

Effect of Heat Stress on Growth and Yield in Mungbean Genotypes

DIVYA BATRA, SANDEEP GHOSH, ALPA YADAV¹ AND YOGESH KUMAR*

Department of Botany, Kurukshetra University, Kurukshetra-136 119 (Haryana), India
*(e-mail: ykskuk11@gmail.com; Mobile: 90500 37311)

Received: February 15, 2023; Accepted: March 24, 2023

ABSTRACT

Several studies have been carried out to explore and improve the mungbean tolerance to high-temperature stress. Therefore, the present work was conducted to analyze the impact of heat stress on the vegetative, physiological and reproductive traits of 13 mungbean genotypes. The mungbean genotypes were grown at two sowing times i. e. the last week of March (normal sown) and April (late sown). In late-sown, leaves chlorosis signs, scorching and rolling of leaf were observed due to high temperature. High-temperature stress decreased leaf area, plant height, relative water content, chlorophyll content and increased the electrolyte leakage. In addition to this, phenology was hastened, resulting in a noticeable decrease in flowers' number, pods and seeds weight, thereby reducing pod and seed yields. During reproductive period, heat stress was detrimental in all late sown mungbean genotypes. Based on present study, MH 125, MH 421 and PDM 139 were tolerant to heat stress and MH 318, IPM 02-3 and PM-5 were sensitive.

Key words: Heat stress, mungbean, phenology, tolerant, sensitive

INTRODUCTION

The earth's increasing average temperature due to climate change is proving stressful at all stages of plant growth and development, mainly in tropical and sub-tropical regions (Li *et al.*, 2018). There is a need for sustainable development because climate change and increasing population threaten food security and the agricultural system. Climate change involves the increasing concentration of greenhouse gases, and subsequent rise in earth's temperature that leads to acclimation or adaptation in the plants causing a low yield in crop plants. The earth's mean global temperature is predicted to rise by 1.5°C in the next two decades, as reported by Intergovernmental Panel on Climate Change (IPCC, 2021). This increased temperature over a prolonged period induces irreversible damages to plants that cause heat stress. The impacts of heat stress vary with the degree, intensity and duration of the elevated temperature. Heat stress enforces changes at various organizational levels with harmful impacts on vegetative and reproductive traits. Moreover, in plants, elevated temperature can disturb the physiological processes resulting in a reduction in photosynthesis and nitrogen assimilation, increased proteolysis, and

accumulation of lipid peroxidation end products. Heat-stressed plants show shorter vegetative and pod-filling periods that subsequently reduce yield (Sharma *et al.*, 2016).

In flowering plants, legumes are the third largest with nearly 20,000 species, which makes it the second largest crop family (Sita *et al.*, 2017). They are a vital source of protein, oil, starch and flavonoids (Suso *et al.*, 2015; Ozga *et al.*, 2017; Song *et al.*, 2017) and hence they can ensure food security for the world's increasing population size (Foyer *et al.*, 2016; Considine *et al.*, 2017; Liu *et al.*, 2019). In the farming system, legumes are often used in crop rotation or as an intercrop, resulting in a decrease in weed populations, insect-pests and diseases while increasing overall productivity and income for smallholder farmers (Khatun *et al.*, 2021). Various abiotic stresses, such as temperature, drought and salt affect the growth of legumes and cereals at different developmental stages (Rane *et al.*, 2021).

Among legumes, mungbean plays a vital role in complementing cereal-based diets. Mungbean is adapted to the sub-tropical and tropical environment as a warm season and short duration crop (Raturi *et al.*, 2015). Many nutrients such as protein, carbohydrates, minerals, fibres, phenolics and antioxidants

¹Department of Botany, Indira Gandhi University, Meerpur, Rewari-123 401 (Haryana), India

are enriched in mungbean seeds (Hou *et al.*, 2019). Apart from these, the grains are also a good source of alkaloids and phytosterols, which are known to tranquilise the metabolism of animals and human beings (Kaur *et al.*, 2018). The rising attention to nutritional benefits has contributed to the increasing demand for mungbean (Chauhan and Williams, 2018). However, with the changing global climate, the rise in temperature causes severe and more frequent heat stress in legumes (Sita *et al.*, 2017). Therefore, plant scientists are either to characterise or develop thermo-tolerant genotype transgenically. To meet these challenges, some efforts have been made in other crop plants like chickpea (Devi *et al.*, 2022), wheat (Li *et al.*, 2022), soybean (Krishnan *et al.*, 2020) and lentil (Sehgal *et al.*, 2017). In the present study, it was tried to analyze the impact of heat stress on various mungbean genotypes and evaluating their thermo-tolerance by studying the effect of heat stress on their vegetative and reproductive traits.

