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# ASSESSING THERMO-TOLERANCE IN SOYBEAN THROUGH THE HEAT SUSCEPTIBILITY INDEX

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**ABSTRACT**

Soybean (*Glycine max*. L.) productivity is limited by high temperatures, a key environmental stress factor. Improving soybean heat tolerance is a key breeding target. The current study was carried out to identify thermo-tolerant genotypes on the basis heat susceptibility index using 20 genotypes in a split plot design, with two replications at three different sowing dates (15th January, 30thJanuary and 15th February).Various characteristics such yield attributing character, root length, root biomass , plant biomass , oil content , protein content, canopy temperature, number of leaves per plant, Leaf Area Index, chlorophyll content, TSS(Total Soluble Sugar), proline content at pre and post anthesis (µmole/g) studied and evaluated susceptibility index (HSI). KDS-344, KDS-992, KDS-726, KDS-753, JS-335, JS-9305, AMS-100-39, and DS-228 are selected as thermo-tolerant on the basis of HSI and grain yield after screening twenty soybean genotypes under field conditions for high temperature stress generated by varied sowing dates.
***Keywords*:** Heat susceptibility index, canopy temperature, proline content, oil content, protein content.

## Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the important oilseeds grown in the temperate and tropical climate. It ranks first in terms of area and production in the world in relation to the oilseed crop. The soybean, soy bean, or soya bean (*Glycine max*) is an East Asian legume that is commonly grown for its edible bean, which has a variety of purposes. The crop being pulse and oilseed plays three dimensional roles as a pulse, oilseed and legume. Therefore, it has got importance in the rotation of crops. India is the world's fourth largest producer of oilseeds. Even then the production of oilseed in the country remained stagnant during the last two decades. Because of the presence of symbiotic bacteria from the *Rhizobia* group, soybeans, like many legumes, can fix atmospheric nitrogen. Soya oil is popular in U.S.A. while soybean cake has got importance as poultry feed. Soybean seeds are rich in proteins and contain important amino acids such as lysine, methionine, threonine etc. The seeds are rich in minerals and also rich in vitamin A, B, D while in sprouted seeds Vitamin-C. Soybean straw accounts high content of digestive proteins. Soymilk is popular for consumption. Therefore, soybean provides unique food material for human consumption, valuable feed for cattle and being oilseed, it provides industrial.

Soybean is mainly grown in *Kharif season* in the Maharashtra state. Now, it is also cultivated in summer season under the command areas. Summer season in which water is provided through canals intervals are fixed there is a provision of conjunctive use of water through wells. Therefore, under both the conditions irrigation water can be monitored at right time of its requirement. In view of this it is necessary to work out the correct interval of irrigation for irrigating soybean in summer season to harness maximum production.

The day length remains always more in the summer season besides warm temperature. Therefore, the photosynthetic activity remains comparatively best in this season. The incidence of pest and pathogenic problems remain less than other seasons. Climate requirement is different from crop to crop, germination soybean grows well in warm and humid condition. Excessive cold, moisture or prolonged drought causes injury and therefore the most optimum temperature for its growth is 24-30 °C while the range is 18-30 °C. The minimum temperature for most growth and development is about 10 °C. Soybean is sensitive to day length as flowering as well as maturity is controlled by it. It is short day plant and requires at least 10 or more of daily darkness for flowering. Photoperiod also affects the development stage. Moisture is required for germination and early development. Artificial irrigation is required during their seed-filling season. Soybean, on the other hand, can endure some drought once established.

Gibson and Mullen (1996) reported influence of day and night temperature on soybean seed yield. Increase in day temperature resulted in decreased seed formation when plant was exposed during flowering and pod set. Seed growth reduction in plants exposed to high day temperature were accompanied by decreased photosynthetic rates.

Mengxuan Hu and Wiatrak (2011) reported that changes in photoperiod, temperature, and precipitation with delayed planting decrease the duration of vegetative and reproductive stages. Chapman (1986) reported that the photo thermal unit gave measure of the interactive effect of photoperiod and temperature on the length of the pre-flower phase Highly significant correlation between days to flower and photo thermal unit were found. Duthion and Pigeaire (1991) reported higher temperatures during reproductive growth stage may shorten the time for seed to develop fully before maturity resulting in a decrease in seed size. Camara *et al.* (1997) evaluated the effect of short and long photoperiod and air temperature regimes (winter and summer growing season) on soybean behaviour. He concludes that the vegetative period from emergence to flowering and juvenile period are significantly affected by the photoperiod and temperature differences, shorter photoperiod or higher temperature regime or higher temperature under same photoperiod regime result in higher plant.

Hence soybean crop improvement programme is aimed to identify and development of varieties tolerant to heat stress. The season-long plant growth and final yield production are both significantly influenced by the planting date. In areas with extreme climatic condition and changes, where weather is the most important limiting factor for agricultural systems, this component is even more crucial.

## Materials and Methods

The present investigation, "Identification of thermo-tolerant genotypes in soybean (*Glycine max* L.)" was conducted at Botany Farm, College of Agriculture, Pune during Summer season, 2022-23. During Summer season 2022-23, 60 treatment combinations were used. Each treatment was replicated 2 times. Main's treatment consisted of three sowing dates and sub treatment consisted of 20 soybean genotypes. The experiment was laid out in a split plot design. The high temperature stress was induced by manipulations of sowing dates.

**A. Main plot -Sowing dates**

S1- 15 January, 2023
S2- 1 February, 2023
S3- 15 February, 2023

**B. Sub plots- Soybean Genotypes**

The experimental material for the study consisted of 20 genotypes of soybean obtained from Officer Incharge, Agricultural Research Station (ARS), Kasbe Digraj, Dist- Sangli. The list of genotypes along with their source is presented in Table No. 1.

