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IDENTIFICATION OF THERMOTOLERANT LINES IN RICE (*ORYZA SATIVA* L.) USING STRESS INDICES

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ABSTRACT

Stress from high temperatures is a significant environmental factor influencing crop yield. A diverse set of rice germplasm consisting of 48 genotypes (released rice varieties, advanced breeding lines along with tolerant (Nagina 22) and susceptible (Vandana) checks) was grown at two different conditions (Control and Heat stress conditions) in *Kharif* 2023 Under heat stress conditions, the genotypes showed a significant reduction in grain yield.Yield-based indices were computed using grain yield data collected under control and heat stress conditions. The Stress Tolerance Index (STI), Geometric Mean Production (GMP), Mean Production (MP), Yield Index (YI), Heat Index (HI), and Modified Stress Tolerance (K1STI and K2STI) were all positively and significantly correlated with yield under control and high temperature stress conditions, making them suitable indices for screening rice genotypes under high temperature conditions. Highest correlation was observed in STI, GMP, and MP with Ys (Yield under heat stress)under both control and heat stress conditions.The genotypes IET 28960, MTU 1153, MTU 1156, N 22, NLR 3778, L 663 and MTU 1290 highest mean rank and a lower standard deviation of rank, hence they can be identified as heat tolerant genotypes.

Keywords: Rice, High temperature, Stress indices, Correlation, Heat tolerance, Grain yield

INTRODUCTION

Rice (*Oryza sativa* L.) is a globally important cereal plant, and as a primary source of food it accounts for 35–75% of the calorie intake of more than 3 billion humans. An increase in food production by 70% is necessary to meet the dietary requirements of the expected 9 billion population by 2050 (Bita and Gerats, 2013). Rice is the primary food source for nearly half of the world's population, accounting for 21% of total global caloric intake. Rice cultivation accounts for 11% of the total cultivated land area worldwide. Global rice consumption is expected to rise from 480 million tons in 2014 to nearly 550 million tons by 2030 (Yuan *et al*., 2021). Abiotic stress conditions pose a significant challenge to modern agriculture, leading to substantial crop failure and productivity losses ranging from 50-80%. One significant environmental factor influencing crop growth and yield is high temperature stress (Yang *et al*., 2017). Rice yield is estimated to decrease by up to 10%

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with every 1°C increase in land surface temperature (Peng *et al*., 2004).Rice plants are particularly sensitive to temperature stress during reproductive growth and maturation, and when exposed to high temperatures, it significantly affects development and yield(Lawas *et al.,* 2019, Chen *et al.,* 2020). High temperatures during grain filling can decrease rice yields by 50%(Sreenivasulu *et al*., 2015). It can also cause failure of grain filling in rice by affecting the accumulation of starch granules, eventually resulting in yield losses (Impa *et al*., 2021).Therefore,to mitigate the reduction in yield caused by high temperatures, the development and cultivation of new thermotolerant crop varieties has emerged as an important strategy for sustainable agriculture. Stress indices based on yield loss when grown under stress conditions compared to normal conditions have been used for screening stress-tolerant genotypes for many abiotic stresses (Khodarahmpour *et al.,* 2011).

MATERIAL AND METHODS

The present investigation was conducted in *Kharif* 2023 at Regional Agricultural Research Station, Maruteru with forty-eight rice genotypes.The experiment was set up in alpha lattice design with a spacing of 20x15 cm. Recommended dose of Nitrogen (N), Phosphorus (P) and Potassium (K) applied. All recommended practices for irrigated transplanted rice were followed one set of genotypes was grown under ambient conditions (control) and another set of genotypes was grown under high temperature stress by enclosing a polythene sheet at panicle initiation stage (PI). The data in the polyhouse was recorded using a data logger (RC-4HC) installed inside the polyhouse. During cropping season, the ambient mean monthly maximum temperature was 30.7° C and mean monthly minimum temperature was 24.8°C. However, during the stress imposition period (from panicle initiation to maturity), the mean maximum temperature in ambient conditions was 30.6 °C, and the mean minimum temperature was 24.3°C. During this period, the mean maximum temperature inside the polyhouse was 35.0 °C, while the mean minimum temperature was 27.9 °C. The mean maximum and minimum temperatures increased by 4.4°C and 2.3°C, respectively, under the polyhouse. At physiological maturity, panicles from each plant in both stress and non-stress conditions were harvested, sun dried, threshed, and cleaned, and grain weight was measured and expressed in grams per plant.Spikelet fertility was worked out as number of filled grains/ total number of grains x 100 and expressed in percentage.