MATERIALS AND METHODS

In this study, the seeds of 13 genotypes with three replicates were grown twice at the standard sowing time in the last week of March (~34-36°C) and late sowing in the last week of April (>38-40°C). The experiment was performed in the experimental plot at the Department of Botany, Kurukshetra University, Kurukshetra, India. Seeds were treated with *Rhizobium* spp. and sown in pots. The plants were fully irrigated and screened for their tolerance to heat stress for growth and yield parameters.

The plants' leaf area was estimated using leaf area meter (Systronics 211) at maturity. The plant height was determined making use of a measurement scale.

The young leaves were taken to record their fresh weights. Then, the leaves were cut into small segments and floated on distilled water in Petri dish for 3 h at low light intensity and the turgid weight was estimated. After that, the dry weight was recorded, keeping the leaves in an oven at 85°C for 24 h. Relative water content was worked out as:

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

The chlorophyll content was measured against 80% acetone as a blank. For chlorophyll content estimation, fresh leaf (100 mg) was ground in 10 ml of 80% acetone. The mixture was centrifuged in a Remi-centrifuge at 5000 rpm for 20 min. After centrifugation, the supernatant was collected, and final volume was raised to 10 ml by adding 80% acetone; then using spectrophotometer, absorbance of the supernatant was read at 645 and 663 nm. The total chlorophyll content (mg/g fresh weight) was determined as:

$$\text{Total chlorophyll} = \text{Chlorophyll a} + \text{Chlorophyll b}$$

$$\text{Chlorophyll a} = 12.3 \times \text{Absorbance (663)} - 0.86 \times \text{Absorbance (645)} \times V / \alpha \times 1000 \times w$$

$$\text{Chlorophyll b} = 19.3 \times \text{Absorbance (645)} - 3.6 \times \text{Absorbance (663)} \times V / \alpha \times 1000 \times w$$

Where, V = volume of extract (ml)

α = path length in cm (1 cm)

w = fresh weight of sample (mg)

Electrolyte leakage was calculated by utilizing an electrical conductivity (EC) meter. For electrolyte leakage estimation, 100 mg leaf tissues were taken and placed in 10 ml of double-distilled water at 25°C for 24 h and EC₁ was read. The same was put in water bath at 100°C boiling for 10 min, and electrical conductivity was recorded (EC₂). Then, the electrolyte leakage was worked as:

$$\text{Electrolyte leakage (\%)} = (\text{EC}_1 / \text{EC}_2) \times 100$$

At both the sowing times, the total numbers of flowers/plant for each of the genotype were considered till the termination of flowering period. New emerged flowers were marked on every second day and totalled. At maturity, single pod weight, pod weight per plant, seed weight and seed number per pod were calculated in both normal and late sown genotypes.

The data of 13 genotypes with three replicates were subjected to analysis of variance (ANOVA) using SPSS 16 statistical software. The difference among data was determined by a Post hoc test (Tukey) using the same software. The mean values, along with standard errors and least significant differences (P<0.05) for interaction (genotype × date of sowing) are presented in the figures.

RESULTS AND DISCUSSION

In present research, mungbean genotypes were subjected to heat stress by sowing seeds one month later than the suggested sowing time. As a result, newly emerging and developing flowers, pods and seeds experienced the effect of heat stress (>40°C). In late sown mungbean plants, leaf area decreased from 8.5 to 38.3%. The minimum reduction was observed in genotypes MH 125, MH 421 and SML 832 and maximum in genotypes in IPM 02-3, MH 318 and PM-5 over their respective control (Fig. 1). In addition, high temperature resulted in sunburns, rolling and drying of leaves (Fig. 2). The maximum plant height was shown by the genotypes MH 125, MH 421 and SML 832 and the minimum height was observed in MH 318, MH 2-15 and PM-5 in normal sown plants. In late sown plants, minimum height was observed in genotypes IPM 02-3, MH 318 and PM-5 and maximum in genotypes MH 125, MH 421 and SML 832 (Fig. 3). Due to heat stress, the plant height was reduced by 9.9 to 30.9% in late sown plants.