Observations were made on five randomly selected plants in each treatment for various characteristics such as days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight (g), yield per plant (g), root length (cm), root biomass (g), plant biomass (g), oil content (%), protein content (%), canopy temperature ($^{o}$C), number of leaves per plant, leaf surface area (sq.cm), Leaf Area Index, chlorophyll content, TSS(Total Soluble Sugar), proline content at pre and post anthesis (µmole/g), Heat Susceptibility Index. For each character, an analysis of variance and a heat susceptibility index (HSI) were obtained.

Heat susceptibility index (HSI) was calculated for grain yield and other quantitative traits over high temperature stress (very late sown) and non-stress environment (normal sown) by using the formula as suggested by Fisher and Maurer (1978).

$$HSI = [1-YD/YP]/D$$

Where,

YD = mean of the genotypes in stress environment.

YP = mean of the genotypes under non-stress environment.

D = 1-[mean YD of all genotypes/mean YP of all genotypes].

## Result and Discussion

### Days to 50% flowering

The genotype JS-335 (2.55) had the maximum heat susceptibility index value in this experiment for days to 50% flowering over S1 and S2 conditions, followed by JS-9305 (2.16), KDS-1388 (1.74), KDS-1275 (1.40), AMS-100-39(1.33) and KDS-992 (1.28). This demonstrated that these genotypes were vulnerable. The genotypes KDS-1193 (0.02), KDS-726 (0.14), MACS-1188 (0.26) and KDS-1279 had the lowest values, indicating their tolerance to late sown conditions. Higher numbers indicate susceptibility to temperature change, while lower values indicate genetic resistance. HSI values over S1 and S3 conditions were higher for genotypes KDS-992 (1.28), DS-228 (1.26), JS-335 (1.17), KDS-1149 (1.17), KDS-1188 (1.12) and KDS-1279 (1.09). Lower HSI values were obtained for genotypes MACS-1188 (0.62), MACS-1281 (0.69), KDS-1193 (0.76) and MACS-1520 (0.85), indicating tolerance for very late sowing conditions.

### Days to maturity

The genotypes' HSI for days to maturity differed. Higher HSI was reported in genotypes MACS-1188 (1.70), KDS-344 (1.60), MACS-1460 (1.52), MACS-1520 (1.45), KDS-726 (1.37) and KDS-1279 (1.17) over S1-S2 condition. Lower HSI values were found in genotypes KDS-1388 (0.26), AMS-100-39 (0.36), KDS-1203 (0.45), KDS-753 (0.52), JS-335 (0.69) and DS-228.

For the S1-S3 condition, genotypes MACS-1460 (1.61), MACS-1520 (1.38), MACS-1188 (1.29), KDS-344 (1.15), MACS-1281 (1.13) and KDS-1188 (1.12) had higher HSI. While genotypes KDS-1096 (0.62), AMS-100-39 (0.64), KDS-753 (0.66), JS-335 (0.75), KDS-1149 (0.76) and KDS-1203 (0.76) exhibited lower HSI.

### Plant height

KDS-1279 (2.35) had the highest HSI for plant height across S1-S2 condition, followed by JS-9305 (1.71), MACS-1520 (1.60), KDS-1188 (1.43) and MACS-1188 (1.29). Genotypes AMS-100-39 (0.16), KDS-344 (0.39), MACS-1460 (0.40), KDS-1203 (0.58) and KDS-1275 (0.70), on the other hand, had lower HSI.

The genotype KDS-992 had the highest HSI for the S1-S3 condition (19.75), followed by KDS-344 (17.91), KDS-1203 (14.83) and AMS-100-39 (14.41). While genotypes KDS-1279 (-34.38), KDS-1096 (-30.96), KDS-1188 (-14.03) and KDS-1149 (-11.21) had lowest HSI.

### Number of branches per plant

The genotype AMS-100-39 (3.62) had the highest HSI for number of branches per plant across S1-S2 condition, followed by JS-335 (3.33), KDS-1388 (1.86), KDS-1279 (1.79) and KDS-1193(1.57). Lower HSI was demonstrated by genotypes DS-228 (-2.96), KDS-1188 (0.15), KDS-1203 (0.43), MACS-1520 (0.46), MACS-1460 (0.58) and MACS-1281 (0.61).

The genotype JS-335 (13.81) had the highest HSI for the S1-S3 condition, followed by AMS-100-39 (13.78), KDS-1279 (6.36), KDS-1388 (5.33), KDS-344 (3.36) and KDS-1275 (2.21). Lower HSI values were seen in genotypes DS-228 (-14.73), KDS-1149 (-3.72), KDS-1188 (-3.09) and KDS-1203 (-2.29).

**Table 1 :** List of 20 genotypes of Soybean

| Sr. No. | Genotype | Sr. No. | Genotype |
|---|---|---|---|
| 1 | AMS-100-39 | 11 | KDS-1188 |
| 2 | DS-228 | 12 | KDS-1193 |
| 3 | JS-335 | 13 | KDS-1203 |
| 4 | JS-9305 | 14 | KDS-1275 |
| 5 | KDS-344 | 15 | KDS-1279 |
| 6 | KDS-726 | 16 | KDS-1388 |
| 7 | KDS-753 | 17 | MACS-1188 |
| 8 | KDS-992 | 18 | MACS-1281 |
| 9 | KDS-1096 | 19 | MACS-1460 |
| 10 | KDS-1149 | 20 | MACS-1520 |

**Table 2 :** Heat Susceptibility Index of days to 50 %flowering, days to maturity, plant height and number of branches per plant.

