Plant Archives Vol. 25, No. 2, 2025 pp. 256-262 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.037

EVALUATION OF MAIZE GENOTYPES THROUGH STRESS TOLERANCE INDICES FOR HEAT STRESS TOLERANCE

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(Date of Receiving-28-05-2025; Date of Acceptance-07-08-2025)

ABSTRACT

The present study was carried out by 29 maize inbred lines with two different sowing dates, 30.01.2015 and 03.03.2015, representing normal and heat stress conditions, respectively, at Research Farm, Bihar Agricultural College, Sabour. The aim of the study was to use morpho-physiological evaluation to identify genotypes that are heat tolerant. All characters under both conditions showed significant genotypic variance. The inbreds *viz*., CML 306 and CML 307 were found to be consistently high-performing in both conditions based on the selection indices, *i.e*., Mean Productivity (MP), Geometric Mean Productivity (GMP), Yield Index (YI), and Stress Tolerance Index (STI). Heat-resilient lines may be identified using stress-specific indices such the Stress Susceptibility Index (SSI), Yield Stability Index (YSI), and Tolerance (TOL). The inbreds *viz*., CML 305, CML 306, and CML 307 indicated high tolerance to heat stress. Grain yield under stress was enhanced by traits that contribute to heat resilience, such as significant ground coverage, prolonged vegetative development before heading, and a longer grain filling phase.

***Key words*: Maize, Heat stress, Stress tolerance indices, and Correlation**

Introduction

Heat stress caused by high ambient temperatures is regarded as a significant threat to global crop productivity (Hall, 2001). With rising worldwide demand for food and feed, along with unpredictable temperature fluctuations caused by climate change, optimizing crop yields has become a major challenge. While heat is a natural and sometimes sometimes beneficial environmental factor, it can become harmful when it surpasses the optimal range for plant development. Optimal growth temperatures vary by plant species, and when temperatures rise beyond a critical threshold, it can induce stress responses that negatively impact plant growth. Heat stress is defined as temperatures 10-15^{o}C above normal growing conditions, usually between 35-45^{o}C in plants (Wahid *et al*., 2007). A number of features of plant physiology and development are impacted by high temperatures (He and Huang, 2007). If heat stress arises at critical stages such as flowering, it can affect pollination and fertilization processes, resulting in poor grain formation (Schoper *et al*., 1987a). High temperatures in maize have been associated to shorter growth periods (Muchow *et al*., 1990), lower light interception (Stone, 2001), decreased photosynthetic efficiency and higher respiration (Crafts-Brandner and Salvucci, 2002), and pollen sterility (Schoper *et al*., 1987b). Interestingly, investigations have demonstrated that female reproductive organs in maize are more resistant to heat stress than their male counterparts (Dupis and Dumas, 1990). Nonetheless, recent research suggests that the time between silking and fertilization is especially important for achieving consistent grain yield under heat stress (Cicchino *et al*., 2010). When heat stress coincides with reproductive stages, yields can reduced up to 80% (Maukus *et al*., 2000). In the context of climate change, producing heat-tolerant tropical maize cultivars has emerged as a critical priority. Maize cannot be sown too early, such as in January, because cold temperatures have a negative impact on germination and early growth. Delayed sowing, on the other hand, exposes the crop to heat stress during the reproductive stage. Thus, creating genotypes capable of withstanding high temperatures is a primary objective for maize breeders in India. To improve heat tolerance, plant breeders must use effective screening and selection procedures to uncover and utilize genetic variation between genotypes (Clarke *et al*., 1984). Many strategies have been presented, but few have been properly tailored for maize. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the yield difference between stress and non-stress conditions, and mean productivity (MP) as the average yield between across both. Their findings showed a positive connection between MP and yield under stress (Ys), implying that MP-based selection could improve performance across conditions. Fischer and Maurer (1978) proposed the stress susceptibility index (SSI), which compares genotype performance under stress and normal settings and assesses yield stability. Fernandez (1992) established the stress tolerance index (STI), which identifies genotypes that perform well in both settings. Geometric mean productivity (GMP), as defined by Ramirez and Kelly (1998), is another useful statistic, especially for breeders seeking consistent performance under diverse environments. Additional indices, such as the yield index (YI) and yield stability index (YSI), have been employed to assess tolerance (Bouslama and Schapaugh, 1984; Lin *et al*., 1986; Gavuzzi *et al*., 1997). Among them, indicators such as SSI, STI, and GMP have proven to be particularly efficient in identifying maize genotypes with high heat tolerance and yield potential (Khodarahmpour *et al*., 2011). Their findings underscored the strong and significant association between GMP and yield under both stress and non-stress settings, indicating that these indices can be used to choose parent lines for hybrid development. As a result, the current study was aimed to evaluate the efficiency of several stress tolerance indices to identify maize inbred lines with higher yields under heat stress conditions.