Yield based indices

Based on grain yield under control (Yp) and grain yield under stress (Ys) heat-tolerant indices were computed *viz*., Stress Susceptibility Index (SSI), Relative Heat Index (RHI), Stress tolerance index (STI), Geometric Mean Production (GMP), Mean Production (MP), Yield Index (YI), Heat resistance index (HI), Yield Stability Index (YSI), Stress Susceptibility Percentage Index (SSPI) and Modified stress tolerance (K1STI and K2STI) (Moosavi *et al*., 2008; Farshadfar and Sutka, 2002).To identify a suitable screening index, a correlation between grain yield under control and stress conditions and the calculated yield-based indices was performed in Microsoft Excel.

The indices were computed based on the formulas given below

SSI$= (1-(Ys/Yp)/(1-(\overline{Y}s/\overline{Y}p)$

RHI$= (Ys/Yp)/(\overline{Y}s/\overline{Y}p)$

STI$=Ys \times Yn/(\overline{Y}n^2)$

GMP$=\sqrt{YS \times YP}$

Table 1. Tolerant and susceptibility indices of rice genotypes under high temperature conditions.

Entry	SSI	RHI	STI	GMP	MP	YI	HI	YSI	SSPI	K1STI	K2STI
IET 29859 (New Delhi)	1.53	0.84	0.75	13.02	13.33	0.90	0.58	0.64	19.19	1.16	0.82
IL 19019	1.29	0.91	0.71	12.71	12.91	0.92	0.64	0.70	15.15	1.02	0.85
IL 19020	1.12	0.96	0.82	13.63	13.79	1.01	0.75	0.74	13.74	1.11	1.03
IL 19021	1.51	0.85	0.48	10.41	10.65	0.73	0.47	0.65	15.00	0.74	0.53
IL 19022	0.97	1.01	0.82	13.63	13.74	1.04	0.80	0.77	11.62	1.06	1.08
IL 19024	0.82	1.06	0.61	11.71	11.77	0.91	0.74	0.81	8.18	0.75	0.83
IL 19185	1.15	0.95	0.83	13.73	13.89	1.02	0.75	0.73	14.24	1.14	1.04
IL 19198	0.76	1.07	0.74	12.89	12.95	1.01	0.83	0.82	8.38	0.89	1.02
IL 19202	0.93	1.02	0.84	13.79	13.89	1.06	0.83	0.78	11.21	1.07	1.12
IL 19211	0.48	1.16	0.79	13.37	13.39	1.09	0.97	0.89	5.25	0.89	1.19
IL 19247	0.92	1.03	0.68	12.43	12.52	0.95	0.75	0.79	9.90	0.87	0.91
IL 19396	0.91	1.03	0.85	13.89	13.98	1.07	0.84	0.79	11.01	1.08	1.14
JB 680-2 (Hyderabad (AICRIP))	1.99	0.70	0.39	9.40	9.85	0.60	0.32	0.54	19.60	0.72	0.36
JB 683-1 (Hyderabad (AICRIP))	0.89	1.03	0.86	13.91	14.00	1.07	0.85	0.79	10.69	1.08	1.15
JB 687-3 (Hyderabad (AICRIP))	1.23	0.93	0.76	13.11	13.29	0.96	0.69	0.72	14.65	1.06	0.92
JB 689-1 (Hyderabad (AICRIP))	1.01	1.00	0.80	13.44	13.56	1.02	0.78	0.77	12.02	1.04	1.04
JBC 159-11	1.06	0.98	0.71	12.71	12.83	0.95	0.72	0.75	12.02	0.95	0.91
Krishna hamsa (Hyderabad)	0.92	1.02	0.97	14.83	14.94	1.14	0.89	0.79	11.92	1.24	1.30