| Heat Susceptibility Index | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sr. No.** | **Genotypes** | **Days for 50 %flowering** | | **Days for maturity** | | **Plant Height** | | **Number of branches per plant** | |
| | | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 |
| 1 | AMS-100-39 | 1.33 | 1.09 | 0.36 | 0.64 | 0.16 | 14.41 | 3.62 | 13.78 |
| 2 | DS-228 | 0.99 | 1.26 | 0.73 | 0.96 | 0.87 | 7.48 | -2.96 | -14.73 |
| 3 | JS-335 | 2.55 | 1.17 | 0.69 | 0.75 | 0.95 | 9.70 | 3.33 | 13.81 |
| 4 | JS-9305 | 2.16 | 0.94 | 1.06 | 0.81 | 1.71 | 0.90 | 0.70 | 0.17 |
| 5 | KDS-344 | 0.83 | 1.09 | 1.60 | 1.15 | 0.39 | 17.91 | 1.13 | 3.36 |
| 6 | KDS-726 | 0.14 | 1.04 | 1.37 | 1.00 | 1.05 | 11.86 | 1.29 | 1.77 |
| 7 | KDS-753 | 1.21 | 1.02 | 0.52 | 0.66 | 0.91 | 12.52 | 0.67 | 1.34 |
| 8 | KDS-992 | 1.28 | 1.28 | 0.86 | 1.11 | 0.92 | 19.75 | 1.09 | -0.17 |
| 9 | KDS-1096 | 0.96 | 1.03 | 0.91 | 0.62 | 1.13 | -30.96 | 1.21 | 1.33 |
| 10 | KDS-1149 | 0.63 | 1.17 | 0.77 | 0.76 | 0.88 | -11.21 | 0.85 | -3.72 |
| 11 | KDS-1188 | 1.22 | 1.12 | 1.15 | 1.12 | 1.43 | -14.03 | 0.15 | -3.09 |
| 12 | KDS-1193 | 0.02 | 0.76 | 1.11 | 1.00 | 0.88 | 3.85 | 1.57 | -0.22 |
| 13 | KDS-1203 | 0.85 | 1.05 | 0.45 | 0.76 | 0.58 | 14.83 | 0.43 | -2.29 |
| 14 | KDS-1275 | 1.40 | 1.01 | 1.03 | 0.96 | 0.70 | 9.15 | 1.33 | 2.21 |
| 15 | KDS-1279 | 0.28 | 1.09 | 1.17 | 0.96 | 2.35 | -34.38 | 1.79 | 6.36 |
| 16 | KDS-1388 | 1.74 | 0.98 | 0.26 | 1.06 | 1.13 | -10.01 | 1.86 | 5.33 |
| 17 | MACS-1188 | 0.26 | 0.62 | 1.70 | 1.29 | 1.29 | -8.47 | 1.22 | 0.35 |
| 18 | MACS-1281 | 0.55 | 0.69 | 1.01 | 1.13 | 1.00 | -9.25 | 0.61 | -0.25 |
| 19 | MACS-1460 | 0.73 | 0.86 | 1.52 | 1.61 | 0.40 | 5.99 | 0.58 | -0.12 |
| 20 | MACS-1520 | 0.82 | 0.85 | 1.45 | 1.38 | 1.60 | -9.43 | 0.46 | -1.14 |

**Table 3 :** Heat Susceptibility Index of number of pods per plant, number of seeds per pod, 100 seed weight and yield per plant.

| Heat Susceptibility Index | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sr. No.** | **Genotypes** | **Number of pods per plant** | | **Number of seeds per pod** | | **100 seed weight** | | **Yield per plant** | |
| | | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 |
| 1 | AMS-100-39 | 1.91 | 0.40 | -2.33 | 1.06 | 1.18 | 13.48 | 0.61 | 0.38 |
| 2 | DS-228 | 0.51 | 0.52 | 0.44 | 0.62 | 1.44 | -1.02 | 1.62 | 1.02 |
| 3 | JS-335 | 0.67 | 0.43 | -2.84 | 1.34 | 1.03 | -5.85 | 0.47 | 0.00 |
| 4 | JS-9305 | 1.57 | -0.27 | 1.32 | 0.37 | 1.14 | -1.23 | 0.43 | 1.45 |
| 5 | KDS-344 | 0.63 | 0.67 | -3.71 | 1.46 | 1.01 | 12.29 | 1.55 | 3.10 |
| 6 | KDS-726 | 0.78 | 0.60 | 3.86 | 0.12 | 0.50 | 6.33 | 0.28 | 1.41 |
| 7 | KDS-753 | 0.72 | 0.95 | 6.96 | 0.33 | 0.31 | 7.62 | 0.79 | 0.47 |
| 8 | KDS-992 | 0.58 | 0.51 | -1.71 | 1.09 | 1.51 | -7.63 | 0.48 | 0.53 |
| 9 | KDS-1096 | 0.12 | 2.01 | 5.97 | 1.20 | 1.22 | -2.61 | 0.71 | 1.06 |
| 10 | KDS-1149 | 0.71 | 1.86 | -2.01 | 1.64 | 1.63 | -3.04 | 0.81 | 0.20 |
| 11 | KDS-1188 | 0.47 | 1.60 | -6.63 | 2.35 | 0.70 | -2.37 | 1.11 | 2.00 |
| 12 | KDS-1193 | 0.47 | 2.30 | 2.30 | 2.03 | 0.00 | -0.26 | 2.15 | -1.10 |
| 13 | KDS-1203 | 1.48 | 0.98 | 7.55 | 0.76 | 0.58 | 1.64 | 1.41 | -4.54 |
| 14 | KDS-1275 | 1.22 | 1.38 | 0.56 | 1.11 | 0.12 | 3.39 | 0.75 | -1.35 |
| 15 | KDS-1279 | 1.52 | 1.32 | 5.33 | 0.67 | 1.26 | -1.81 | 1.35 | -3.75 |
| 16 | KDS-1388 | 2.11 | 0.96 | 0.58 | 0.66 | 1.50 | -4.31 | 1.35 | 1.20 |
| 17 | MACS-1188 | 1.00 | 2.09 | 5.38 | 1.02 | 0.84 | 8.83 | 0.62 | 3.49 |
| 18 | MACS-1281 | 1.93 | 0.94 | 0.00 | 1.24 | 1.47 | 4.88 | 1.04 | 3.33 |
| 19 | MACS-1460 | 1.35 | 1.17 | 1.17 | 1.08 | 2.10 | -3.82 | 1.61 | 4.36 |
| 20 | MACS-1520 | 1.31 | 1.44 | 1.17 | 1.33 | 0.80 | -4.91 | 1.21 | 6.08 |

