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Evaluation of stress indices for screening of rice cultivars for high temperature tolerance

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ABSTRACT

High temperature during the crop growing period is detrimental as it results in reduction of yield. A diverse set of rice germplasm consisting of 60 genotypes was grown at two different sowing times (normal and late) and were exposed naturally to high temperature in the late sown condition (stress). There was a severe reduction in grain yield and spikelet fertility in all the genotypes in the late sown crop. Yield based indices were computed based on grain yield recorded under normal and stress conditions. Indices Stress Susceptibility Index (STI), Geometric Mean Production (GMP), Mean Production (MP), Yield Index (YI), Modified stress tolerance (K1STI and K2STI) were positively correlated with yield recorded under both normal and high temperature stress condition and can be considered as suitable indices for screening of rice genotypes under high temperature conditions. Ranking genotypes based on the indices revealed that Rasi, HKR47, IR64, Khudaridhan, Akshayadhan and N22 exhibited the highest mean rank and hence they can be identified as heat-tolerant genotypes. ADT43, Vandana, IR36, MTU1001, ADT49 and Krishnahamsa had a lower rank and were identified as susceptible genotypes to high-temperature stress.

Key words: *Rice, stress tolerance index, high temperature, ranking method, spikelet sterility*

INTRODUCTION

Rice cultivation is the basis for majority of the farmers and increasing productivity is the main challenge faced by them. Around the world, rice is majorly cultivated in tropics and sub-tropics where high temperature is a major constraint (Wahid et al., 2007). Shi et al. (2014) reported that a increase in daytime temperature to more than 34°C decreased rice yield up to 8 %. High temperature stress would be a major challenge in the context of changing climate and a continuous demand for increased rice production throughout the globe.

Physiology of the plants is greatly affected by high temperature stress (Pal et al., 2014). Pradhan et al. (2016) and Shah et al. (2011) reported that in rice flowering and booting stages are sensitive to increase in the temperature that affects the vital processes such as anther dehiscence, germination of pollen grains on the stigmatic surface and growth of pollen tube resulting spikelet sterility therby reducing yield. Exposure of rice spikelet during anthesis even for less than an hour at 33.7°C may result in spikelet sterility (Jagadish et al., 2007).

Loss of yield is a concern to the plant breeders and hence there is a need to identify genotypes that yield higher under stress situations (Naghavi et al., 2013). Though there are several reports revealing morphological and biochemical traits to identify tolerant genotypes but when a large germplasm is considered it becomes tedious to handle. Hence, stress indices based on loss of yield when grown under stress conditions in comparison to the normal conditions have been used for screening stress-tolerant genotypes for many abiotic stresses (Khodarahmpour et al., 2011). These yield-based indices could also be used for the evaluation of high-temperature tolerance for applied plant breeding programs (Porch, 2006). Khodarahmpour et al. (2011) evaluated the heat stress tolerance indices in maize genotypes and reported that Stress Susceptibility Index (SSI), Stress Tolerance Index (STI) and Geometric Mean Production (GMP) indices were more accurate criteria for selection of heat-tolerant and high yielding genotypes. Previous studies by Khalili et al. (2004) in maize, Souri et al. (2005) in pea, Karami et al. (2006) in barley, Smith (2004) in common bean and Rezaeizad (2007) in sunflower found that GMP is an effective index in identification of genotypes having high yield under both normal and stressed conditions.

Yield based indices are required for the evaluation of abiotic stress tolerant genotype and in the present experiment, the response of 60 diverse rice germplasm lines to high temperature stress was carried out. Indices which measures the yield loss under high temperature conditions compared to normal can be used for screening genotypes as done in case of drought stress by Mitra (2001). So, based on this yield-based indices were calculated from our experiment for identification of high temperature stress tolerant genotype and also to identify suitable selection indices that could be used as screening criteria for selecting tolerant genotypes.

MATERIALS AND METHODS

Plant material

A diverse set of sixty rice genotypes comprising of germplasm lines (2), green super rice (11), wild introgression (2), landraces (8), tropical japonica (2), released varieties (35) were grown in the field during dry season of 2015-16 at ICAR- Indian Institute of Rice Research, Hyderabad. The experiment was laid out in Randomised Block Design. The spacing of 20 x 10cm was maintained. Recommended dose of Nitrogen (N), Phosphorus (P) and Potassium (K) (100:60:60 kg/ha) was applied. All packages of practices recommended for irrigated transplanted rice were followed. The genotypes were sown at different sowing dates (normal and late sowing) to enable crop to be exposed to different temperature regimes naturally during reproductive stage (anthesis to physiological maturity). The first sowing was considered as control and second sowing as high temperature stress.