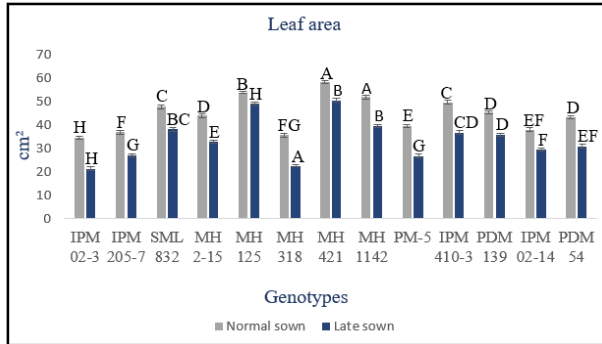


Fig. 1. Leaf area of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

Heat stress remarkably decreased leaf area, plant height in late sown plants. Similar results were observed in mungbean by Sharma *et al.* (2016) under heat stress. The decrease in relative humidity during late sown might be a vital factor for this decline (Sharma *et al.*, 2016). Leaves were more vulnerable to high temperature as compared to other plant parts. In sugarcane and other plant species, leaf senescence and abscission, rolling and drying of leaves, necrosis, damage to leaf-tips and margins, visible scorching and sunburns were

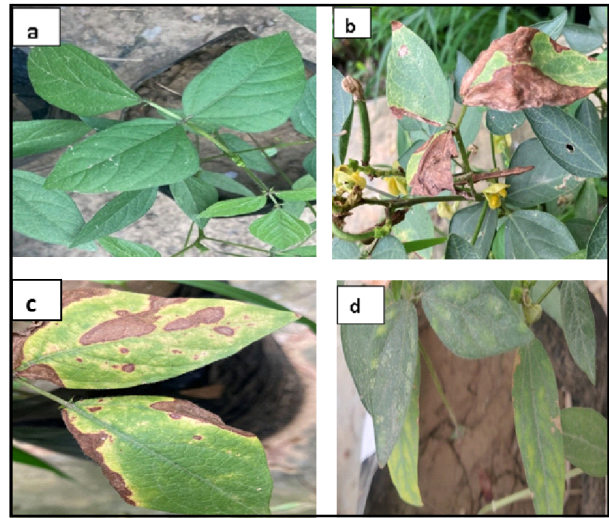


Fig. 2. Effect of high temperature on leaves a: healthy leaves; b, c and d: leaves showing signs of heat stress.

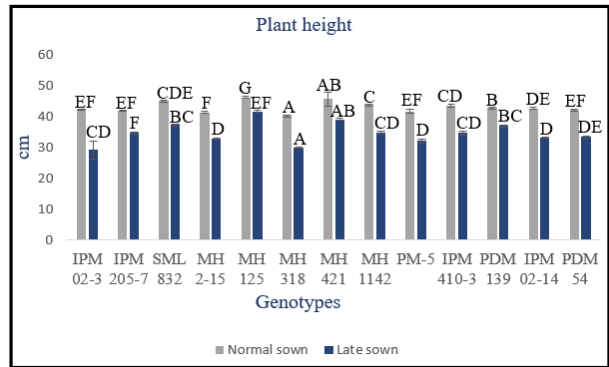


Fig. 3. Plant height of normal and late sown genotypes. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

the major symptoms associated with heat stress-induced leaf deterioration which finally caused a decrease in crop productivity (Arif *et al.*, 2022).

Due to heat stress, the relative water content decreased from 8.8 to 20.9% in late sown genotypes. In normal sown plants, the maximum relative water content was maintained by genotypes MH 125, MH 421 and PDM 139 and the minimum by IPM 02-3, MH 318 and PM-5. However, in late sown condition, genotypes MH 125 maintained higher relative water content followed by MH 421 and PDM 139 and minimum in genotypes IPM 02-3, MH 318, PDM 54 and PM-5 (Fig. 4). The maximum chlorophyll content was noticed in genotypes

MH 421, IPM 410-3, MH 1142 and MH 125 and minimum in genotypes MH 318, IPM 02-3 and IPM 205-7 in normal sown plants. In late sown genotypes, the chlorophyll content was reduced from 6.3 to 29.1%. Under high temperature, the genotypes MH 421, MH 125 and PDM 139 exhibited maximum chlorophyll content, and MH 318, PM-5 and IPM 02-3 had minimum chlorophyll content (Fig. 5).