**Table 4 :** Heat Susceptibility Index of root length, root biomass, plant biomass, oil content and protein content.

| **Heat Susceptibility Index** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sr.No.** | **Genotypes** | **Root length** | | **Root Biomass** | | **Plant Biomass** | | **Oil Content** | | **Protein content** | |
| | | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 |
| 1 | AMS-100-39 | -0.96 | 0.23 | -0.43 | 1.97 | 0.98 | 1.35 | 0.20 | 0.48 | 0.76 | 5.31 |
| 2 | DS-228 | -1.84 | 0.44 | -0.10 | 1.00 | 1.03 | 0.88 | 0.30 | 1.14 | 0.59 | 7.04 |
| 3 | JS-335 | 1.27 | -0.30 | -0.38 | 1.59 | 1.95 | 0.32 | 0.94 | 3.79 | 1.01 | 6.63 |
| 4 | JS-9305 | -0.28 | 0.07 | -0.67 | 1.33 | 2.02 | -0.45 | 0.18 | 1.78 | 1.95 | 6.95 |
| 5 | KDS-344 | 11.68 | -2.80 | 1.35 | 0.90 | 1.51 | -0.36 | 0.58 | 1.31 | 0.71 | 18.94 |
| 6 | KDS-726 | 0.16 | -0.04 | 0.46 | 1.39 | -0.13 | 0.63 | 0.53 | 4.54 | 0.79 | 7.02 |
| 7 | KDS-753 | -0.47 | 0.11 | -0.84 | 1.68 | 2.52 | -0.56 | 0.71 | 3.30 | 1.04 | 14.24 |
| 8 | KDS-992 | 5.07 | -1.22 | 1.22 | 0.81 | 3.41 | -0.23 | 0.66 | 1.11 | 1.19 | 14.45 |
| 9 | KDS-1096 | 1.06 | -0.25 | 1.52 | 0.54 | 0.52 | 1.09 | 0.61 | 0.86 | 0.50 | 5.31 |
| 10 | KDS-1149 | -0.92 | 0.22 | 0.65 | 1.44 | 0.52 | 1.61 | 0.76 | 1.07 | 0.53 | 12.06 |
| 11 | KDS-1188 | 1.69 | -0.41 | 1.20 | 0.45 | 0.51 | 1.27 | 0.40 | 2.16 | 0.60 | 9.97 |
| 12 | KDS-1193 | 0.92 | -0.22 | 1.13 | 0.57 | 0.27 | 2.01 | 1.63 | 0.79 | 0.58 | 10.52 |
| 13 | KDS-1203 | 2.91 | -0.70 | 1.18 | 1.18 | 0.60 | 1.67 | 1.22 | 6.09 | 2.94 | 9.86 |
| 14 | KDS-1275 | -0.09 | 0.02 | -1.08 | 2.71 | 0.81 | 2.14 | 2.13 | -3.35 | 0.53 | 15.64 |
| 15 | KDS-1279 | -1.12 | 0.27 | 1.18 | 0.65 | 0.60 | 1.66 | 0.78 | -0.51 | 1.80 | 5.01 |
| 16 | KDS-1388 | 1.03 | -0.25 | 1.19 | 0.40 | 0.65 | 3.11 | 1.86 | -2.73 | 0.77 | 10.71 |
| 17 | MACS-1188 | -0.75 | 0.18 | 1.30 | 1.18 | 0.48 | 0.80 | 0.77 | 2.01 | 0.77 | 7.89 |
| 18 | MACS-1281 | 0.97 | -0.23 | 2.05 | 0.68 | 0.75 | 0.79 | 2.17 | -2.12 | 1.40 | 2.99 |
| 19 | MACS-1460 | 1.50 | -0.36 | 0.72 | 1.44 | 0.31 | 2.03 | 3.14 | -5.90 | 0.77 | 9.71 |
| 20 | MACS-1520 | -0.71 | 0.17 | 1.53 | 1.53 | 0.22 | 0.77 | 1.34 | 2.70 | 1.47 | 13.74 |

**Table 5 :** Heat Susceptibility Index of canopy temperature ($^{0}C$) , number of leaves per plant and Leaf Area Index (LAI).

