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Original Research Article

MORPHO-PHYSIOLOGICAL DISSECTION OF HEAT TOLERANCE IN CERTAIN POOL OF SOYBEAN GENOTYPES

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Abstract *Under the scenario of climate change, crop diversification through the incorporation of non-conventional oilseed crops like soybean in the cropping pattern is a need of the time. However, being native to regions having mild temperatures, soybean faces difficulty in adaptation in areas of lower latitude with high temperatures and short day lengths during growing periods. This situation directs the researchers to determine the tolerance of soybean genotypes against high temperatures and to establish a selection criterion for the identification of adaptable traits. For this purpose, a study was conducted at Oilseeds Research Institute, Faisalabad. Forty soybean genotypes including approved varieties were screened for tolerance against high temperatures in the growth chamber and glass house. At the seedling stage, genotypes were categorized into tolerant, moderately tolerant, and susceptible categories based on their STI values in the growth chamber and values of certain morpho-physiological parameters in a glass house. Considering the seed yield an ultimate goal in the adaptation process, its study is crucial in field conditions. Tolerant and moderately tolerant genotypes from previous experiments were sown in the field. Data of yield and contributing traits were recorded at maturity and subjected to analysis. Results showed great variability among genotypes for all the traits. AARI Soybean gave the best yield followed by Faisal Soybean, ORI-SOY-91, and ORI-SOY-102. All of these genotypes/varieties also performed well in terms of electrolyte leakage and leaf-relative water content. To conclude, these varieties would show better adaptation in high-temperature areas. Moreover, both the varieties along with 2 best-performing genotypes may prove to be better parents in future hybridization programs.*

Keywords: *Glycine max; heat tolerance; yield; electrolyte leakage; leaf relative water content*

Introduction

Soybean (Glycine max L.) Merr. 2n=40 is a legume crop, that originated in Northeast Asia, and was later designated as one of the vital sources of edible oil (20%) and high-quality protein (40%) which can be used for livestock as well as human diet. Additionally, oil extracted from its seed is being used to make diesel biofuel (Avila *et al*., 2013). In the year 2023, the world's top-ranked soybean producers are Brazil (153 million tons), the United States (13.34 million tons), Argentina (50 million tons), China (20.84 million tons), and India (11.88 million tons. Cumulative production of these countries represents a major share of global soybean production) (USDA, 2023). In the past, soybean cultivation area and production in Pakistan has remained negligible for decades representing one of the most challenging issues for the soybean industry in Pakistan. Therefore, the local annual demand for soybeans has been met through imports mainly from United States and Brazil. In Oct 2022, the Government of Pakistan ceased import of genetically engineered (GE) commodities, and this way import of Soybean was also banned resulting in an import of 248000 metric tons which was a decline of 86% year on year (YoY) basis. It drastically reduced soymeal production in the country. The Federal Cabinet of Pakistan lifted the ban on the import of GE commodities in November 2023 with prospects of resuming the imports again (Putri, 2023). It emphasizes how local soybean production is important to the country for a flourishing food and feed industry.

Soybean yield in Pakistan is much lower as compared to the world average which can be attributed to the climatic conditions of Pakistan. Climate occupies chief importance among all the factors that collectively decide agricultural production, as it is the most difficult to control and

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change. Therefore, it exercises the greatest limiting effect over yield (Avila *et al*., 2013). So, keeping the facts in view, detailed information regarding climatic conditions at the site of interest is inevitable for proper management of the soybean crop. Pakistan stretches over 30 degrees of latitude, ranging approximately from 24° to 35°, hence it lies in subtropics (American Institute of Pakistan Studies). Being a short-day plant (Garner & Allard, 1920), soybean is sensitive to photoperiod so its adaptability varies with latitude (Mourtzinis *et al.*, 2017). Temperature regions are at higher latitudes whereas tropical and sub-tropical areas being at lower latitudes have short day conditions. Varieties when introduced from former to later altitude give poor yield because they flower too early and without having sufficient vegetative growth to enter into the reproductive phase (Langewisch *et al.,* 2017). So, soybean varieties, relatively insensitive to photoperiod are needed of the day for Pakistan.

The delay between emergence and flowering has been demonstrated to be influenced by temperature in addition to photoperiod. Soybean growth is optimal at temperatures ranging from 20°C to 30°C (Saryoko *et al*., 2017). The maximum number of pods that can be produced by plants is facilitated by a moderate temperature combination of 26°C during the day and 14°C at night (Thomas & Raper, 1981). Development is restricted and blossoming is expedited when temperatures in the vegetative stage surpass 40°C. High temperatures during the reproductive phase may reduce the number and weight of seeds, which can lead to a decrease in grain quality and yield, as per Onat *et al.*, (2017). Soybeans are a delicate crop that necessitates temperatures of approximately 40°C from germination to flowering, which primarily takes place in the autumn. Therefore, the crop's economic viability is restricted because the produce was insufficient to satisfy the crop's cost-benefit ratio.