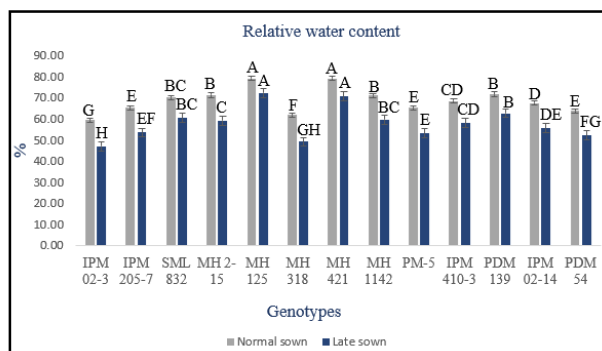


Fig. 4. Relative water content of normal and late sown genotypes. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD ($P < 0.05$) and Interaction: genotypes \times date of sowing.

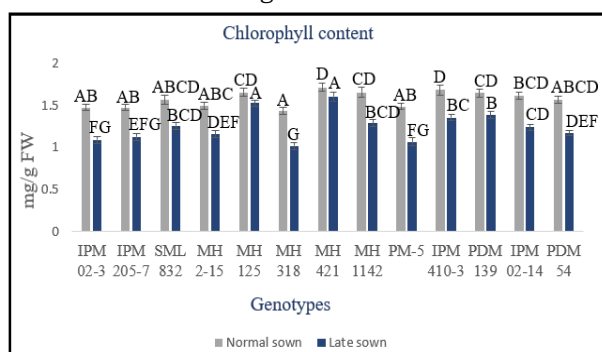


Fig. 5. Chlorophyll content of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD ($P < 0.05$) and Interaction: genotypes \times date of sowing.

The electrolyte leakage increased from 19.5 to 55.1% in late sown genotypes. In normal sown genotypes, minimum electrolyte leakage was observed in MH 125, MH 421 and PDM 139 and maximum noticed in genotypes MH 318, MH 1142 and PM-5 (Fig. 6). However, the maximum electrolyte leakage was observed in genotypes PM-5, MH 318 and IPM 02-3, the minimum was observed in genotypes MH 125, MH 421 and PDM 139 in late sown plants.

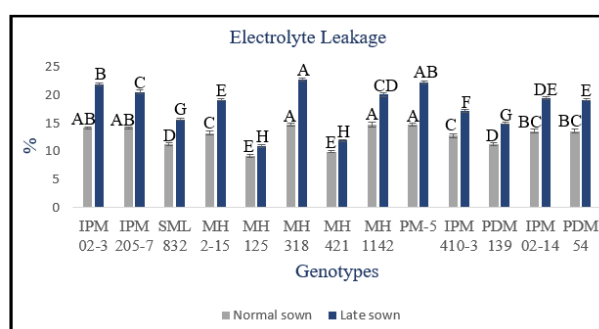


Fig. 6. Electrolyte leakage of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD ($P < 0.05$) and Interaction: genotypes \times date of sowing.

High temperature remarkably reduced relative water content and chlorophyll content in late sown plants, which might significantly influence all cellular functions. Similar results were also found in other crop plants such as in chickpea (Devi *et al.*, 2022), barley (Templer *et al.*, 2017) and tomato (Nankishore and Farrell, 2016). Leaf chlorophyll content reduced in heat-stressed plants and this may be because of its impaired biosynthesis and degradation due to photo-oxidation. The chlorophyll reduction was also related to repressed chlorophyll fluorescence, a measure of photosynthetic efficiency. In late sown plants, an inhibition in function of PSII was also reported in other crop plants (Wang *et al.*, 2018) which might be related to reduction in water and chlorophyll content of the leaves. Therefore, the maintenance of leaf photosynthetic machinery was vital for producing and trans-locating sucrose to leaves under heat stress (Bindumadhava *et al.*, 2016). In present investigation, the leaves were seen to be damaged by high-temperature stress, as shown by the increase in electrolyte leakage from leaf tissues; similar findings were also noticed in earlier studies on alfalfa (Wassie *et al.*, 2019), chickpea (Devi *et al.*, 2022) and rice (Taratima *et al.*, 2022).