| **Heat Susceptibility Index** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sr.No.** | **Genotypes** | **Canopy temperature ($^{0}C$)** | | **Number of leaves per plant** | | **Leaf Area Index (LAI)** | |
| | | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 |
| 1 | AMS-100-39 | 1.45 | 1.17 | 0.38 | 0.26 | 0.77 | -3.58 |
| 2 | DS-228 | 1.84 | 1.12 | 0.59 | 0.71 | 1.30 | 2.91 |
| 3 | JS-335 | 0.50 | 0.92 | 0.14 | 0.30 | 0.86 | 1.68 |
| 4 | JS-9305 | 1.35 | 0.97 | 0.33 | 0.02 | 0.20 | 3.60 |
| 5 | KDS-344 | 0.70 | 1.01 | 1.75 | -0.68 | 1.09 | 2.47 |
| 6 | KDS-726 | 2.63 | 1.35 | 1.12 | 1.70 | 1.68 | -4.74 |
| 7 | KDS-753 | 0.46 | 0.89 | 0.43 | -0.21 | 1.72 | -3.38 |
| 8 | KDS-992 | 0.85 | 0.87 | 0.90 | 0.09 | 0.76 | 3.62 |
| 9 | KDS-1096 | 0.85 | 0.90 | 0.32 | -0.03 | 0.94 | 1.82 |
| 10 | KDS-1149 | -0.39 | 0.65 | 0.89 | 1.54 | 0.35 | 5.02 |
| 11 | KDS-1188 | 0.37 | 1.08 | 1.19 | -0.01 | 1.25 | -0.97 |
| 12 | KDS-1193 | 0.88 | 1.07 | 1.61 | 0.30 | 0.99 | 0.32 |
| 13 | KDS-1203 | 1.00 | 0.83 | 1.62 | -0.96 | 0.70 | 5.18 |
| 14 | KDS-1275 | 2.35 | 1.19 | 1.20 | 2.57 | 0.84 | 3.99 |
| 15 | KDS-1279 | 1.03 | 0.92 | 0.82 | -0.45 | 1.12 | -5.05 |
| 16 | KDS-1388 | 0.72 | 1.08 | 1.03 | 0.18 | 0.54 | -4.84 |
| 17 | MACS-1188 | 1.43 | 1.06 | 1.18 | 4.22 | 0.79 | 4.62 |
| 18 | MACS-1281 | 0.41 | 1.02 | 2.72 | 8.23 | 2.04 | 1.61 |
| 19 | MACS-1460 | 1.41 | 1.00 | 0.99 | 4.93 | 0.80 | 4.71 |
| 20 | MACS-1520 | 0.35 | 0.91 | 1.52 | 0.37 | 1.44 | -4.56 |

**Table 6 :** Heat Susceptibility Index of Chlorophyll content, Total Soluble Sugar (TSS), Proline content at pre anthesis (µmole/g) and Proline content at post anthesis (µmole/g)

| **Heat Susceptibility Index** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sr. No.** | **Genotypes** | **Chlorophyll content** | | **Total Soluble Sugar (TSS)** | | **Proline content at pre anthesis (µmole/g)** | | **Proline content at post anthesis (µmole/g)** | |
| | | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 | S1-S2 | S1-S3 |
| 1 | AMS-100-39 | 1.25 | 1.16 | -17.25 | -0.61 | 1.93 | 1.27 | 1.03 | 1.11 |
| 2 | DS-228 | 0.78 | -1.83 | -6.90 | 1.21 | 1.07 | 1.00 | 0.29 | 0.93 |
| 3 | JS-335 | 0.83 | 0.03 | 5.98 | 1.58 | 0.71 | 0.51 | 1.12 | 0.34 |
| 4 | JS-9305 | 1.09 | 0.58 | -3.20 | 1.69 | 1.19 | 1.02 | 0.28 | 0.53 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | KDS-344 | 2.46 | 4.30 | 0.00 | 1.82 | 1.14 | 1.05 | 0.97 | 0.91 |
| 6 | KDS-726 | 1.67 | 0.44 | -6.90 | -0.61 | 1.38 | 1.13 | 1.64 | 0.81 |
| 7 | KDS-753 | 0.43 | 2.01 | 0.00 | 0.00 | 0.87 | 0.82 | 1.26 | 1.26 |
| 8 | KDS-992 | 0.56 | 0.00 | 11.96 | 2.63 | 1.36 | 1.10 | 1.27 | 1.12 |
| 9 | KDS-1096 | 0.56 | -0.24 | 0.00 | 1.43 | 1.22 | 1.14 | 1.26 | 1.16 |
| 10 | KDS-1149 | 0.63 | -0.74 | 5.28 | 1.86 | 0.85 | 1.16 | 0.86 | 1.02 |
| 11 | KDS-1188 | 1.12 | 1.99 | -6.90 | -1.21 | 1.79 | 1.92 | 2.14 | 1.78 |
| 12 | KDS-1193 | 1.15 | 2.52 | 0.00 | 1.58 | 0.88 | 1.19 | 1.28 | 0.98 |
| 13 | KDS-1203 | 1.22 | 1.58 | -2.80 | 1.97 | 1.07 | 1.09 | 1.00 | 1.05 |
| 14 | KDS-1275 | 1.44 | 0.10 | 6.90 | -2.43 | 0.81 | 0.79 | 1.19 | 0.92 |
| 15 | KDS-1279 | -0.39 | 1.93 | 0.00 | -0.61 | 0.66 | 0.78 | 1.24 | 1.62 |
| 16 | KDS-1388 | 1.40 | 1.32 | -6.41 | 1.13 | 0.87 | 0.69 | 0.59 | 1.18 |
| 17 | MACS-1188 | 1.08 | 5.24 | 8.54 | 2.25 | 0.28 | 1.24 | 0.49 | 0.80 |
| 18 | MACS-1281 | 0.41 | -0.38 | 8.41 | 1.97 | 0.82 | 0.96 | 0.47 | 0.89 |
| 19 | MACS-1460 | 1.08 | 0.29 | 4.48 | 1.58 | 1.03 | 1.00 | 0.55 | 1.05 |
| 20 | MACS-1520 | 1.43 | 1.12 | 8.97 | 0.53 | 0.30 | 0.51 | 1.62 | 1.11 |

### Number of pods per plant

Over the S1-S2 condition, genotype KDS-1388 (2.11) had the highest HSI for number of pods per plant. In addition, genotypes MACS-1281 (1.93), AMS-100-39 (1.91), JS-9305 (1.57) and KDS-1279 (1.52) had significant HSI, indicating their susceptibility to high temperatures. KDS-1096 (0.12), KDS-1193 (0.47), KDS-1188 (0.47), DS-228 (0.51), KDS-992 (0.58), KDS-344 (0.63) and JS-335 (0.67) genotypes exhibited lower HSI. KDS-1193 (2.30) had the highest HSI for number of pods per plant over S1-S3 conditions, followed by MACS-1188 (2.09), KDS-1096 (2.01), KDS-1149 (1.86), KDS-1188 (1.60) and MACS-1520 (1.44). While genotype JS-9305 (-0.27) had the lowest HSI, it was followed by AMS-100-39 (0.40), JS-335 (0.43), KDS-992 (0.51), DS-228 (0.52), KDS-726 (0.60) and KDS-344 (0.67).