Materials and Methods

The present study was carried out by 29 maize inbred lines (Table 1) with two different sowing dates, 30.01.2015 and 03.03.2015, representing normal and heat stress conditions, respectively, at Bihar Agricultural College Farm, Sabour in Complete Randomized Block Design (CRBD) with three replications. Each plot included two rows, each 5 m row length, with spacing of 60 cm between rows and 20 cm between plants within a row. Standard agronomic practices were implemented to maintain healthy crop growth. The aim of the study was to use morpho-physiological evaluation to identify genotypes that are heat tolerant. In the heat stress condition, frequent irrigation was applied to minimize the impact of water stress, ensuring that observed effects were primarily due to temperature. Climatic data for the cropping season are presented in Table 2. During the pollination period, the mean minimum and maximum temperatures were 19.85°C and 31.04°C under normal conditions, and 23.21°C and 35.98°C under heat stress conditions. Observations were recorded on thirteen quantitative traits associated with heat tolerance namely, days to 50% anthesis, days to 50 % silking, pollen viability, anthesis-silking interval (ASI), cell membrane thermo-stability

Table 1: List of maize inbred lines used under study.

Sl. No.	Pedigree	Source of procurement
1.	CML18	CIMMYT, Hyderabad
2.	CML19	CIMMYT, Hyderabad
3.	CML25	CIMMYT, Hyderabad
4.	CML27	CIMMYT, Hyderabad
5.	CML28	CIMMYT, Hyderabad
6.	CML33	CIMMYT, Hyderabad
7.	CML50	CIMMYT, Hyderabad
8.	CML70	CIMMYT, Hyderabad
9.	CML 73	CIMMYT, Hyderabad
10.	CML 116	CIMMYT, Hyderabad
11.	CML118	CIMMYT, Hyderabad
12.	CML 130	CIMMYT, Hyderabad
13.	CML 139	CIMMYT, Hyderabad
14.	CML 161	CIMMYT, Hyderabad
15.	CML 162	CIMMYT, Hyderabad
16.	CML 164	CIMMYT, Hyderabad
17.	CML 165	CIMMYT, Hyderabad
18.	CML 171	CIMMYT, Hyderabad
19.	CML 172	CIMMYT, Hyderabad
20.	CML 189	CIMMYT, Hyderabad
21.	CML 304	CIMMYT, Hyderabad
22.	CML 305	CIMMYT, Hyderabad
23.	CML 306	CIMMYT, Hyderabad
24.	CML 307	CIMMYT, Hyderabad
25.	CML 308	CIMMYT, Hyderabad
26.	CML 328	CIMMYT, Hyderabad
27.	CML 411	CIMMYT, Hyderabad
28.	CML 451	CIMMYT, Hyderabad
29.	CML 474	CIMMYT, Hyderabad

Table 2: Average Maximum and Minimum temperature of research farm in heat stress and non-stress conditions, during the cropping season-2015.

Months	Temperature °c	
	Maximum	Minimum
January	20.6	8.82
February	26.53	11.36
March	16.30	76.68
April	31.92	19.46
May	35.79	24.21
June	35.30	25.82

(CMT), plant height, ear height, days to 50 % physiological maturity, grain filling duration, number of grains per plant, 500-grain weight, shelling percentage, and grain yield per plant. Selection indices for stress tolerance were calculated using the formula cited below-

(i) Stress susceptibility index proposed by Fischer and Maurer, 1978.

$$SSI = \frac{1-(y_s/y_p)}{1-(\bar{y}_s/\bar{y}_p)}$$

Here, $\mathbf{y_s}$ represents the yield of a genotype under heat stress conditions, while $\mathbf{y_p}$ refers to its yield under normal (timely sown) conditions. The average yields of all genotypes under heat stress and normal conditions are also denoted by $\mathbf{y_s}$ and $\mathbf{y_p}$, respectively. The term $1-(y_s/y_p)$ is used to calculate the stress intensity. The experiment conducted under timely sowing was treated as a non-stress environment to provide a more accurate representation of optimal growing conditions.