During the 1st sowing, the average monthly maximum temperature was 35.2°C and the average monthly minimum temperature was 18.5°C. Whereas, for 2nd sowing the average monthly maximum temperature was 38.0°C and the average monthly minimum temperature was 21.3°C. However, the average of maximum temperature during the critical stages of flowering to grain filling was 36.0°C during the 1st sowing and 41.5oC during the 2nd sowing, and the average of minimum was 17.3°C during the 1st sowing and 21.6°C during the 2nd sowing.

At physiological maturity, panicles from each genotype in both normal and high temperature condition from demarcated area of one-meter square were collected, dried, threshed, cleaned and the weight of grains was recorded and expressed in kg ha-1. Spikelet fertility was worked out as number of filled spikelets/ total number of spikelets x 100 and expressed in percentage.

Yield based indices

Based on the grain yield under control (Yp) and grain yield under stress (Ys) heat-tolerant indices were computed namely, 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). Correlation between grain yield under both the conditions and computed yield-based indices were performed in MS-Excel.

The indices were computed based on the formulas given below.

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

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

$$STI = (Ys \times Yp)/(\bar{Y}p^2)$$

$$GMP = \sqrt{Y_s \times Y_p}$$

$$MP = (Ys+Yp)/2$$

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

$$HI = (Ys \times (Ys/Yp))/\bar{Y}s$$

$$YSI = Ys/Yp$$

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

$$STI,\ K1STI = Yp^2/\bar{Y}p^2 \text{ and } K2STI = Ys^2/\bar{Y}s^2$$

In the above formulas, Ys, Yp, $\bar{Y}s$ and $\bar{Y}p$ represent yield under high temperature stress, yield under control for each cultivar, yield mean in high temperature stress and control conditions for all cultivars, respectively.

The genotypes were ranked according to each index in such a way that a good performing genotype was given the highest rank. Mean rank and standard deviation for the ranks were calculated.

Statistical analysis

Two-way analysis of variance (ANOVA) was performed using an open-source software R (R Core Team 2012) with Agricolae package (de Mendiburu 2012). Statistical significance of the parameter means was determined by performing Fisher's LSD test to test the statistical significance.

RESULTS AND DISCUSSION

Grain yield (kg ha^{-1}) and spikelet fertility (%)

There was a substantial reduction of 26.7 % in grain yield during the 2nd sowing. Grain yield was higher in Rasi followed by Akshayadhan, HKR47, IR64 and Assanchidiya, whereas lower in ADT43, Vandana, NDR359, MTU1001 and IR36 under high temperature stress (Fig. 1). Lesser reduction in grain yield was evident in N22 (9.7 %), IR64 (12.0 %), Rasi (14.5 %) and Khudaridhan (14.9 %). On the contrary, higher reduction was in Jaya (36.2%), MTU1001 (36.3 %), Lalat (36.5 %), Varadhan (36.5 %), IR36 (37.7 %), Vandana (45.4 %) and ADT43 (54.0 %).

Elevated temperature led to a reduction of spikelet fertility and the differences among the treatments were highly significant (P<0.05). Spikelet fertility under high temperature was higher in Rasi, N22, Akshayadhan and IR64. Lower spikelet fertility was noted in Vandana, IR36 and ADT43 (Fig. 2).

Performance of cultivars based on the resistance/ tolerance indices

Stress Susceptibility Index (SSI)

The SSI values indicating the degree of susceptibility was highest in ADT43 (1.98), Vandana (1.69), IR36 (1.41), Lalat (1.36) and MTU1001 (1.34) and lowest was in N22 (0.34), IR64 (0.44), Khudaridhan (0.47), HKR47 (0.51) and Rasi (0.52) (Table 1).

Relative Heat Index (RHI)

RHI varied from 0.64 (ADT43) to 1.24 (N22). High RHI was noted in N22 (1.24), IR64 (1.20), Khudaridhan (1.19), HKR47 (1.18) and Rasi (1.18). Low values for RHI was in ADT43 (0.64), Vandana (0.75) and IR36 (0.85).