### Number of seeds per pod

Over S1-S2 conditions, genotype KDS-1203 (7.55) had the highest HSI for number of seeds per pod, followed by KDS-753 (6.96), KDS-1096 (5.97), MACS-1188 (5.38) and KDS-1279 (5.33), indicating their susceptibility to high temperatures. While KDS-1188 had a low HSI (-6.63), indicating its resistance to temperature stress conditions. Other genotypes were in the increasing order as KDS-1188 (-6.63), KDS-344 (-3.71), JS-335 (-2.84) and AMS-100-39 (-2.33).

KDS-1188 (2.35) had the highest HSI for number of seeds per pod over the S1-S3 condition, followed by KDS-1193 (2.03), KDS-1149 (1.64), KDS-344 (1.46), JS-335 (1.34) and MACS-1520 (1.33). On the contrary, genotypes KDS-726 (0.12), KDS-753 (0.33), JS-9305 (0.37), DS-228 (0.62) and KDS-1388 (0.66) had lower HSI.

### 100 seed weight (g)

Over S1-S2 conditions, the genotype MACS-1460 (2.10) had the highest HSI for 100 seed weight, followed by KDS-1149 (1.63), KDS-992 (1.51), KDS-1388 (1.50), MACS-1281 (1.47) and DS-228 (1.44). The lowest HSI genotype was KDS-1193 (0.00), followed by KDS-1275 (0.12), KDS-753 (0.31), KDS-726 (0.50) and KDS-1203 (0.58).

Under S1-S3 conditions, genotype AMS-100-39 (13.48) had the highest HSI, indicating its susceptibility to high temperatures. It was followed by KDS-344 (12.29), MACS-1188 (8.83), KDS-753 (7.62), KDS-726 (6.33) and MACS-1281 (4.88). On the other hand, genotype KDS-992 (-7.63) had the lowest HSI, indicating its resistance to high temperatures, followed by JS-335(-5.85), MACS-1520 (-4.91), KDS-1388 (-4.31) and MACS-1460 (-3.82).

### Yield per plant

Over S1-S2 conditions, the genotype KDS-1193 (2.15) had the highest HSI for yield per plant, followed by DS-228 (1.62), MACS-1460 (1.61), KDS-344 (1.55), KDS-1203 (1.41), KDS-1279 (1.35) and KDS-1388 (1.35). KDS-7260 (0.28) had the lowest HSI, followed by JS-9305 (0.43), JS-335 (0.47), KDS-992 (0.48), AMS-100-39 (0.61) and MACS-1188 (0.62).

Under S1-S3 conditions, genotype MACS-1520 (6.08) had the highest HSI, indicating its susceptibility to high temperatures. Following that were genotypes MACS-1460 (4.36), MACS-1188 (3.49) and MACS-1281 (3.33). On the other hand, genotype KDS-1203 (-4.54) had the lowest HSI, indicating its tolerance to high temperatures, and was followed by KDS-1279 (-3.75), KDS-1275 (-1.35), KDS-1193 (-1.10), JS-335 (0.00), KDS-1149 (0.20) and AMS-100-39 (0.38).

### Root length

In this experiment, for root length over S1 and S2 condition, the highest HSI value was recorded for genotype KDS-344 (11.68) which was followed by KDS-992 (5.07), KDS-1203 (2.91), KDS-1188 (1.69) and MACS-1460 (1.50) showed their high susceptibility for late sown condition and lower values were recorded by the genotypes DS-228 1.84), KDS-1279 (-1.12), AMS-100-39 (-0.96) and KDS-1149 (-0.92) indicated their tolerance to late sown condition.

HSI was higher in genotypes DS-228 (0.44), KDS-1279 (0.27), AMS-100-39 (0.23) and KDS-1149 (0.22). While genotypes KDS-344 (-2.80), KDS-992 (-1.22), KDS-1203 (-0.70), and KDS-1188 (-0.41) had lower HSI, this suggested their tolerance for late sown conditions.

**Root biomass**

Over S1-S2 conditions, the genotype MACS-1281 (2.05) had the highest HSI for root biomass, followed by MACS-1520 (1.53), KDS-1096 (1.52), KDS-344 (1.35), MACS-1188 (1.30), KDS-992 (1.22) and KDS-1188 (1.20). KDS-1275 (-1.08) had the lowest HSI, followed by KDS-753 (-0.84), JS-9305 (-0.67), AMS-100-39 (-0.43) and JS-335 (-0.38).

Under S1-S3 conditions, genotype KDS-1275 had the greatest HSI (2.71), indicating its susceptibility to high temperatures. Following that were genotypes AMS-100-39 (1.97), KDS-753 (1.68), JS-335 (1.59), MACS-1520 (1.53), MACS-1460 (1.44) and KDS-1149 (1.44). KDS-1388 (0.40) had the lowest HSI, indicating its endurance to high temperatures, and was followed by KDS-1188 (0.45), KDS-1096 (0.54), KDS-1193 (0.57), KDS-1279 (0.65) and MACS-1281 (0.68).

**Plant biomass**

Over S1-S2 conditions, the genotype KDS-992 (3.41) had the highest HSI for plant biomass, followed by KDS-753 (2.52), JS-9305 (2.02) and JS-335 (1.95). KDS-726 (-0.13) had the lowest HSI, followed by MACS-1520 (0.22), KDS-1193 (0.27) and MACS-1460 (0.31).