MTU 1153 (Maruteru)	0.70	1.09	0.85	13.90	13.95	1.10	0.92	0.84	8.18	1.02	1.21
MTU 1156 (Maruteru)	0.51	1.15	0.85	13.84	13.86	1.13	0.99	0.88	5.76	0.96	1.27
MTU 1273 (Maruteru)	1.16	0.95	0.66	12.23	12.38	0.90	0.66	0.73	12.83	0.90	0.82
MTU 1290 (Maruteru)	0.72	1.09	0.85	13.87	13.92	1.10	0.91	0.83	8.38	1.02	1.20
MTU 1293 (Maruteru)	1.61	0.81	0.77	13.21	13.58	0.90	0.57	0.63	20.81	1.23	0.82
N-22 (Meerut)	1.03	0.99	1.03	15.25	15.39	1.15	0.88	0.76	13.95	1.35	1.32
NLR 3776 (Nellore)	0.96	1.01	0.55	11.11	11.20	0.85	0.66	0.78	9.35	0.70	0.72
NLR 3778 (Nellore)	1.04	0.99	1.01	15.09	15.23	1.14	0.87	0.76	13.84	1.32	1.30
CO-51 (Coimbatore)	1.02	0.99	0.92	14.40	14.53	1.09	0.83	0.76	13.03	1.20	1.18
NLR 3775 (Nellore)	1.27	0.92	0.68	12.43	12.62	0.90	0.64	0.71	14.44	0.97	0.82
NLR 3768 (Nellore)	1.33	0.90	0.49	10.57	10.75	0.76	0.53	0.69	12.99	0.71	0.58
IET 28954 (New Delhi)	0.98	1.01	0.71	12.65	12.76	0.96	0.74	0.77	10.91	0.92	0.93
IET 28960 (New Delhi)	0.48	1.16	1.08	15.65	15.68	1.28	1.14	0.89	6.16	1.22	1.63
L 648 (Maruteru)	0.58	1.13	0.71	12.63	12.67	1.02	0.88	0.87	6.06	0.82	1.04
L 663 (Maruteru)	0.97	1.01	0.98	14.90	15.02	1.14	0.88	0.78	12.63	1.26	1.29
MTU 2897-35-1-1(Maruteru)	0.66	1.10	0.81	13.53	13.58	1.08	0.91	0.85	7.47	0.96	1.16
JGL 24423 (Jagityal)	1.18	0.95	0.89	14.15	14.33	1.04	0.76	0.73	15.15	1.22	1.09
KNM 733 (Kunaram)	0.61	1.12	0.80	13.45	13.48	1.08	0.92	0.86	6.87	0.93	1.16
KNM 1638 (Kunaram)	0.76	1.07	0.79	13.39	13.45	1.05	0.87	0.82	8.69	0.96	1.11
NLR 3648 (Nellore)	0.67	1.10	0.72	12.76	12.80	1.01	0.86	0.84	7.17	0.85	1.03
MTU 2896-58-1-1(Maruteru)	0.55	1.13	0.70	12.56	12.59	1.01	0.88	0.87	5.76	0.80	1.03
NDLR 24 (Nandyal)	0.89	1.03	0.84	13.81	13.91	1.06	0.84	0.79	10.72	1.06	1.13
NDLR 26 (Nandyal)	1.02	0.99	0.55	11.17	11.27	0.84	0.64	0.76	10.10	0.72	0.71
NDLR 25 (Nandyal)	0.78	1.07	0.84	13.75	13.82	1.08	0.88	0.82	9.09	1.02	1.16
SAL 10(Cuttak)	0.93	1.02	0.84	13.75	13.85	1.05	0.83	0.79	11.11	1.06	1.11
PR 126(Ludhiana (PAU))	1.06	0.98	0.84	13.74	13.88	1.03	0.78	0.75	12.93	1.11	1.07
RNR 15048 (Rajendranagar)	1.50	0.85	0.99	14.97	15.31	1.05	0.68	0.65	21.38	1.52	1.10
Pusa Samba 1850 (New Delhi)	1.40	0.88	0.62	11.88	12.11	0.84	0.57	0.68	15.66	0.92	0.71
Vandana (Cuttak)	1.32	0.90	0.50	10.67	10.85	0.77	0.54	0.70	13.00	0.72	0.59
MTU 1010 (Maruteru)	0.75	1.07	0.88	14.07	14.14	1.11	0.91	0.83	8.99	1.06	1.22