(ii) Mean productivity proposed by Hossain *et al.*, 1990.

$$MP = \frac{y_p + y_s}{2}$$

(iii) Tolerance proposed by Hossain *et al.*, 1990.

$$TOL = y_p - y_s$$

(iv) Stress tolerance index (STI) proposed by Fernandez, 1992)

$$STI = \frac{y_p \times y_s}{2}$$

(v) Geometric mean productivity (GMP) proposed by (Fernandez, 1992)

$$GMP = \sqrt{y_p \times y_s}$$

(vi) Yield Index (YI) proposed by Gavuzzi *et al.*, 1997 and Lin *et al.*, 1986.

$$YI = \frac{y_s}{\bar{y}_s}$$

(vii) Yield stability index (YSI) proposed by Bouslama and Schapaugh, 1984

$$YSI = \frac{y_s}{y_p}$$

The collected data were analyzed using analysis of variance (ANOVA), and differences between means were assessed using Duncan's Multiple Range Test (DMRT) as outlined by Gomez and Gomez (1984). Correlation coefficients among traits were calculated following the procedure described by Johnson *et al.*, (1955).

Results and Discussion

The analysis of variance for nine quantitative traits was summarized in Table 3. The mean square attributable to genotypes was highly significant for all traits under both conditions, indicating the presence of substantial genetic variation. Selection indices were computed based on grain yield performance (Table 4). Among the tested inbreds *viz.*, CML 307, CML 306, CML 305, and CML 304 indicated superior grain yield and maintained stable performance across both environments. These findings conformity with previous reports by Fischer and Maurer (1978) and Bruckner and Frohberg (1987), also observed stable, high yielding genotypes under stress conditions despite moderate or low yield potential in optimal environments. The inbreds namely, CML 411, CML 305,

Table 3: Analysis of variance for design of experiment for nine quantitative characters of maize lines.

Sl. No.	Characters	Mean squares		
		Replication d. f. = 2	Treatmentsd. f. = 28	Errord. f. = 56
1.	Grain Weight (Normal)	42.31	263.93**	20.74
2.	Grain Weight (HST)	2.90	324.23**	5.83
3.	Stress Susceptibility Index	0.01	0.21**	0.01
4.	Stress Tolerance Index	0.01	0.21**	0.01
5.	Tolerance Index	24.29	265.54**	17.97
6.	Mean Productivity	1.41	229.36**	6.65
7.	Geometric Mean Productivity	15154.56	1236259.88**	21706.27
8.	Yield Stability Index	0.01	0.08**	0.00
9.	Yield Index	0.01	1.02**	0.02

Table 4: Mean performance of genotypes for the traits under study.

Sl. No.	Entry	Grain weight (n)	Grain weight (HST)	Stress Susceptibility Index	Stress Tolerance Index	Tolerance Index	Mean Productivity	Geometric Mean Productivity	Yield Stability Index	Yield Index
1.	CML 18	58.33	21.33	0.99	0.52	34.67	39.83	1256.67	0.37	1.19
2.	CML 19	32.67	8.33	1.17	0.12	26.00	20.50	276.67	0.25	0.47
3.	CML 25	57.67	6.67	1.39	0.16	50.00	32.17	384.00	0.11	0.37
4.	CML 27	45.00	14.33	1.06	0.27	27.67	29.67	643.33	0.32	0.80
5.	CML 28	30.67	8.00	1.16	0.10	23.67	19.33	243.33	0.27	0.45
6.	CML33	35.33	10.00	1.13	0.15	23.33	22.67	357.33	0.28	0.56
7.	CML50	54.67	10.67	1.26	0.25	44.67	32.67	585.33	0.20	0.60
8.	CML474	58.33	28.33	0.80	0.69	26.00	43.33	1647.67	0.49	1.58
9.	CML70	32.33	9.33	1.12	0.13	21.33	20.83	301.67	0.29	0.52
10.	CML73	46.67	11.67	1.18	0.22	36.00	29.17	542.00	0.25	0.66
11.	CML116	49.67	9.67	1.26	0.20	37.67	29.67	482.00	0.20	0.54
12.	CML118	45.67	10.33	1.21	0.19	32.67	28.00	465.67	0.23	0.58
13.	CML130	45.33	14.67	1.06	0.28	28.00	30.00	663.33	0.33	0.82
14.	CML139	36.00	10.00	1.13	0.15	29.33	23.00	356.00	0.28	0.56
15.	CML161	54.33	20.00	0.99	0.45	32.00	37.17	1084.67	0.37	1.12
16.	CML162	45.00	23.00	0.76	0.43	18.67	34.00	1038.33	0.51	1.28
17.	CML164	48.00	6.33	1.36	0.13	39.33	27.17	302.33	0.13	0.36
18.	CML165	58.33	13.00	1.22	0.32	43.33	35.67	762.33	0.22	0.73
19.	CML171	46.67	14.67	1.08	0.29	30.33	30.67	686.00	0.32	0.82
20.	CML172	54.67	16.33	1.10	0.38	37.33	35.50	897.33	0.30	0.91
21.	CML189	52.33	20.67	0.94	0.45	33.67	36.50	1073.67	0.40	1.16
22.	CML304	55.67	34.00	0.61	0.79	20.00	44.83	1896.00	0.61	1.90
23.	CML305	52.67	36.00	0.49	0.79	15.67	44.33	1892.67	0.69	2.01
24.	CML308	59.67	23.33	0.96	0.59	34.00	41.50	1403.00	0.39	1.30
25.	CML328	34.00	9.67	1.11	0.14	20.33	21.83	325.00	0.29	0.54
26.	CML411	55.33	35.33	0.55	0.80	15.33	45.33	1934.67	0.65	1.98
27.	CML451	59.00	13.33	1.22	0.33	45.00	36.17	784.67	0.23	0.75
28.	CML306	59.00	38.67	0.54	0.95	18.00	48.83	2284.67	0.66	2.17
29.	CML307	58.00	40.33	0.48	0.98	21.33	49.17	2335.33	0.70	2.26
Mean		49.00	17.86	1.01	0.39	29.84	33.43	927.78	0.36	1.00
C.V.(%)		9.29	13.51	9.43	18.14	14.20	7.71	15.88	17.85	12.76
S.E.±(m)		2.629	1.393	0.055	0.041	2.447	1.488	85.061	0.037	0.074
C.D.at 5%		7.45	3.95	0.16	0.11	6.93	4.22	240.98	0.10	0.21