In 1988, international agricultural specialists-initiated climate change research following the IPCC's principles. The average temperature of the Earth is expected to increase from 1.8ºC to 4.0ºC over the next century, as per IPCC Report 4, 2007. The capacity of Pakistan's soybean crop to adjust in the coming decades may be restricted by the increasing temperatures caused by global warming. However, possible adverse effects of temperature change on soybean production in the growing season have still not been studied to a conclusion in Pakistan. Problems with temperature stress need to be resolved by developing new soybean genotypes with high-temperature tolerance. Keeping this in view, Oilseeds Research Institute (ORI), Faisalabad initiated research activities to develop new Soybean genotypes with better yield potential in the scenario of current climate change. To increase the adaptability of soybean, a comprehensive understanding of the impact of increased temperature during vegetative growth of the crop ultimately over yield and its components is required.

Material and Methods

The experimental material consisted of 40 genotypes of soybean having better yield potential, out of which two were released commercial varieties (Faisal Soybean and AARI Soybean) of Oilseeds Research Institute, Faisalabad, and one variety named Ajmeri. Faisal Soybean and Ajmeri being commercially cultivated varieties were used as check varieties. Evaluation of these genotypes/varieties against high-temperature stress was done at Ayub Agricultural Research Institute, Faisalabad, Pakistan, in three components.

In the first experiment, the genotypes/varieties were screened for their ability to tolerate high-temperature stress at the seedling stage in the controlled growth chamber of the Oilseeds Physiology Laboratory of Oilseeds Research Institute (ORI). Seeds of all genotypes in both the sets: treatment as well as control were sown in petri plates using completely randomized design (CRD) in three repeats. Petri plates were lined with filter paper to retain moisture and avoid drought stress. Seeds were allowed to germinate under optimum conditions i.e. temperature 28˚C and Relative Humidity (RH) 60%. Five-day-old seedlings (Chandola *et al*., 2016) of the treatment were subjected to high-temperature stress i.e. 45ºC for 24 hours while control was kept under optimum conditions.

The STI, or seedling thermos-tolerance index, was employed as a metric to assess a genotype's capacity to withstand elevated temperatures. It was determined by calculating the percentage of seedlings that emerged and seedlings that survived. The formula is as follows: STI = (Total number of seedlings / Number of seedlings that survived) x 100

As a result, according to Chandola *et al.,* (2016), genotypes showing 71–100% survival percentage were classified as tolerant, 51–70% survival percentage as moderately tolerant, and 0–50% survival percentage as susceptible. In the second experiment, all of the 40 genotypes/varieties were screened in the glass house of the Agricultural Biotechnology Research Institute (ABRI). Seeds were sown in seed trays filled with sandy loam soil. The experimental design used was CRD with 3 replications. One set of genotypes at the first trifoliate leaf stage was shifted into a glass house where it was exposed to temperature treatment for five days. Day/night temperature of 45ºC/35ºC and relative humidity (RH) of 60% was maintained. Control remained in optimum condition. Data for some morphological and physiological parameters i.e. root/shoot length, root/shoot fresh and dry mass, relative water contents, and cell membrane

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thermostability was recorded to evaluate the response of plants to cope with high-temperature stress. Standard statistical methods were used to analyze the data.

In the third experiment, pre-screened heat-tolerant and moderately heat-tolerant genotypes of soybean from the above-mentioned experiments were evaluated for their tolerance to high temperature under natural field conditions at the farm area of ORI. Faisalabad is located at 31ºN latitude where August 2023 received 12.3 mm rainfall. Highest daytime temperature during August was 45°C (Agromet Bulletin August, 2023), much enough to affect soybean at its early vegetative stage of growth. Entries were sown in the first week of August with the help of a hand seed drill in Randomized Complete Block Design (RCBD) with three replications. Plot size for each entry was 3m^2 consisting of 30cm apart 2 rows, each of length 5m. The applied dose of fertilizer for N:P:K was 75:75:30kg/ha. All recommended agronomic and cultural practices were applied throughout the growing period. Data for yield and yield-contributing traits were recorded and subjected to statistical analysis.