MP= $(Ys + Yp)/2$

YI= $(Ys)/(\overline{Y}s)$

HI= $(Ys \times ((Ys/Yp))/ \overline{Y}S$

YSI= Ys/Yp

SSPI= $Yp - Ys/2(\overline{Y}p)) \times 100$

K1STI= $Yp^2 / \overline{Y}p^2$ and K2STI= $Ys^2 / \overline{Y}s^2$

In the above formulae, Ys, Yp, $\overline{Y}s$ and $\overline{Y}p$ represent yield under high temperature stress, yield under control for each genotype, mean yield in high temperature stress and control conditions for all genotype, respectively. The genotypes were ranked according to each index in such a way that a good performing genotype was given the highest rank.

Statistical analysis:

Two-way analysis of variance (ANOVA) was carried out using the open source software R (R Core Team, 2012) and the Agricolae package (de Mendiburu, 2012). The statistical significance of the parameter means was tested using Fisher's LSD test.

RESULTS AND DISCUSSION

Grain Yield(g/plant) and Spikelet fertility(%)

The genotypes RNR 15048 (18.5 g) recorded the greatest grain yield per plant followed by N-22 (17.5 g) and NLR 3778 (17.3 g) under the control conditions while under the elevated temperature stress conditions the genotypes IET 28960 (14.8 g), NLR 3778 (13.2g) and L663 recorded highest grain yield (13.1g).Further, the genotypes NLR 3776 (12.6 g)recorded lowg rain yield under control conditions followed by NLR 3768 (12.7 g), JB 680-2 (12.8 g) and NDLR 26 (12.8 g) and Vandana (12.8). During heatstress conditions lowest grain yield was observed in JB 680-2 (6.9 g) followed by IL 19021(8.4), NLR 3768 (8.8) and Vandana (8.9 gAll of these genotypes showed a highly susceptible reaction to heat stress(Fig1.).High temperatures during the reproductive period decrease seed set. Under controlled conditions, the genotype RNR 15048 (93.1 %) had highest spikelet fertility which was comparable to that of the tolerant control N22 (92.2 per cent). Meanwhile, the genotypes with the highest spikelet fertility during heat stress were MTU 1153 (85.2%), N-22 (84.9%) and MTU 1156 (84.8%) and MTU 1290 (84.5%). Under the elevated temperature stress conditions, the genotype IL 19021(67.0%) recorded least spikeletfertility followed by Vandana (68%) (Fig2.). These genotypes also exhibited highly susceptible reaction to heat stress.The genotype MTU 1153 (6.6 %) showed the lowest drop in spikelet fertility after

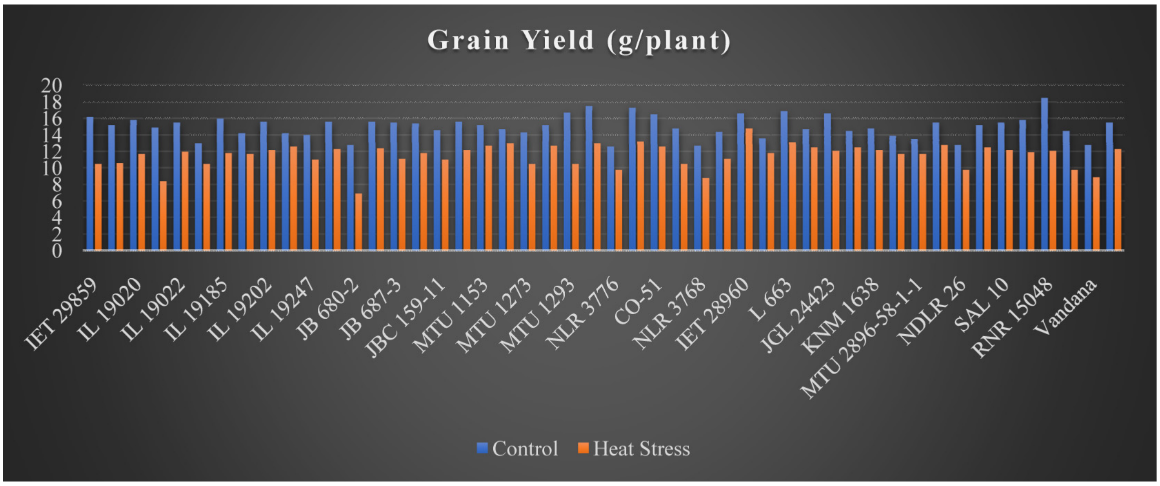

Fig 1.Impact of high temperatures on grain yield (g/plant) in rice genotypes

imposition of heatstress, followed by MTU1156 (7.9%), N-22(7.9%),MTU 1293 (8.0%) and MTU 1290 (8.3 %) and these genotypes could be identified as heat stress-tolerant. Besides, MTU 2897-35-1-1 showed the largest drop in spikelet fertility (25.9%)followed by JGL 2443(24.4) and L 648(24.3%).The data analysis revealed that IET 28960 had the lowest reduction (10.8%). Meanwhile, the highest reduction (46.0%) was recorded in JB 680-2.