In present experiment, high temperature significantly decreased flower numbers, seed numbers and seed weight on account of increased pod losses and fewer filled pods. The maximum numbers of flowers were seen in genotypes MH 125, MH 421 and PDM 139 and minimum flowers were observed in genotypes

PM-5, MH 318 and IPM 205-7 in normal sown genotypes. Under heat stress, genotypes MH 125, MH 421 and SML 832 showed the maximum number of flowers and minimum flowers were observed in MH 318, PM-5 and IPM 02-3 (Fig. 7). The number of flowers was reduced from 10.5 to 35.9% in late sown genotypes.

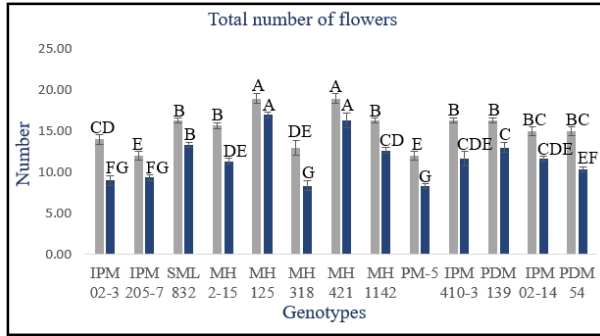


Fig. 7. Total number of flowers of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

In normal sown plants, single pod weight was observed higher in genotypes MH 125, MH 421 and IPM 410-3 and lower in genotypes MH 2-15, MH 318, PM-5 and IPM 02-3. However, single pod weight decreased from 11.7 to 32.0% due to high temperatures. In late sown condition, maximum single pod weight was observed in genotypes MH 125, MH 421 and MH 1142 and minimum was noticed in genotypes MH 318, MH 2-15 and IPM 205-7 (Fig. 8). Due to high temperatures, the pod weight per plant in late sown genotypes decreased from 11.4 to 64.65%. The minimum reduction was observed in genotypes MH 125, MH 421 and PDM 139 and maximum reduction was observed in genotypes MH 318, PM-5 and IPM 02-3 over their respective control (Fig. 9).

The maximum seed number per pod was in genotypes MH 125, MH 421 and IPM 205-7 and the minimum in genotypes PM-5, IPM 02-3, PDM 54 and MH 1142 in normal sown plants. The seed number reduced from 15.7 to 51.7% in late sown plants. At high-temperatures, the maximum number of seeds per pod was noticed in genotypes MH 125, MH 421, IPM 410-3 and SML 832 and a minimum in IPM 02-3, MH 318 and PM-5 (Fig. 10). In late sown plants, seed weight per pod decreased from 9.8 to 30.70%.

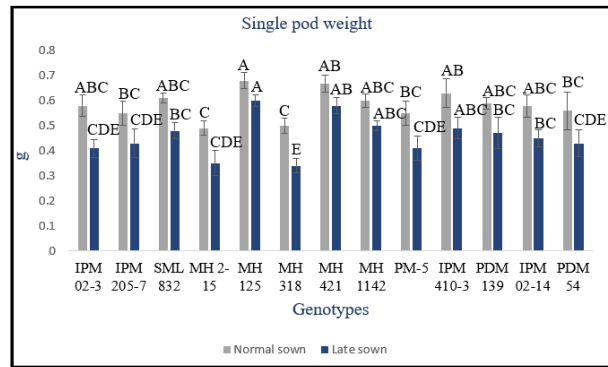


Fig. 8. Single pod weight of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

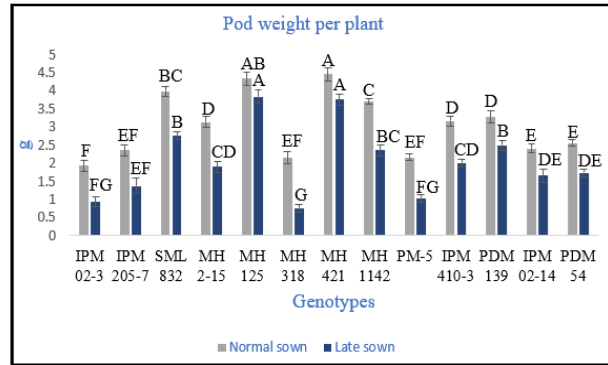


Fig. 9. Pod weight per plant of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