Table 1. List of evaluated soybean genotypes

Sr. No.	Genotype	Sr. No.	Genotype	Sr. No.	Genotype	Sr. No.	Genotype
1	ORI-SOY-102	**11**	ORI-SOY-135	**21**	Ajmeri	**31**	ORI-SOY-136
2	ORI-SOY-19	**12**	ORI-SOY-34	**22**	ORI-SOY-10	**32**	ORI-SOY-124
3	ORI-SOY-93	**13**	William-82	**23**	ORI-SOY-126	**33**	ORI-SOY-04
4	ORI-SOY-36	**14**	ORI-SOY-70	**24**	ORI-SOY-50	**34**	ORI-SOY-24
5	ORI-SOY-54	**15**	ORI-SOY-145	**25**	ORI-SOY-56	**35**	ORI-SOY-06
6	ORI-SOY-68	**16**	ORI-SOY-146	**26**	ORI-SOY-132	**36**	ORI-SOY-11
7	ORI-SOY-147	**17**	ORI-SOY-05	**27**	ORI-SOY-01	**37**	ORI-SOY-74
8	ORI-SOY-09	**18**	AARI Soybean	**28**	ORI-SOY-08	**38**	ORI-SOY-03
9	ORI-SOY-02	**19**	ORI-SOY-46	**29**	Faisal Soybean	**39**	ORI-SOY-12
10	ORI-SOY-125	**20**	ORI-SOY-101	**30**	ORI-SOY-30	**40**	ORI-SOY-91

Results and Discussion

Component 1

The seedling survival percentage in heat treatment is presented in Table 2. The genotypes were categorized based on the percentage of seedlings that survived as under.

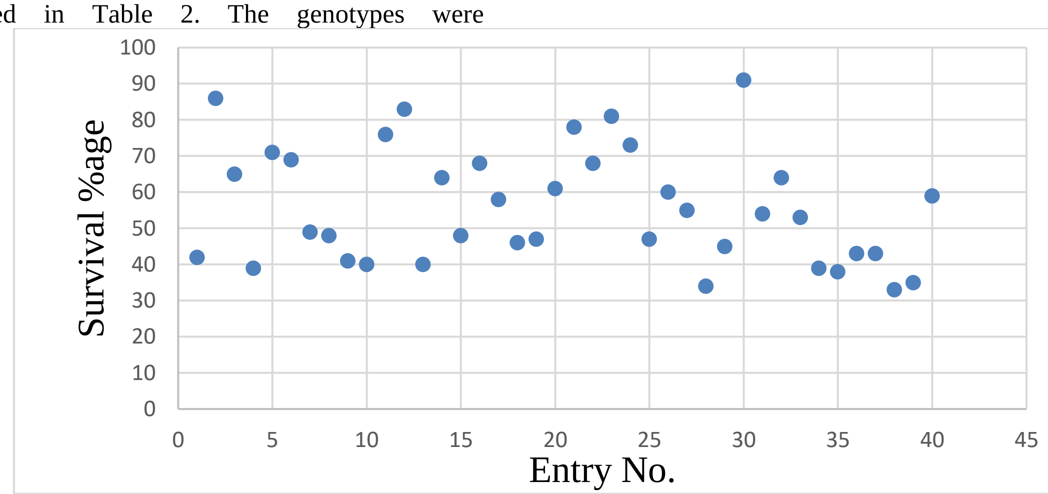

Figure 1: Graph illustrating survival percentage of Soybean Genotypes in Growth Chamber

Table 2: Classification of Soybean genotypes based on the survival percentage

Heat Tolerance Level	Survival %age	Frequency
Tolerant	(71-100%)	8
Moderately Tolerant	(51-70%)	13
Susceptible	(<50%)	19

Component 2

Genetic Variability and Descriptive Statistics for Parameters Conferring Thermal Tolerance

Pre-evaluated 40 soybean genotypes were subjected to heat stress in a glass house to evaluate the impact of rising temperature on their early vegetative growth. Eight phenotypic characteristics that administer resilience to heat stress were recorded and subjected to descriptive statistics. Analysis of variance showed high variability among genotypes via highly significant differences concerning the

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changes for all the eight parameters that dictate heat resistance both under heat stress and control conditions. Descriptive statistics showed that root length increased under heat stress which in turn increased root fresh and dry weights. On the other hand, shoot length was negatively affected by heat that decreased relative leaf water content, shoot fresh, and dry weight due to drastically increased electrolyte leakage. Relative leaf water content and electrolytic leakage can be subjected to high selection for thermal tolerance due to their high heritability and range. An increase in GCV and PCV values for electrolyte leakage and relative leaf water content indicated the presence of more genetic diversity among the genotypes in their response to heat stress which suggested that some genotypes may show greater thermal tolerance while others became more susceptible to heat (Table 3 and 4).