Under S1-S3 conditions, genotype KDS-1388 had the greatest HSI (3.11), indicating its susceptibility to high temperatures. Following that were genotypes KDS-1275 (2.14), MACS-1460 (2.03), KDS-1193 (2.01) and KDS-1203 (1.67). KDS-753 (-0.56) had the lowest HSI, indicating its endurance to high temperatures, and was followed by JS-9305 (-0.45), KDS-344 (-0.36), KDS-992 (-0.23) and JS-335 (0.32).

**Oil content**

Over S1-S2 conditions, the genotype MACS-1460 (3.14) had the highest HSI for oil content, followed by MACS-1281 (2.17), KDS-1275 (2.13), KDS-1388 (1.86), KDS-1193 (1.63), MACS-1520 (1.34) and KDS-1203 (1.22). JS-9305 (0.18) had the lowest HSI, followed by AMS-100-39 (0.20), DS-228 (0.30), KDS-1188 (0.40), KDS-726 (0.53) and KDS-344 (0.58).

Under S1-S3 conditions, genotype KDS-1203 (6.09) had the highest HSI, indicating its susceptibility to high temperatures. Following that were genotypes KDS-726 (4.54), JS-335 (3.79) and KDS-753 (3.30). On the other hand, genotype MACS-1460 (-5.90) had the lowest HSI, indicating its tolerance to high temperatures, and was followed by KDS-1275 (-3.35), KDS-1388 (-2.73), MACS-1281 (-2.12), KDS-1279 (-0.51) and AMS-100-39 (0.48).

**Protein content**

Under S1-S2 conditions, genotype KDS-1203 (2.94) had the highest HSI, indicating its susceptibility to high temperatures. Following that were genotypes JS-9305 (1.95), KDS-1279 (1.80) and MACS-1520 (1.47). On the other hand, genotype KDS-1096 (0.50) had the lowest HSI, indicating its tolerance to high temperatures, and was followed by KDS-1149 (0.53), KDS-1275 (0.53), KDS-1193 (0.58), DS-228 (0.59) and KDS-1188 (0.60).

Over S1-S3 conditions, the genotype KDS-344 (18.94) had the highest HSI for protein content, followed by KDS-1275 (15.64), KDS-992 (14.45) and KDS-753 (14.24). MACS-1281 (2.99) had the lowest HSI, followed by KDS-1279 (5.01), AMS-100-39 (5.31), KDS-1096 (5.31), JS-335 (6.63), JS-9305 (6.95) and KDS-726 (7.02).

**Canopy temperature**

KDS-726 (2.63) obtained the highest HSI for canopy temperature over S1-S2 conditions. Followed by genotypes in decreasing order as KDS-1275 (2.35), DS-228 (1.84), AMS-100-39 (1.45), MACS-1188 (1.43) and MACS-1460 (1.41) exhibited high HSI, indicating their susceptibility to high temperature conditions. In contrast, genotypes KDS-1149 (-0.39), MACS-1520 (0.35), KDS-1188 (0.37), MACS-1281 (0.41), KDS-753 (0.46), JS-335 (0.50) and KDS-344 (0.70) exhibited lower HIS.

HSI value for canopy temperature over S1-S3 condition was highest for KDS-726 (1.35), followed by KDS-1275 (1.19), AMS-100-39 (1.17), DS-228 (1.12), KDS-1388 (1.08) and KDS-1188 (1.08). While KDS-1149 had the lowest HSI (0.65), it was followed by KDS-1203 (0.83), KDS-992 (0.87), KDS-753 (0.89) and KDS-1096 (0.90).

**Number of leaves per plant**

Over S1-S2 conditions, genotype MACS-1281 (2.72) had the highest HSI for number of leaves per plant, followed by KDS-344 (1.75), KDS-1203 (1.62), KDS-1193 (1.61), MACS-1520 (1.52) and KDS-1275 (1.20), indicating their susceptibility to high temperature. While JS-335 had a low HSI (0.14), indicating its resistance to thermal stress conditions. Other genotypes include KDS-1096 (0.32), JS-9305 (0.33), AMS-100-39 (0.38), KDS-753 (0.43), and DS-228 (0.59) in increasing order.

MACS-1281 (8.23) had the highest HSI for number of leaves per plant over the S1-S3 condition, followed by MACS-1460 (4.93), MACS-1188 (4.22), KDS-1275 (2.57), KDS-726 (1.70) and KDS-1149 (1.54). On the other hand, genotypes KDS-1203 (-0.96), KDS-344 (-0.68), KDS-1279 (-0.45), KDS-753 (-0.21) and KDS-1096 (-0.03) had lower HSI.

**Leaf Area Index (LAI)**

MACS-1281 (2.04) got the greatest HSI for leaf area index (LAI) in the S1-S2 condition. In addition, genotypes KDS-753 (1.72), KDS-726 (1.68), MACS-1520 (1.44), DS-228 (1.30), and KDS-1188 (1.25) exhibited significant HSI, indicating their susceptibility to high temperatures. JS-335 (0.20), KDS-1149 (0.35), KDS-1388 (0.54), KDS-1203 (0.70) and KDS-992 (0.76), on the other hand, had lower HSI.

KDS-1203 had the highest HSI value for LAI over S1-S3 condition (5.18), followed by KDS-1149 (5.02), MACS-1460 (4.71), MACS-1188 (4.62), KDS-1275 (3.99) and KDS-992(3.62). While genotype KDS-1279 had the lowest HSI (-5.05), it was followed by KDS-1388 (-4.84), KDS-726 (-4.74), MACS-1520 (-4.56) and AMS-100-39 (-3.58).

**Chlorophyll content**

Genotype KDS-344 (2.46) had highest HSI for chlorophyll content over S1-S2 condition. Followed by genotypes KDS-726 (1.67), KDS-1275 (1.44), MACS-1520 (1.43) and KDS-1388 (1.40) had high HSI showing their susceptible nature to high temperature condition. On the contrary genotypes KDS-1279 (-0.39), MACS-1281 (0.41), KDS-753 (0.43) and KDS-992 (0.56) had less HSI.