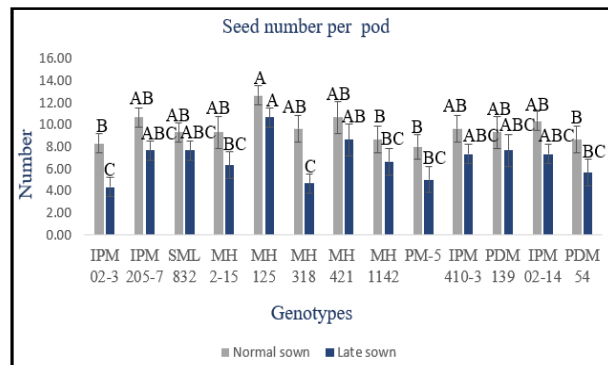


Fig. 10. Seed number per pod of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD (P<0.05) and Interaction: genotypes × date of sowing.

The minimum reduction was noticed in genotypes MH 125, MH 421 and PDM 139 and the maximum decrease was observed in genotypes MH 318, IPM 02-3 and PDM 54 over their respective control (Fig. 11).

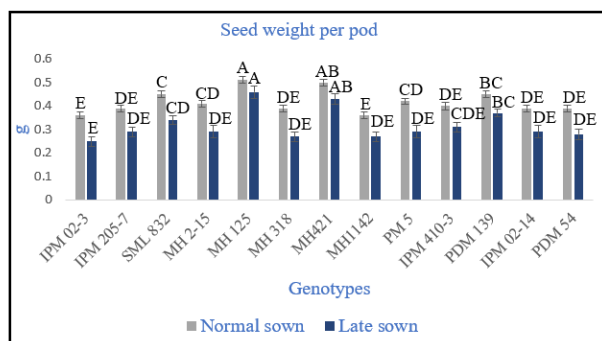


Fig. 11. Seed weight per pod of normal and late sown plants. Small vertical bar errors represent standard errors. Mean values with different letters on the same graph indicate significant differences among treatments. LSD ($P < 0.05$) and Interaction: genotypes \times date of sowing.

The experiment showed a significant effect of high temperature on reproductive traits of mungbean genotypes, which might probably be due to a noticeable decrease in production and transport of sucrose, aggravated by chlorosis-triggered leaf tissue damage. Seed filling was mainly related to the sucrose import and precursors of fats, proteins and minerals from the leaves (Sharma *et al.*, 2016). In general, the phenology of mungbean was accelerated under high temperatures (Gaur *et al.*, 2015). So, changes in reproductive traits damages inhibited the floral components' function and flower development, resulting in smaller number of pods and seeds (Sharma *et al.*, 2016). Similar observations were found in drought-stressed lentil (Sehgal *et al.*, 2017) and chickpea (Bindumadhava *et al.*, 2016) and heat-stressed lentil (Sita *et al.*, 2017) and chickpea (Devi *et al.*, 2022). Heat stress also led to loss of pods and yield reduction in *Pisum sativum* (Mohapatra *et al.*, 2020). These results showed that increasing temperatures would be very harmful to total mungbean yield, particularly during the reproductive stage, thus reiterating a focused research need to develop thermo-tolerant genotypes in the mungbean.

The screening of various genotypes showed that some genotypes showed minor damage to seed yield than other genotypes, which might

be related to leaves' stability to retain more water under high temperature, as measured by less damage to photosynthetic function. The reduced chlorophyll content under high temperatures in the present work could be the other reason for the reduction in seed yield. These outcomes showed an interaction between temperature and genotype in late sowing, and it may be suitable for identifying thermo-tolerant genotypes. Under heat stress, reproduction duration and early maturity are the primary adaptive traits to produce seeds.

CONCLUSION

The research showed that high-temperature stress negatively affected vegetative, physiological and reproductive traits. Heat stress reduced leaf area, plant height, chlorophyll content, relative water content, number of flowers, pod and seed weight and increased electrolyte leakage over their respective control. As per screening results, genotypes IPM 02-3, MH 318 and PM-5 were sensitive, and MH 125, MH 421 and PDM 139 were tolerant ones. Results on different cultivars showed that thermo-tolerant ones suffered minor damage under heat stress than sensitive genotypes. Therefore, these genotypes would be useful in breeding programs and serve as a standard plant source to gain more insight into high temperature-induced effects on cell metabolism.