The heat map as depicted in Figure 3 further makes it easy to select the potential genotypes conferring resistance against the heat treatment. It is interesting to note that genotypes ORI-SOY-102 and ORI-SOY-101 have higher electrolyte leakage and decreased root and shoot lengths with increased fresh and dry weights under heat stress as compared to the control. Genotypes ORI-SOY-93, ORI-SOY-46, and ORI-SOY-126 have higher electrolyte leakage, and decreased root length but higher relative leaf water contents under heat stress. Genotype ORI-SOY-36, ORI-SOY-147, ORI-SOY-10, ORI-SOY-50, ORI-SOY-124, ORI-SOY-04, ORI-SOY-24, ORI-SOY-06, and ORI-SOY-12 exhibited increased electrolyte leakage, higher leaf water contents, increased root and shoot lengths in stressed plants. Genotype ORI-SOY-12 also had increased root and shoot fresh and dry weights. ORI-SOY-68 and ORI-SOY-146 had higher shoot lengths and slightly decreased electrolyte leakage, but enhanced relative leaf water contents keeping the other characters constant under stress. ORI-SOY-09 and ORI-SOY-02 had higher root and shoot fresh weights under heat stress. ORI-SOY-125, and ORI-SOY-135 had slightly lesser electrolyte leakage, and higher relative leaf water contents under thermal stress which makes them suitable for selection for thermal tolerance. ORI-SOY-34 had higher electrolyte leakage, but higher relative leaf water contents, and increased shoot length while other things remained constant under heat stress. ORI-SOY-70 and ORI-SOY-91 remained susceptible in all the parameters determining the heat stress. ORI-SOY-56 maintained electrolytic leakage levels boosted their relative leaf water contents and increased in shoot length but an overall decrease in root length was observed. ORI-SOY-30 also showed the same behavior but a decrease in shoot length was observed under heat stress. ORI-SOY-132, ORI-SOY-01, ORI-SOY-08, and ORI-SOY-136 showed elevated electrolytic leakage, and relative leaf water content levels but the rest of the parameters showed low reading. Faisal Soybean cultivar maintained electrolytic leakage and relative leaf water contents; root and shoot length decreased but weights increased upon heat stress. William-82, ORI-SOY-145, ORI-SOY-74, and AARI-Soybean had no noticeable change in the selected phenotypic parameters for thermotolerance. Ajmeri, and ORI-SOY-05 had elevated electrolytic leakage, and relative leaf water contents while the rest of the traits remained unaltered. ORI-SOY-11 and ORI-SOY-03 showed the same behavior while maintaining the rest of the traits at minimum values in both heat-stressed and normally treated plants.

Table 3: **Estimates of genetic variability and descriptive statistics of evaluated soybean genotypes under normal conditions**

	Mean ± SE	MSS (P < 0.01)	Range	SD	Variance	GCV	PCV	CV %	Heritability
EL	38.8 ± 1.13	470.60**	18.6-68.97	12.48	155.78	156.09	158.41	3.93	0.99
RLWC	80.59 ± 0.84	250.61**	61.5-100.2	9.29	86.32	81.5	87.61	3.07	0.93
RL	10.87 ± 0.20	14.00**	5.99-16.85	2.28	5.21	4.36	5.273	8.76	0.83
RFW	0.52 ± 0.02	0.293**	0.08-1.26	0.31	0.097	0.098	0.099	3.56	0.97
RDW	0.14 ± 0.01	0.014**	0.03-0.36	0.07	0.0048	0.0046	0.005	10.87	0.95
SL	12.68 ± 0.22	14.89**	6.53-17.83	2.48	6.14	4.33	6.227	10.85	0.70
SFW	1.18 ± 0.03	0.321**	0.51-2.2	0.34	0.114	0.102	0.115	9.66	0.89
SDW	0.51 ± 0.01	0.075**	0.17-0.88	0.16	0.024	0.025	0.025	3.09	0.99

EL = Electrolytic Leakage; RLWC = Relative Leaf Water Contents; RL = Root Lenth; RFW = Root Fresh Weight; RDW = Root Dry Weight; SL = Shoot Length; SFW = Shoot Fresh Weight; SDW = Shoot Dry Weight

Table 4: **Estimates of genetic variability and descriptive statistics of evaluated soybean genotypes under heat stress**

	Mean ± SE	MSS (P < 0.01)	Range	SD	Variance	GCV	PCV	CV %	Heritability
EL	55.22 ± 1.44	756.60**	21.6-80.7	15.81	250.09	251.19	254.23	3.16	0.99
RLWC	68.96 ± 1.37	680.56**	14.65-100	15.05	226.36	225.17	230.23	3.26	0.98