Performance of cultivars based on tolerance indices

Stress Susceptibility Index (SSI) values indicating the degree of susceptibility was highest in JB680-2 (1.99), MTU 1293 (1.61), IET 29859 (1.53), and IL 19021 (1.51) and lowest was in IL 19211(0.48), IET 28960 (0.48), MTU 1156 (0.51) and MTU 2896-58-1-1 (0.55) (Table 1).Relative Heat Index(RHI) varied from 0.70 (JB680-2) to 1.16 IET 28960 and IL 19211. High RHI was noted in IL 19211(1.16), IET 28960 (1.16), MTU 1156 (1.15) and L 648 (1.13). Low values for RHI was noted in JB680-2 (0.70), MTU 1293(0.81), IET 29859 (0.84) and IL 19021 (0.85).Stress Tolerance Index(STI) was maximum in IET 28960 (1.08), N22 (1.03), NLR 3778 (1.01) and RNR 15048 (0.99). Minimum STI was recorded in JB680-2 (0.39), IL 19021 (0.48), NLR3768 (0.49) and Vandana (0.50).Geometric Mean Production (GMP) ranged from 9.40 (JB680-2) to 15.65 (IET 28960). It was highest in IET 28960 (15.70), N22 (15.25), NLR 3778 (15.09) and RNR 15048 (14.97). Lowest was in JB680-2 (9.40), IL 19021 (10.40), NLR3768 (10.57) and Vandana (10.67).Mean Production (MP)was recorded maximum in IET 28960 (15.70), N-22 (15.40), RNR 15048 (15.31) and NLR 3778 (15.23). Minimum MP was in JB 680-2 (9.85), IL 19021 (10.65), NLR3768 (10.75), and Vandana (10.85). Yield Index (YI) the rice genotype with high values of Yield index (YI) is suitable for heat condition.Highest values of YSI was noted in IET 28960 (1.28), N-22 (1.15), Krishna hamsa (1.14), NLR 3778 (1.14) and L 663 (1.14). Lower YI was in JB 680-2 (0.60), IL19021 (0.73), NLR 3768 (0.76) and Vandana (0.77). Heat Resistance Index (HI) ranged from 0.32 (JB680-2) to 1.14 (IET 28960). Maximum HI was observed in IET 28960 (1.14), MTU 1156 (0.99) and IL 19211 (0.97), MTU 1153 (0.92) and KNM 733 (0.92). Minimum HI was recorded in JB680-2 (0.32), IL 19021 (0.47), NLR 3768 (0.53) and Vandana (0.54).Yield Stability Index (YSI), maximum values are the better indication of the superior performance of genotypes under heat stress environment. Yield Stability Index,maximum was observed in IL 19211 (0.89), IET 28960 (0.89), MTU 1156 (0.88), and MTU 2896-58-1-1 (0.87). Lower values were noted in JB680-2 (0.54), MTU 1293 (0.63) IET 28959 (0.64) and IL19021 (0.65) and RNR 15048 (0.65).Stress Susceptibility Percentage Index (SSPI) maximum was in, RNR 15048 (21.38), MTU 1293 (20.81), JB680-2 (19.60) and IET 28959 (19.19). However, minimum values were in IL 19211 (5.25), MTU 1156 (5.76), MTU-2896-58-1-1 (5.76) and L 648 (6.06). Modified stress tolerance (K1STI and K2STI) showed highest in RNR 15048 (1.52), N-22 (1.35), NLR 3778 (1.32) and L 663 (1.26). NLR 3776 (0.70), NLR 3768 (0.71), JB680-2 (0.72), NDLR 26 (0.72) and Vandana (0.72) recorded lowest K1STI. Maximum values for K2STI were noted in IET 28960 (1.63), N-22 (1.32), Krishna hamsa (1.30), NLR 3778 (1.30) and L 663 (1.29) andthe lowest was observed in JB680-2 (0.36), IL 19021 (0.53), NLR 3768 (0.58) and Vandana (0.59).

Correlation analysis

The correlation analysis between grain yield under heat stress (Ys), grain yield under control (Yp), and other tolerance and susceptibility indices revealed a negative but