ACKNOWLEDGEMENT

The senior author is thankful to Rashtriya Uchchatar Shiksha Abhiyan (RUSA) 2.0 for providing fellowship to conduct this study.

REFERENCES

- Arif, M., Jan, T., Munsif, F., Zaheer, S., Rasul, F., Mian, I. A., Riaz, M., Fahad, S., Saud, S., Adnan, M. and Saleem, M. H. (2022). Extreme high temperature and plant life. In : *Climate Change and Ecosystems*. CRC Press. pp. 61-70.
- Bindumadhava, H., Nair, R. M. and Nayyar, H. (2016). Salinity and high temperature tolerance in mungbean [*Vigna radiata* (L.) Wilczek] from a physiological perspective. *Front. Plant Sci.* **7**: 01-20.
- Chauhan, Y. S. and Williams, R. (2018). Physiological and agronomic strategies to

- increase mungbean yield in climatically variable environments of Northern Australia. *Agronomy* **8**: 83. <https://doi.org/10.3390/agronomy8060083>.
- Considine, M. J., Siddique, K. H. and Foyer, C. H. (2017). Nature's pulse power: Legumes, food security and climate change. *J. Exp. Bot.* **68**: 1815-1818.
- Devi, P., Jha, U. C., Prakash, V., Kumar, S., Parida, S. K., Paul, P. J., Prasad, P. V., Sharma, K. D., Siddique, K. H. and Nayyar, H. (2022). Response of physiological, reproductive function and yield traits in cultivated chickpea (*Cicer arietinum* L.) under heat stress. *Front. Plant Sci.* **13**. <https://doi.org/10.3389/fpls.2022.880519>.
- Foyer, C. H., Lam, H. M., Nguyen, H. T., Siddique, K. H., Varshney, R. K. and Colmer, T. D. (2016). Neglecting legumes has compromised human health and sustainable food production. *Nat. Plants.* **2**: 01-10.
- Gaur, P. M., Samineni, S., Krishnamurthy, L., Varshney, R. K., Kumar, S., Ghanem, M. E., Beebe, S. E., Rao, I. M., Chaturvedi, S. K., Basu, P. S. and Nayyar, H. (2015). High temperature tolerance in grain legumes. *Legum. Res. Conference* **7**: 23-24.
- Hou, D., Yousaf, L., Xue, Y., Hu, J., Wu, J., Hu, X., Feng, N. and Shen, Q. (2019). Mungbean (*Vigna radiata* L.): Bioactive polyphenols, polysaccharides, peptides, and health benefits. *Nutrients* **11**: 1238. <https://doi.org/10.3390/nu11061238>.
- Kaur, G., Joshi, A. and Jain, D. (2018). SSR-marker assisted evaluation of genetic diversity in mungbean [*Vigna radiata* (L.) Wilczek] genotypes. *Braz. Arch Biol Technol.* **61**. <https://doi.org/10.1590/1678-4324-2016160613>.
- Khatun, M., Sarkar, S., Era, F. M., Islam, A. K. M. M., Anwar, M. P., Fahad, S., Datta, R. and Islam, A. K. M. A. (2021). Drought stress in grain legumes: Effects, tolerance mechanisms and management. *Agronomy* **11**: 2374. <https://doi.org/10.3390/agronomy11122374>.
- Krishnan, H. B., Kim, W. S., Oehrle, N. W., Smith, J. R. and Gillman, J. D. (2020). Effects of heat stress on seed protein composition and ultrastructure of protein storage vacuoles in the cotyledonary parenchyma cells of soybean genotypes that are either tolerant or sensitive to elevated temperatures. *Int. J. Mol. Sci.* **21**: 4475. <https://doi.org/10.3390/ijms21134775>.
- Li, B., Gao, K., Ren, H. and Tang, W. (2018). Molecular mechanisms governing plant responses to high temperatures. *J. Integr. Plant Biol.* **60**: 757-779.
- Li, M., Feng, J., Zhou, H., Najeeb, U., Li, J., Song, Y. and Zhu, Y. (2022). Overcoming reproductive compromise under heat stress in wheat: Physiological and genetic regulation and breeding strategy. *Front. Plant Sci.* **13**. <https://doi.org/10.3389/fpls.2022.881813>.
- Liu, W., Min, X. and Wang, Y. (2019). Genome-wide development of micro RNA-based SSR markers in *Medicago truncatula* with their transferability analysis and utilization in related legume species. *The Model Legume Medicago truncatula*. pp. 936-945.
- Mohapatra, C., Chand, R., Tiwari, J. K. and Singh, A. K. (2020). Effect of heat stress during flowering and pod formation in pea (*Pisum sativum* L.). *Physiol. Mol. Biol. Plants.* **26**: 1119-1125.
- Nankishore, A. and Farrell, A. D. (2016). The response of contrasting tomato genotypes to combined heat and drought stress. *J. Plant Physiol.* **202**: 75-82.
- Ozga, J. A., Kaur, H., Savada, R. P. and Reinecke, D. M. (2017). Hormonal regulation of reproductive growth under normal and heat-stress conditions in legume and other model crop species. *J. Exp. Biol.* **68**: 1885-1894.
- Rane, J., Singh, A. K., Kumar, M., Boraiah, K. M., Meena, K. K., Pradhan, A. and Prasad, P. V. (2021). The adaptation and tolerance of major cereals and legumes to important abiotic stresses. *Int. J. Mol. Sci.* **22**: 12970. <https://doi.org/10.3390/ijms222312970>.
- Raturi, A., Singh, S. K., Sharma, V. and Pathak, R. (2015). Genetic variability, heritability, genetic advance and path analysis in mungbean [*Vigna radiata* (L.) Wilczek]. *Legume Res.* **38**: 157-163.
- Sehgal, A., Sita, K., Kumar, J., Kumar, S., Singh, S., Siddique, K. H. M. and Nayyar, H. (2017). Effects of drought, heat and their interaction of the growth, yield and photosynthetic function of lentil (*Lens culinaris* Medikus) genotypes varying in heat and drought sensitivity. *Front. Plant Sci.* **8**: 1776. <https://doi.org/10.3389/fpls.2017.01776>.
- Sharma, L., Priya, M., Bindumadhava, H., Nair, R. M. and Nayyar, H. (2016). Influence of high temperature stress on growth, phenology and yield performance of mungbean [*Vigna*