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RL	13.23 ± 0.29	15.77**	5.6-22.5	3.21	10.31	2.68	10.42	21.02	0.26
RFW	0.83 ± 0.03	0.36**	0.15-1.44	0.36	0.12	0.11	0.13	15.48	0.87
RDW	0.37 ± 0.01	0.09**	0.05-0.78	0.18	0.03	0.03	0.03	12.21	0.94
SL	10.15 ± 0.22	17.40**	4.2-14.5	2.50	6.27	5.51	6.37	9.13	0.87
SFW	0.94 ± 0.02	0.19**	0.36-1.44	0.28	0.07	0.06	0.08	14.71	0.75
SDW	0.37 ± 0.01	0.04**	0.12-0.7	0.13	0.01	0.02	0.02	8.79	0.94

EL = Electrolytic Leakage; RLWC = Relative Leaf Water Contents; RL = Root Lenth; RFW = Root Fresh Weight; RDW = Root Dry Weight; SL = Shoot Length; SFW = Shoot Fresh Weight; SDW = Shoot Dry Weight

Component 3

Genetic Variability and Descriptive Statistics for Yield Contributing Parameters under Field Conditions

Selected tolerant and moderately tolerant soybean genotypes under study were analyzed for their yield potential in field conditions after their screening under heat stress in the growth chamber and glass house. Under field conditions, data for important yield-contributing agronomic parameters along with the final yield per plot were recorded. Plant height and pods per plant relatively showed high genetic and phenotypic co-variabilities which suggest substantial genetic and overall variability. On the other hand, most of the traits viz; plant height, pods per plant, and yield per plot showed high heritability which indicates a significant amount of variation can be attributed to genetic differences among soybean genotypes. These findings indicate considerable potential for selection and breeding of soybean genotypes with desirable traits such as height, pod production, and yield, which may contribute to improved soybean crop performance under specific conditions.

Heat map further visualizes the best-performing genotypes under field conditions based on their final yield and its contributing factors (Figure 3). AARI Soybean had the maximum yield potential with moderate plant height, No. of branches per plant and pods per plant. However, it had a mediocre number of seeds per pod. ORI-SOY-91 also depicted excellent performance in all the yield-contributing parameters and the final yield per plant. Faisal Soybean and ORI-SOY-102 showed high performance in yield with a high number of pods per plant and seeds per pod but medium to dwarf phenotype respectively. ORI-SOY-70, ORI-SOY-56, and ORI-SOY-2 were observed with good overall plant yield. ORI-SOY-70, and ORI-SOY-2 performed well due to the higher number of pods per plant while ORI-SOY-56 had tall plants in addition to the higher number of pods per plant.

Table 5: Estimates of genetic variability and descriptive statistics of evaluated soybean genotypes under field conditions

	Mean ± SE	MSS (P < 0.01)	Range	SD	Variance	GCV	PCV	CV %	Heritability
PH (cm)	60.46 ± 1.72	710.40**	24-90	15.27	233.16	235.53	239.34	3.23	0.98
BPP	2.60 ± 0.10	1813**	1-4	0.89	0.79	0.50	0.80	18.05	0.63
PPP	106.19 ± 3.89	3623.25**	29-168	34.41	1184.30	1203.96	1215.34	3.18	0.99
SPP	2.22 ± 0.03	0.180**	1.3-3	0.32	0.10	0.04	0.11	11.65	0.36
YPP (g)	427.79 ± 13.89	45677.30**	143-690	122.72	15060.0	15111.58	15454.14	4.33	0.98

PH = Plant Height (cm); BPP = Branches per Plant; PPP = Pods per Plant; SPP = Seeds per Pod; YPP = Yield per Plot (g)

Correlation Analysis

Genotypic and phenotypic correlation coefficients of plant height, branches per plant, pods per plant, seeds per pod, and yield per plot were recorded. (Table 6) Plant height showed a significant genotypic and phenotypic correlation with branches per plant. Yield per plot showed a slight genotypic and phenotypic positive correlation with plant height. Interestingly, Seeds per Pod showed a slight positive genotypic correlation with plant height, but this correlation was non-significant phenotypically which suggested no increase in the number of seeds per pod with the increase in plant height. Similarly, pods per plant remained non-significant for genotypic and phenotypic correlation with the plant height.

Branches per plant showed highly significant genotypic and phenotypic correlation with the pods per plant and thus yield per plant. No. of branches per plant also remained highly positively correlated with seeds per pods especially genotypically. Pods per plant remained highly significant in positive correlation with the yield per plant as depicted by their relatively higher values for both genotypic and phenotypic correlation. Pods per plant also showed significant genotypic and phenotypic correlation with the seeds per pod. Seeds per pod were observed positively correlated with the final yield per plant.