Stress Tolerance Index (STI)

STI was maximum in GSR310 (1.18), Pantdhan4 (1.12), GSR330 (1.04) and GSR319 (1.04). Minimum STI was

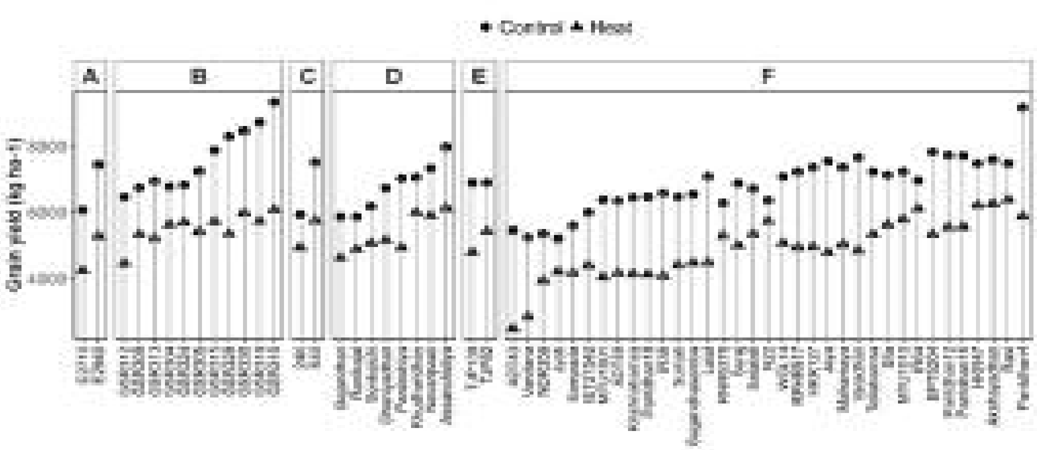

Fig. 1. Effect of high temperature on grain yield (kg ha^{-1}) of rice genotypes. A- Germplasm lines; B- Green super rice; C- Wild introgression; D- Landrace; E- Tropical *Japonica* and F- Released varieties.