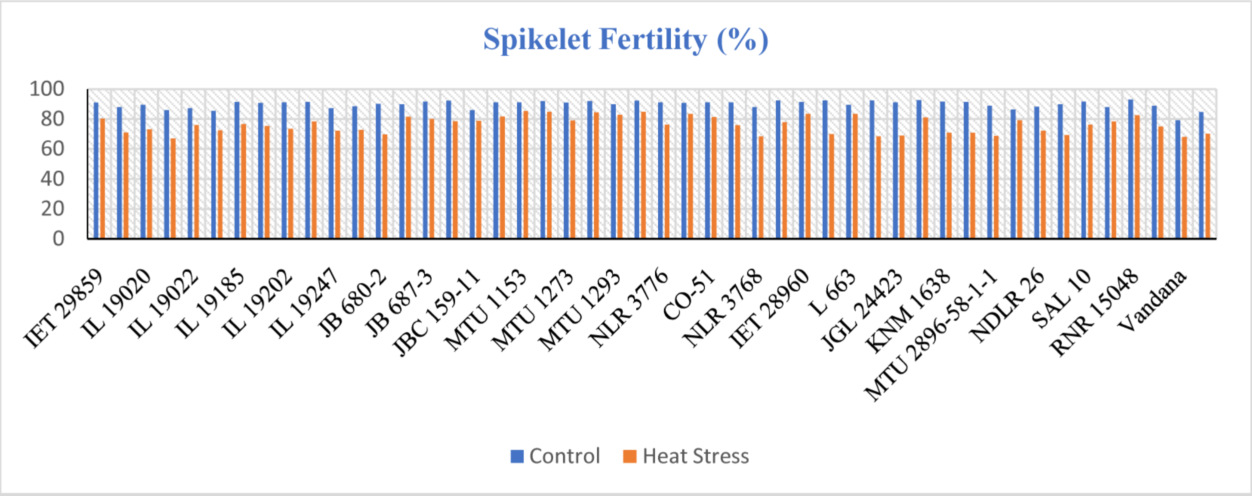

Fig.2. Impact of high temperature on spikelet fertility in rice genotypes

statistically significant correlation between SSI and Ys. A significant but negative correlation was discovered between SSPI and Ys. Given their strong and positive correlation with Ys, the remaining indices RH, STI, GMP, MP, YI, HI, YSI, and K1STI and K2STI could be regarded as useful selection indicators. Under both control and heat stress conditions, STI, GMP, and MP had the strongest correlation with Ys. (Table 2.)

Ranking method

The genotypes IET 28960, MTU 1153, MTU 1156, N 22, NLR 3778, L 663 and MTU 1290 had the highest mean rank and a lower standard deviation of rank, hence they can be identified as heat tolerant genotypes. Genotypes *viz*., JB 680-2, NLR 3768, IL19021 and Vandana are susceptible to high temperature stress as they recorded lower mean rank (Table 3). Yield and yield components were known to be effective for evaluation of genotypes under stress conditions and computing the yield-based indices essential to identify the tolerant genotypes. Yield-based indices have been used for screening large germplasm of many crops for abiotic stresses include drought, salinity and high temperature.

A positive correlation between the indices MP, GMP and Ys, Yp was reported by Toorchi *et al*. (2012). A positive and significant relationship between GMP, MP and STI and Ys was reported by Khalili *et al*. (2012) and these indices were used to identify the tolerant genotypes. In the present study, also a highly positive significant correlation was obtained and hence the genotypes possessing a higher GMP, MP and STI can be categorized as tolerant. Ilker *et al*. (2011) have reported that indices MP, GMP and STI are suitable to select high yielding wheat genotypes in both stress and non-stress conditions. Similarly, Veronica *et al*. (2021) reported that indices MP, GMP and STI are suitable to select high yielding genotypes in rice under both control and heat stress conditions. Mazal (2021) reported in rice the heat tolerant index (HTI) and meanproductivity (MP) index had the highest correlation with yield under both the conditions.

The correlation analysis revealed that the negative correlation of tolerance index and stress susceptibility percentage index with the grain yield of genotypes under heat stress condition (Ys) and a highly positive correlation of stress tolerance index, mean productivity, geometric mean, harmonic mean, and mean relative performance with grain yield (Yp and

Table 2. Correlation coefficient between Yp, Ys and tolerance or susceptibility indices in rice genotypes

	Yp	Ys	SSI	RH	STI	GMP	MP	YI	HI	YSI	SSPI	K1STI	K2STI
Yp	1.00												
Ys	0.66***	1.00											
SSI	0.05	-0.71***	1.00										
RH	-0.05	0.71***	-1.00	1.00									
STI	0.89***	0.93***	-0.41	0.41	1.00								
GMP	0.88***	0.94***	-0.43	0.43	1.00	1.00							
MP	0.91***	0.92***	-0.37	0.37	1.00	1.00	1.00						
YI	0.66***	1.00***	-0.71	0.71	0.93	0.94	0.92	1.00					
HI	0.37**	0.94***	-0.90	0.90	0.75	0.77	0.72	0.94	1.00				
YSI	-0.05	0.71***	-1.00	1.00	0.41	0.43	0.37	0.71	0.90	1.00			
SSPI	0.37**	-0.45***	0.94	-0.94	-0.10	-0.12	-0.06	-0.45	-0.73	-0.94	1.00		
K1STI	1.00***	0.64***	0.07	-0.07	0.88	0.87	0.90	0.64	0.35	-0.07	0.39	1.00	
K2STI	0.66***	0.99***	-0.70	0.70	0.93	0.94	0.91	0.99	0.94	0.70	-0.45	0.65	1.00

** indicates Significance at 0.01 level, *** indicates Significance at 0.001 level

Table 3. Rank, rank mean and standard deviation of ranks (SDR) of heat tolerance and susceptibility indices in rice genotypes.