Table 6: Genotypic and phenotypic correlation coefficients among the recorded agronomic attributes

		BPP	PPP	SPP	YPP
PH	**G**	0.28**	0.21^{NS}	0.19*	0.21*
	P	0.22*	0.21 ^{NS}	0.09 ^{NS}	0.21*
BPP	**G**		0.38**	0.61**	0.44**
	P		0.30**	0.24*	0.33**
PPP	**G**			0.39**	0.97**
	P			0.22*	0.95**
SPP	**G**				0.39**
	P				0.22*

PH = Plant Height (cm); BPP = Branches per Plant; PPP = Pods per Plant; SPP = Seeds per Pod; YPP = Yield per Plot (g)

Path Coefficient Analysis

Path coefficient analysis, showing the direct (diagonal elements) and indirect effects of different quantitative traits (Plant Height - PH, Branches per Plant - BPP, Pods per Plant - PPP, Seeds per Pod - SPP) on seed yield per plant. Additionally, the table provides the genotypic correlations between each trait and seed yield. Path coefficient analysis depicted the genotypic effect of agronomic traits under experiment that contribute to the final yield. Plant height and seeds per pod with the values of -0.0097 and -0.0538 respectively showed a direct negative effect on yield. This implied that an increase in plant height and seeds per pod decrease the yield per plant. On the other hand, branches per plant and pods per plant augmented the yield with their direct effects. (0.11018 and 0.95463 respectively) Genotypic correlations with yield are also represented which indicate the strength of the relationship between each trait and seed yield across different genotypes. Among the traits, Pods per Plant (PPP) showed the highest genotypic correlation with seed yield (0.97358), indicating a strong positive association between the number of pods per plant and seed yield. The other traits like Plant Height (PH), Branches per Plant (BPP), and Seeds per Pod (SPP), exhibit relatively lower positive genotypic correlations with seed yield compared to Pods per Plant.

Table 7: Path coefficient analysis showing direct (diagonal) and indirect effects of different quantitative traits on seed yield/plant

	PH	BPP	PPP	SPP	Genotypic Corr. With Yield
PH	-0.0097	0.03169	0.20659	-0.0104	0.21819
BPP	-0.0028	0.11018	0.36877	-0.0329	0.44331
PPP	-0.0021	0.04256	0.95463	-0.0215	0.97358
SPP	-0.0019	0.06725	0.38173	-0.0538	0.39329

PH = Plant Height (cm); BPP = Branches per Plant; PPP = Pods per Plant; SPP = Seeds per Pod

Discussion

Adaptation of soybean in regions of lower latitude demands screening out efficient genotypes that can tolerate high-temperature stress during the growing period specifically at the early vegetative stage**.** Selection of such genotypes/varieties is an important step to choosing the best variety for farming communities and better parents for future breeding programs. In this regard, an experiment comprised of 3 components was conducted. Forty soybean genotypes/varieties given heat stress (45ºC for 24 hours) at the seedling stage in growth chamber were categorized into tolerant (8), moderately tolerant (13), and susceptible (19) categories based on seedling thermo-tolerance index (STI) values. STI values are a good criteria to determine the heat response of a diverse gene pool (Ali and Malik 2021; Ali *et al.*, 2024; Chandola *et al*., 2016).

The same set of genotypes/varieties was studied again at the seedling stage for tolerance against high temperature stress in a glass house. Data recorded for morphological and physiological traits exhibited genetic dissimilarity among genotypes/varieties as can be seen clearly in a heat map. The genotypes/varieties with relatively unaltered behavior in control and treatment with low electrolyte leakage and high leaf relative water content were put in the tolerant category. Conversely, genotypes/varieties with high electrical conductivity and low leaf relative water content when subjected to high temperature, were declared susceptible (Hassan *et al.*, 2022). Entries with medium-altered values were said to be moderately susceptible. Both of the physiological parameters i.e. electrolyte leakage and leaf relative water content serve as excellent criteria for screening (*Ali et al.*, 2024; Ali *et al.*, 2016; Savicka and Skute, 2012).