- radiata* (L.) Wilczek] under managed growth conditions. *Sci. Hortic.* **213**: 379-391.
- Sita, K., Sehgal, A., Kumar, J., Kumar, S., Singh, S., Siddique, K. H. M. and Nayyar, H. (2017). Identification of high-temperature tolerant lentil (*Lens culinaris* Medik.) genotypes through leaf and pollen traits. *Front. Plant Sci.* **8**: 744. <http://doi.org/10.3389/fpls.2017.00744>.
- Song, Y., Wang, X. D. and Rose, R. J. (2017). Oil body biogenesis and biotechnology in legume seeds. *Plant Cell Rep.* **36**: 1519-1532.
- Suso, M., Bebeli, P. and Palmer, R. (2015). Reproductive biology of grain legumes in grain legumes. *Handbook of Plant Breeding, 10th edn.*, A. De Ron, New York, Springer.
- Taratima, W., Chuanchumkan, C., Maneerattanarungroj, P., Trunjaruen, A., Theerakulpisut, P. and Dongsansuk A. (2022). Effect of heat stress on some physiological and anatomical characteristics of rice (*Oryza sativa* L.) cv. KDML105 Callus and Seedling. *Biology* **11**: 1587. <https://doi.org/10.3390/biology11111587>.
- Templer, S. E., Ammon, A., Pscheidt, D., Ciobotea, O., Schuy, C., McCollum, C. and Voll, L. M. (2017). Metabolite profiling of barley flag leaves under drought and combined heat and drought stress reveals metabolic QTLs for metabolites associated with antioxidant defense. *J. Exp. Bot.* **68**: 1697-1713.
- Wang, Q. L., Chen, J. H., He, N. Y. and Guo, F. Q. (2018). Metabolic reprogramming in chloroplasts under heat stress in plants. *Int. J. Mol. Sci.* **19**: 849. <https://doi.org/10.3390/ijms19030849>.
- Wassie, M., Zhang, W., Zhang, Q., Ji, K. and Chen, L. (2019). Effect of heat stress on growth and physiological traits of Alfalfa (*Medicago sativa* L.) and a comprehensive evaluation for heat tolerance. *Agronomy* **9**: 597. <https://doi.org/10.3390/agronomy9100597>.