Entry	SSI	RH	STI	GMP	MP	YI	HI	YSI	SSPI	K1STI	K2STI	MEAN	STD
IET 29859	3	3	18	18	19	7	6	3	3	39	7	11	11.2
IL 19019	7	7	15	15	16	12	9	7	6	23	12	12	5.2
IL 19020	14	14	28	28	28	18	17	14	13	37	18	21	8.0
IL 19021	4	4	7	7	7	6	5	4	5	15	6	6	3.1
IL 19022	24	24	27	27	27	25	23	24	23	28	25	25	1.8
IL 19024	31	31	6	6	6	11	14	31	38	6	11	17	12.6
IL 19185	13	13	29	29	33	21	16	13	11	38	21	22	9.4
IL 19198	33	33	17	17	17	17	27	33	36	12	17	24	8.8
IL 19202	26	26	33	33	34	29	25	26	24	33	29	29	3.8
IL 19211	48	48	21	21	20	36	45	48	48	11	36	35	14.0
IL 19247	29	29	9	9	9	13	18	29	29	10	13	18	9.2
IL 19396	30	30	36	36	37	30	29	30	26	35	30	32	3.6
JB 680-2	1	1	1	1	1	1	1	1	2	3	1	1	0.6
JB 683-1	15	15	45	45	46	42	28	15	8	47	42	32	15.5
JB 687-3	10	10	19	19	18	15	12	10	9	29	15	15	6.0
JB 689-1	21	21	23	23	23	22	20	21	20	27	22	22	2.0
JBC 159-11	16	16	14	14	15	14	13	16	21	17	14	15	2.2
Krishna hamsa	25	25	44	44	44	43	33	25	19	45	43	35	10.1
MTU 1153	43	43	42	42	41	47	47	43	41	34	47	43	3.7
MTU 1156	46	46	34	34	31	41	46	46	47	19	41	39	8.8
MTU 1273	12	12	8	8	8	8	11	12	17	13	8	11	2.9
MTU 1290	38	38	35	35	35	37	42	38	37	25	37	36	4.2
MTU 1293	2	2	20	20	24	9	4	2	1	43	9	12	13.2
N-22	39	39	37	37	36	38	43	39	39	24	38	37	4.7
NLR 3776	22	22	4	4	4	4	10	22	30	2	4	12	10.2
NLR 3778	36	36	38	38	38	40	41	36	33	30	40	37	3.2
CO-51	19	19	41	41	42	35	26	19	14	40	35	30	10.8
NLR 3775	8	8	10	10	11	10	7	8	10	21	10	10	3.8
NLR 3768	6	6	2	2	2	2	2	6	18	1	2	4	4.9
IET 28954	23	23	13	13	13	16	15	23	27	14	16	18	5.1
IET 28960	47	47	48	48	47	48	48	47	44	41	48	47	2.2
L 648	44	44	12	12	12	23	34	44	45	8	23	27	15.2
L 663	28	28	43	43	43	45	38	28	22	44	45	37	8.7
MTU 2897-35-1-1	41	41	25	25	26	32	40	41	40	18	32	33	8.3
JGL 24423	11	11	40	40	40	26	19	11	7	42	26	25	13.8
KNM 733	42	42	24	24	22	33	44	42	43	16	33	33	10.2
KNM 1638	34	34	22	22	21	27	32	34	34	20	27	28	5.9
NLR 3648	40	40	16	16	14	19	30	40	42	9	19	26	12.6
MTU 2896-58-1-1	45	45	11	11	10	20	36	45	47	7	20	27	16.6
NDLR 24	35	35	39	39	39	39	39	35	31	31	39	36	3.2
NDLR 26	20	20	5	5	5	5	8	20	28	4	5	11	8.8
NDLR 25	32	32	32	32	29	34	35	32	33	26	34	32	2.5
SAL 10	27	27	31	31	30	28	24	27	25	32	28	28	2.6
PR 126	17	17	30	30	32	24	21	17	16	36	24	24	7.1
RNR 15048	9	9	47	47	48	44	22	9	4	48	44	30	19.2
Pusa Samba 1850	37	37	26	26	26	31	37	37	35	22	31	31	5.6
Vandana	5	5	3	3	3	3	3	5	15	5	3	5	03.5
MTU 1010	18	18	46	46	45	46	31	18	12	46	46	34	14.5

Ys) under both conditions, helped accurately identify the desirable genotypes in wheat (Lamba *et al*., 2023). Kumar *et al*. (2024) reported that grain yield (Ys) showed negative association with SSI, RSI and RED and significant positive correlation with the indices viz., STI, YI, MP, GMP and HM. Hence these indices could be regarded as the best selection indicators for heat stress tolerance.

CONCLUSIONS

In this experiment, the most effective stress tolerance indices for identifying tolerant rice genotypes under high temperature conditions were STI, GMP, MP, YI, HI, K1STI, and K2STI, which were significantly correlated under both Yp and Ys. When large amounts of germplasm are available, these yield-based indices can help with preliminary screening for high temperature tolerant genotypes.

The genotypes IET 28960, MTU 1153, MTU 1156, N 22, NLR 3778, L 663 and MTU 1290 highest mean rank and a lower standard deviation of rank, hence they can be identified as heat tolerant genotypes. The correlation coefficient results revealed a significant and positive association between spikeletfertility and grain production under elevated temperature stress.Under the elevated temperature stress conditions the genotypes IET 28960, MTU 1153, MTU 1156, N 22, NLR 3778, L 663 and MTU 1290 identified as tolerant to heat stress as they recorded highest spikelet fertility.