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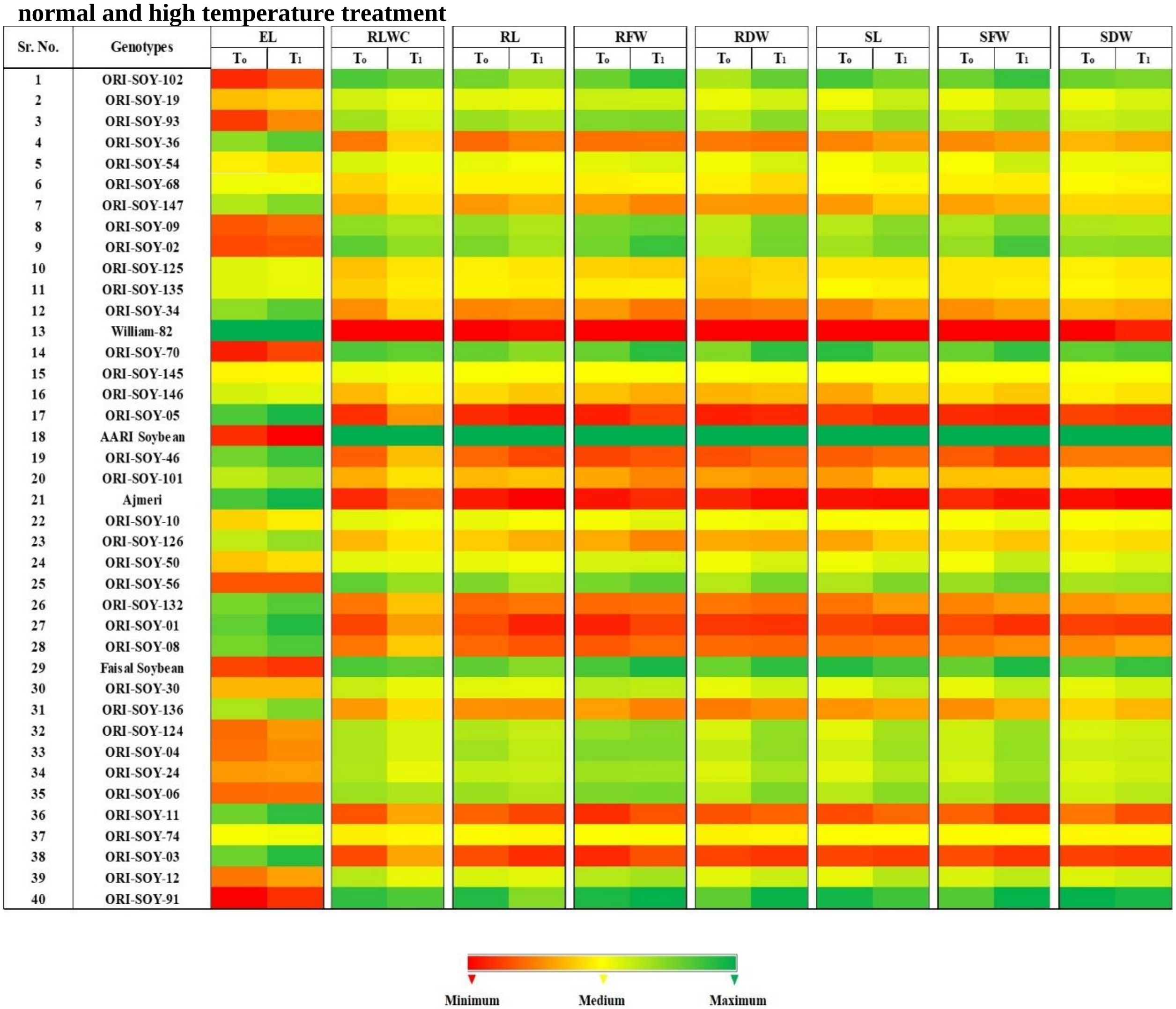
Tolerant and moderately tolerant genotypes/varieties from pre-screened pool of entries were picked for growing in field conditions till maturity. Data recorded for yield and contributing parameters were subjected to analysis. Descriptive statistics revealed significant genotypic and phenotypic co-variability for some characters while high heritability was observed for some other traits. Estimation of heritability determines whether a character is more influenced by the genetic constitution or external environment. So, there is an opportunity to improve plant height, No. of pods per plant and overall yield as they showed high heritability. Additionally, to plan more efficient selection criteria, knowledge of the correlation between yield and other agronomic parameters is crucial (Ali *et al.,* 2013; Ali *et al.,* 2014ab; *Ali et al.,* 2017; Arshad *et al.,* 2009). Pods per plant remained highly significant in positive correlation with the yield per plant as depicted by their relatively higher values for both genotypic and phenotypic correlation in the current study. Further path analysis is conducted for the confirmation of correlation analysis. Path analysis revealed that pods per plant augmented the yield with its direct effect. The results are in alignment with (Andayanie *et al.,* 2017). Entries from tolerant or moderately tolerant category showing good performance under field conditions in terms of yield may serve the best purpose of the current study.