and CML 306 exhibited the lowest values for Tolerance (TOL), indicating minimal yield loss under heat stress and suggesting resilience to elevated temperatures. In contrast, CML 25 recorded the highest value for Tolerance (TOL) value; indicate a significant yield decline and higher vulnerability to heat. As reported by Nouri *et al.*, (2011), high values of TOL and the Stress Susceptibility Index (SSI) are indicative of greater sensitivity to heat, while lower values are preferable for selecting stress-tolerant lines. SSI values less than 1 are generally associated with better stress tolerance (Fischer and Maurer, 1978).

In this present study, the inbreds *viz.*, CML 307, CML 305, and CML 306 had the lowest SSI values, indicating strong tolerance to heat stress and consistent yield performance under late sowing conditions. On the other hand, the inbreds namely, CML 25 and CML 164 had the highest SSI values, categorizing them as highly sensitive to elevated temperatures. These results support the use of SSI as an effective tool for distinguishing heat-tolerant genotypes, as suggested by Nouri *et al.*, (2011). The inbred CML 307 exhibited the highest values for Mean Productivity (MP), Geometric Mean Productivity (GMP), and the Stress Tolerance Index (STI), followed by CML 306 and CML 305. Conversely, the lowest values for these indices were recorded in CML 28, CML 19, and CML 70. Additionally, the highest Yield Index (YI) and Yield Stability Index (YSI) values were observed in CML

Table 5: Phenotypic correlation coefficient between pairs of nine characters in maize inbred lines.

	Grain Weight (Normal)	Grain Weight (HST)	Stress Susceptibility Index	Stress Tolerance Index	Tolerance Index	Mean Productivity	Gometric Mean Productivity	Yield Stability Index	Yield Index
Grain Weight (Normal)	1.000	0.514** (0.591)	-0.248 (-0.392)	0.639** (0.678)	0.370* (0.320)	0.864** (0.875)	0.646** (0.674)	0.251 (0.388)	0.516** (0.590)
Grain Weight (HST)		1.000	-0.944** (-0.977)	0.979** (0.993)	-0.524** (-0.587)	0.872** (0.909)	0.976** (0.995)	0.949** (0.974)	0.992** (1.003)
Stress Susceptibility Index			1.000	-0.871** (-0.942)	0.714** (0.766)	-0.698** (-0.787)	-0.877** (-0.939)	-0.982** (-1.010)	-0.949** (-0.974)
Stress Tolerance Index				1.000	-0.397* (-0.482)	0.929** (0.951)	0.992** (1.004)	0.879** (0.938)	0.970** (0.998)
Tolerance Index					1.000	-0.105 (-0.181)	-0.405* (-0.478)	-0.697** (-0.775)	-0.533** (-0.582)
Mean Productivity						1.000	0.939** (0.946)	0.692** (0.789)	0.876** (0.906)
Gometric Mean Productivity							1.000	0.869** (0.943)	0.981** (0.993)
Yield Stability Index								1.000	0.938** (0.980)
Yield Index									1.000