HSI value for chlorophyll content over S1-S3 condition was highest for MACS-1188 (5.24) followed by KDS-344 (4.30), KDS-1193 (2.52), KDS-753 (2.01) and KDS-1188 (1.99) respectively. While lowest HSI was obtained for genotype DS-228 (-1.83) which was followed by KDS-1149 (-0.74), MACS-1281 (-0.38), KDS-1096 (-0.24), KDS-992 (0.00) and JS-335 (0.03) respectively.

**Total Soluble Sugar (TSS)**

KDS-992 (11.96) had the highest HSI for TSS in the S1-S2 condition. Next, genotypes MACS-1520 (8.97), MACS-1188 (8.54), MACS-1281 (8.41), KDS-1275 (6.90), JS-335 (5.98) and KDS-1149 (5.28) had high HSI, indicating their susceptibility to high temperature conditions. On the other hand, genotypes AMS-100-39 (-17.25), DS-228 (-6.90), KDS-726 (-6.90), KDS-1188 (-6.90), KDS-1388 (-6.41) and JS-9305 (-3.20) had lower HSI.

KDS-992 (2.63) had the highest HSI value for TSS over S1-S3 condition, followed by MACS-1188 (2.25), MACS-1281 (1.97), KDS-1203 (1.97), KDS-1149 (1.86) and KDS-344 (1.82). While genotype KDS-1275 (-2.43) had the lowest HSI, it was followed by KDS-1188 (-1.21), AMS-100-39 (-0.61), KDS-726 (-0.61), KDS-1279 (-0.61) and KDS-753 (0.00).

**Proline content at pre anthesis stage**

The genotype AMS-100-39 (1.93) had the highest HSI for proline content in the S1-S2 condition. In addition, genotypes KDS-1188 (1.79), KDS-726 (1.38), KDS-992 (1.36), KDS-1096 (1.22) and JS-9305(1.19) exhibited significant HSI, indicating their susceptibility to high temperature conditions. MACS-1188 (0.28), MACS-1520 (0.30), KDS-1279 (0.66) and JS-335 (0.71) had lower HSI.

KDS-1188 (1.92) had the greatest HSI value for proline content over S1-S3 condition, followed by AMS-100-39 (1.27), MACS-1188 (1.24), KDS-1193 (1.19), KDS-1149 (1.16), and KDS-1096 (1.14). While MACS-1520 had the lowest HSI (0.51), it was followed by JS-335 (0.51), KDS-1388 (0.69), KDS-1279 (0.78), KDS-1275 (0.79) and KDS-753 (0.82).

**Proline content at post anthesis stage**

KDS-1188 (2.14) had the highest HSI for proline content in the S1-S2 condition. In addition, genotypes KDS-726 (1.64), MACS-1520 (1.62), KDS-1193 (1.28), KDS-992 (1.27) and KDS-753 (1.26) exhibited high HSI, indicating their susceptibility to high temperatures. JS-9305 (0.28), DS-228 (0.29), MACS-1281 (0.47), MACS-1188 (0.49) and MACS-1460 (0.55) had lower HSI.

KDS-1188 (1.92) had the highest HSI value for proline content over the S1-S3 condition, followed by KDS-1279 (1.62), KDS-753 (1.26), KDS-1388 (1.18) and KDS-1096 (1.16). While genotype JS-335 (0.34) had the lowest HSI, it was followed by JS-9305 (0.53), MACS-1188 (0.80), KDS-726 (0.81), MACS-1281 (0.89), KDS-344 (0.91) and KDS-1275 (0.92), in that order.

Similar results by Djanaguiraman *et al.* (2013) studied the high day or night time temperature on leaf assimilation and reproduction success in soybean. High day time or night time temperature increased leaf respiration rates and decreased leaf chlorophyll content, photosynthesis rate. High temperature decreased pollen viability and germination. High day time or night time temperature leading to lower pod set of seed weight. Khan *et al. (*2011) studied the effect of canopy temperature on seed quality and vigour of soybean planted on different dates. Increase in maximum temperature in range of 32 to 37 $^0$C during growth stage of full bloom to seed initiation decreased seedling dry weight and oil content of soybean seed. Temperature stress in range of 35-43 $^0$C during reproductive development of well-watered plant under field conditions was an important factor in determining the yield and quality of both determinate and indeterminate cultivar.

During summer 2023, second sowing had the highest value of growth parameter also other paramters including days to 50% flowering, days to maturity, plant height (cm), number of branches per plant, number of pods per plant, number of seeds per pod, 100 seed weight (g), yield per plant (g), root length (cm), root biomass (g), plant biomass (g), LAI and chlorophyll content. Then came the first and third sowing. Due to high temperature stress, the growth parameter was reduced under third-sown conditions, and hence the yield was reduced. Proline content and canopy temperature rise with sowing date. Because of the increase in temperature, it is high with upcoming sowing dates.

Genotypes KDS-344, KDS-992, KDS-726, KDS-753, JS-335, JS-9305, AMS-100-39, and DS-228 exhibited lower HSI for yield and yield contributing characteristics, indicating that they can withstand high temperatures.

KDS-344, KDS-992, KDS-726, KDS-753, JS-335, JS-9305, AMS-100-39, and DS-228 are selected as thermo-tolerant on the basis of HSI and grain yield after screening twenty soybean genotypes under field conditions for high temperature stress generated by varied sowing dates.

The late sowing date (S2- 30 Jan 2023) found to favourable for cultivation in summer season. KDS-726, JS-9305, KDS-753, KDS-344 and AMS-100-39 genotypes are suited for all three sowing conditions.

This identified genotypes can be used for development of thermotolerant varieties in future breeding programme.

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