Figure 2: Heat map showing average comparative trait variation of evaluated soybean genotypes among normal and high temperature treatment



EL = Electrolytic Leakage; RLWC = Relative Leaf Water Contents; RL = Root Lenth; RFW = Root Fresh Weight; RDW = Root Dry Weight; SL = Shoot Length; SFW = Shoot Fresh Weight; SDW = Shoot Dry Weight; T_o = Normal conditions; T_1 = Heat stress

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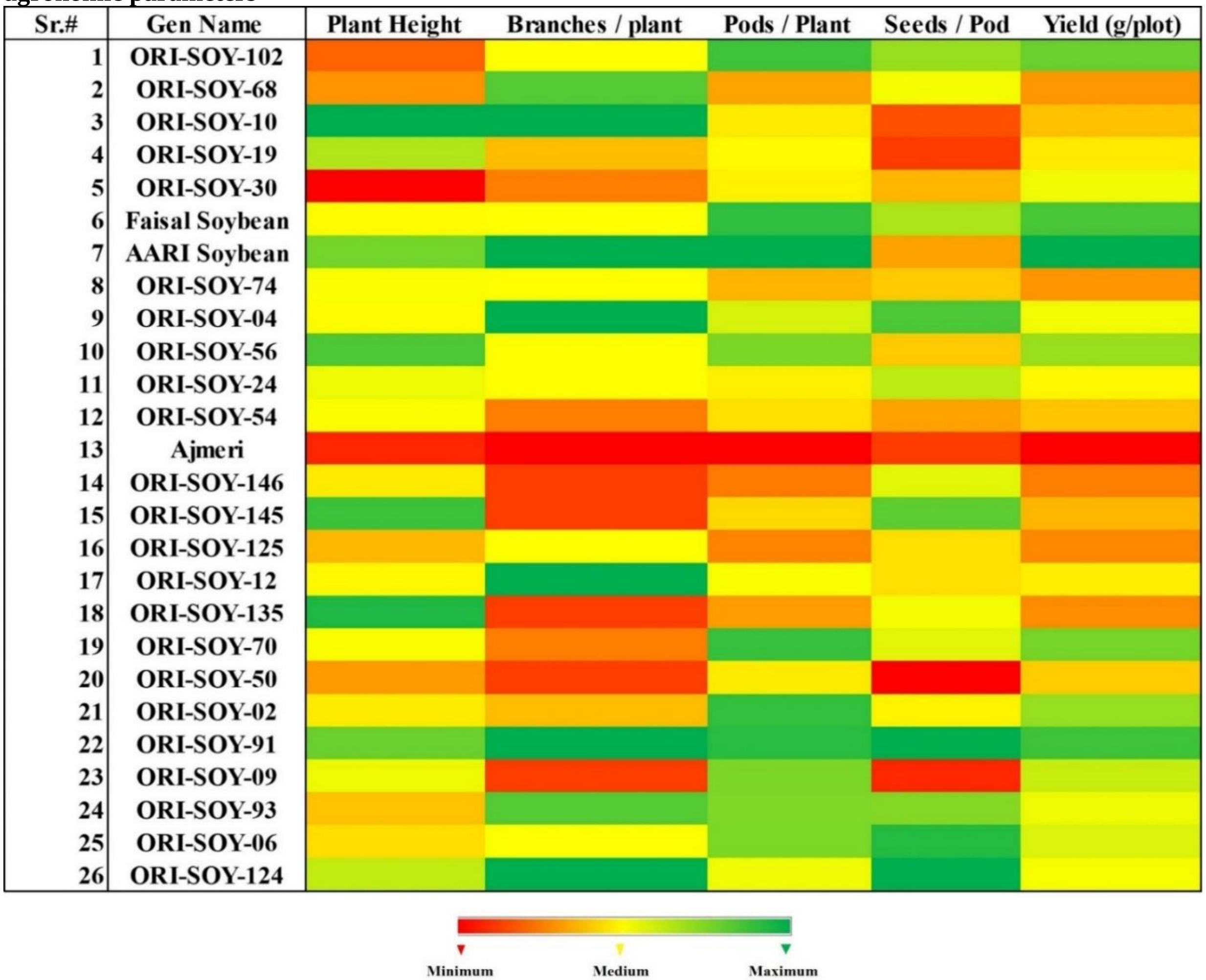
Figure 3: Heat map showing average trait variation of evaluated soybean genotypes under for various agronomic parameters



PH = Plant Height (cm); BPP = Branches per Plant; PPP = Pods per Plant; SPP = Seeds per Pod; YPP = Yield per Plot (g)

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Declaration

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

The study was approved by authors.

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Conflict of Interest

There is no conflict of interest among the authors regarding this case study.

Authors Contribution

All authors contributed equally.

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