Note: genotypic correlation coefficients are shown under parentheses *, ** Significant at 5% and 1% level of probability, respectively. 5% .367, 1% .470

307, CML 305, and CML 306, confirming their stability and adaptability under stress. To identify the most reliable indicators of heat tolerance, correlations were computed between yield under normal (Yp) and stress (Ys) conditions and various selection indices (Table 5). A significant positive correlation between Yp and Ys suggests that genotypes performing well under normal conditions tend to maintain performance under heat stress. This finding is consistent with observations by Khodarahmpour *et al.*, (2011) and Longmei *et al.*, (2023) in maize. Strong and positive correlation was observed between TOL and SSI, while YI and YSI showed negative correlations with both TOL and SSI, indicating that inbreds with increased heat tolerance typically experience less yield reduction. Furthermore, a significant and positive association between YI and Ys reinforces its usefulness in identifying heat tolerant genotypes, echoing results from Nouri *et al.*, (2011). The study also found that TOL was significantly correlated with Yp but showed no significant correlation with SSI. However, SSI had a negative correlation with Ys, implying that certain indices effectively differentiate performance under heat stress. As proposed by Fernandez (1992), selection indices like STI can help identify inbreds with high yield in optimal conditions and lower sensitivity under stress. The genotypes such as CML 308 and CML 306 displayed the highest yield under normal sowing conditions but also exhibited greater yield reductions under heat stress, resulting in high TOL values. Therefore, selecting genotypes based solely on TOL may not always ensure

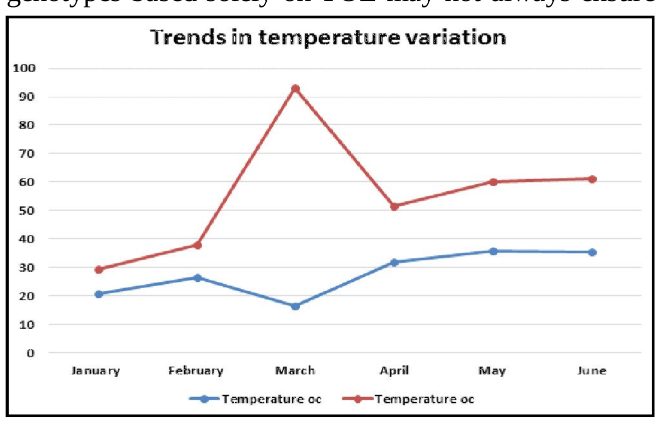

Fig. 1: Temperature variation during crop growing period.

stability under stress conditions. Positive and significant correlations were observed among Yp, MP, GMP, and STI, indicating that performance under timely sowing conditions can be a good predictor of potential yield. Similarly, Ys correlated positively with MP, GMP, YI, YSI, and STI. MP, GMP, and STI were also significantly and positively related to YSI, but they showed negative correlations with SSI. These results corroborate earlier findings by Khan and Kabir (2014) in wheat and Khodarahmpour (2011) in maize. The selection indices MP, GMP, and STI emerged as more reliable predictors of yield performance under both normal and heat stress conditions than TOL and SSI. These conclusions are in agreement with those of Shefazadeh *et al.,* (2012), NikkhahKouchaksaraei *et al.,* (2012), Sareen *et al.,* (2012), and others who have extensively evaluated heat tolerance in wheat and maize.

Conclusion

The selection indices SSI, YSI, and TOL have proven to be effective tools for identifying genotypes with reduced sensitivity to heat stress. In this study, genotypes such as CML 307, CML 305, and CML 306 demonstrated exceptional stability, characterized by high YSI values and low SSI and TOL values, along with consistently high grain yield. These attributes make them strong candidates for cultivation under heat stress conditions. Based on the indices MP, GMP, YI, and STI, the inbreds CML 306 and CML 307 emerged as top-performing genotypes, capable of maintaining high yield potential across both optimal and stress environments. As such, these lines are valuable genetic resources for breeding programs aimed at enhancing tolerance to terminal heat stress. Moreover, analysis of trait associations with the selection indices suggested that genotypes exhibiting greater ground cover during the mid-vegetative phase, delayed flowering (anthesis), and a higher grain filling rate tend to possess better tolerance to heat stress. These physiological traits can therefore serve as important selection criteria in breeding efforts targeting improved heat resilience.

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