REFERENCES

Bita, C.E and Gerats, T. 2013. Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. Frontiers in plant science, 4,273.

Chen, J., Xu, Y., Fei, K., Wang, R., He, J and Fu, L. 2020. Physiological mechanism underlying the effect of high temperature during anthesis on spikelet opening of photo-thermo-sensitive genic male sterile rice lines. Scientific Reports. 10 (1): 2210.

De Mendiburu, F. 2012. Agricolae: Statistical Procedures for Agricultural Research. – R package version 1.1-2. http:// CRAN.Rproject.org/package = agricolae

Farshadfar, E and Sutka, J. 2002. Multivariate analysis of drought tolerance in wheat substitution lines. Cereal Research Communications. 31(1/2): 33-39.

Ilker, E., Tatar, O., Aykut Tonk, F and Tosun M. 2011. Determination of tolerance level of some wheat genotypes to post anthesis drought. Turkish Journal of Field Crops. 16(1): 59-63.

Impa, S. M., Raju, B., Hein, N. T., Sandhu, J., Prasad, P. V. V and Walia, H. 2021. High night temperature effects on wheat and rice: Current status and way forward. Plant Cell Environment. 44 (7): 2049–2065.

Khalili, M., Naghavi, M.R., Aboughadareh PAR and Talebzadeh, J. 2012. Evaluating of drought stress tolerance based on selection indices in spring canola cultivars (Brassica napus L.). Journal of Agricultural Science. 4 (11): 78-85.

Khodarahmpour, Z., Choukan, R., Bihamta, M.R and Majidi Hervan, E. 2011. Determination of the best heat stress tolerance indices in maize (Zea mays L.) inbred lines and hybrids under khuzestan province conditions. Journal of Agricultural Science and Technology .13(1): 111-121.

Kumar, Y., Phougat, D and Devi, S. 2024. Exploring heat stress tolerance indices in barley genotypes based on grain yield. Journal of Cereal Research, 16(1).

Lamba, K., Kumar, M., Singh, V., Chaudhary, L., Sharma, R., Yashveer, S and Dalal, M.S. 2023. Heat stress tolerance indices for identification of the heat tolerant wheat genotypes. Scientific Reports. 13 (1): 10842.

Lawas, L.M.F., Li, X., Erban, A., Kopka, J., Jagadish, S.V.K and Zuther, E. 2019. Metabolic responses of rice cultivars with different tolerance to combined drought and heat stress under field conditions. Gigascience. 8(5):1–21.

Mazal, T.M. 2021. Field evaluation and genetic diversity for heat tolerance usingstress indices and SSR markers in rice. Menoufia Journal of Plant Production.6(5):267-287.

Moosavi, S.S., Yazdi Samadi, B., Naghavi M.R., Zali, A.A., Dashti, H and Pourshahbazi, A. 2008. Introduction of new indices to identify relative drought tolerance and resistance in wheat genotypes. Desert. 12: 165-178.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno,G.S., Khush, G.S and Cassman, K.G. 2004. Rice yields decline with highernight temperature from global warming. Proceedings of the National AcademyofSciences.101(27):9971-9975.

R. Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.ISBN 3-900051-07-0,http://www.R project.org.

Sreenivasulu, N., Butardo, V. M. Jr., Misra, G., Cuevas, R. P., Anacleto, R and Kavi Kishor, P. B. 2015. Designing climate-resilient rice with ideal grain quality suited for high-temperature stress. Journal of Experimental Botany.66 (7): 1737–1748.

Toorchi, M., Naderi, R., Kanbar, A and Shakiba, M.R. 2012. Response of spring canola cultivars to sodium chloride stress. Annals of Biological Research. 2 (5): 312-322.

Veronica, N., Sujatha, T and Ramana Rao, P.V. 2021.Identification of stress indices for screening of rice cultivars under high temperature. International Journal of Agricultural Sciences. 17: 266-272.

Yang, Z., Zhang, Z., Zhang, T., Fahad, S., Cui, K and Nie, L. 2017. The effect of season-long temperature increases on rice cultivars grown in the central and southern regions of China. Frontiers in Plant Science. 8.

Yuan, S., Linquist, B.A., Wilson, L.T., Cassman, K.G., Stuart, A.M and Pede, V. 2021. Sustainable intensification for a larger global rice bowl. Nature Communications. 12 (1): 7163.

Vasantha, Ch., Ramana Rao, P. V., Satish, Y and Veonica, N. 2024. Identification of Thermotolerant Lines in Rice (Oryza sativa L.) Using Stress Indices.
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