic acid at 400 ppm. It's interesting to note that when the crop was sowed on October 30 (D2) and treated with 800 ppm salicylic acid, as opposed to 400 ppm, the maximum seed yield and growth components were seen. Additionally, the tallest plants were grown when the crop was sown on October 30th (D2) and treated with 800 ppm salicylic acid. It is significant to highlight that the terminal heat stress caused by postponing seeding until November resulted in subpar performance in terms of seed yield and its contributing features. Even if planting was postponed until November, seed production might still be increased by using chemicals that produce heat tolerance. These findings lend credence to the theory that treating Indian mustard plants with salicylic acid increases the activity of antioxidant enzymes in response to high temperatures. The increased activity of antioxidative enzymes in Indian mustard enhances growth, metabolism, and photosynthesis by reducing the direct and indirect effects of temperature stress.

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