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

Entry	SSI	RHI	STI	GMP	MP	YI	HI	YSI	K1	K2	SSPI
Germplasm lines											
E2710	0.94	1.02	0.52	10.03	10.33	0.84	0.66	0.75	0.78	0.72	12.92
E2940	1.08	0.97	0.83	12.56	12.75	1.04	0.74	0.71	1.17	1.11	15.43
Green Super Rice											
GSR304	0.61	1.14	0.79	12.38	12.43	1.11	0.93	0.84	0.96	1.23	8.14
GSR305	0.88	1.04	0.81	12.52	12.68	1.07	0.81	0.76	1.10	1.14	13.04
GSR309	0.75	1.09	0.75	12.03	12.12	1.05	0.84	0.80	0.95	1.11	9.93
GSR310	1.29	0.89	1.18	15.09	15.43	1.20	0.78	0.65	1.81	1.44	23.21
GSR312	1.15	0.95	0.60	10.77	10.95	0.88	0.61	0.69	0.87	0.78	14.24
GSR313	0.91	1.04	0.76	12.06	12.18	1.03	0.78	0.76	1.01	1.06	12.32
GSR315	1.02	0.99	0.93	13.44	13.62	1.13	0.82	0.73	1.29	1.27	15.43
GSR319	1.27	0.90	1.04	14.16	14.47	1.13	0.74	0.66	1.57	1.27	21.30
GSR324	0.60	1.15	0.80	12.49	12.55	1.12	0.94	0.84	0.97	1.26	8.02
GSR328	1.31	0.89	0.92	13.37	13.68	1.06	0.69	0.65	1.43	1.12	20.94
GSR330	1.08	0.97	1.04	14.21	14.45	1.17	0.84	0.71	1.48	1.38	17.83
Wild introgression											
24K	0.59	1.15	0.61	10.85	10.90	0.97	0.82	0.84	0.73	0.95	6.94
S40	0.86	1.05	0.89	13.16	13.28	1.13	0.87	0.77	1.17	1.28	12.56
Landraces											
Assanchidiya	0.87	1.05	1.01	13.99	14.12	1.20	0.93	0.77	1.32	1.45	13.28
Bejaridhan	0.78	1.08	0.56	10.45	10.52	0.91	0.72	0.79	0.71	0.84	8.74
Dhaniyadhan	0.85	1.06	0.72	11.81	11.92	1.02	0.79	0.77	0.94	1.04	11.13
Khudharidhan	0.47	1.19	0.86	12.95	13.08	1.18	1.06	0.88	1.05	1.41	7.54
Nevaripeeli	0.71	1.10	0.89	13.17	13.25	1.16	0.94	0.81	1.11	1.35	10.17
Pardeshiya	1.05	0.98	0.72	11.79	12.00	0.97	0.70	0.72	1.03	0.95	14.84
Ranikajal	0.61	1.15	0.60	10.74	10.78	0.96	0.81	0.84	0.71	0.93	6.82
Sonkaichi	0.65	1.13	0.65	11.22	11.28	1.00	0.83	0.83	0.79	1.00	7.78
Tropical Japonicas											
TJP139	1.12	0.96	0.69	11.53	11.72	0.94	0.66	0.70	0.99	0.90	14.96
TJP82	0.77	1.09	0.78	12.26	12.35	1.07	0.85	0.80	0.99	1.14	10.41
Released varieties											
ADT43	1.98	0.64	0.28	7.40	7.98	0.49	0.23	0.47	0.63	0.24	21.18
ADT49	1.23	0.91	0.56	10.30	10.53	0.82	0.55	0.67	0.86	0.68	15.55
Akshayadhan	0.66	1.13	0.99	13.80	13.87	1.23	1.01	0.82	1.19	1.51	9.57
BPT5204	1.19	0.93	0.89	12.97	13.20	1.05	0.72	0.68	1.29	1.14	17.71
HKR127	1.23	0.92	0.77	12.11	12.35	0.98	0.67	0.67	1.13	0.98	17.11
HKR47	0.51	1.18	0.96	13.59	13.72	1.22	1.06	0.86	1.19	1.50	8.97
IET21542	0.99	1.01	0.55	10.29	10.42	0.86	0.64	0.74	0.74	0.75	11.37
IR36	1.41	0.85	0.56	10.39	10.68	0.80	0.50	0.62	0.90	0.64	17.83
IR64	0.44	1.20	0.88	13.06	13.10	1.20	1.07	0.88	1.00	1.45	5.98
Jaya	1.34	0.88	0.75	12.05	12.37	0.94	0.61	0.64	1.18	0.89	19.62
Jyoti	0.69	1.11	0.45	9.38	9.45	0.83	0.68	0.82	0.56	0.69	7.06
Krishnahamsa	1.26	0.91	0.55	10.33	10.62	0.81	0.54	0.66	0.88	0.67	16.39
Lalat	1.36	0.87	0.66	11.28	11.58	0.88	0.56	0.64	1.03	0.78	18.55
Mahamaya	1.13	0.95	0.78	12.18	12.42	0.99	0.68	0.70	1.15	0.99	16.63
MTU1001	1.34	0.87	0.53	10.16	10.45	0.80	0.52	0.64	0.84	0.64	16.63
MTU1010	0.74	1.10	0.87	12.95	13.03	1.14	0.91	0.80	1.08	1.29	10.29
N22	0.34	1.24	0.75	12.09	12.12	1.13	1.03	0.91	0.84	1.27	4.43
NDR359	0.98	1.01	0.44	9.21	9.32	0.77	0.57	0.74	0.60	0.60	10.17
Pantdhan12	1.04	0.99	0.89	13.12	13.30	1.09	0.79	0.72	1.24	1.19	15.55
Pantdhan16	1.02	0.99	0.90	13.12	13.30	1.10	0.79	0.73	1.25	1.21	15.31
Pantdhan18	1.28	0.90	0.56	10.33	10.62	0.81	0.53	0.66	0.89	0.67	16.63
Pantdhan4	1.31	0.89	1.12	14.69	15.07	1.16	0.75	0.65	1.75	1.34	23.45
Rasi	0.52	1.18	0.98	13.81	13.88	1.25	1.09	0.86	1.16	1.59	7.78

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RNR6378	0.54	1.17	0.69	11.55	11.60	1.04	0.89	0.85	0.83	1.09	6.94
RPHR517	1.16	0.94	0.75	11.98	12.20	0.97	0.67	0.69	1.09	0.95	16.27
Sampada	0.77	1.08	0.48	9.62	9.78	0.82	0.65	0.80	0.68	0.67	10.17
Satabdi	0.73	1.10	0.74	11.97	12.08	1.05	0.86	0.81	0.93	1.12	9.69
Sita	0.78	1.08	0.83	12.69	12.78	1.11	0.88	0.79	1.05	1.23	10.65
Sugandhasamba	1.11	0.96	0.61	10.83	11.05	0.88	0.62	0.70	0.91	0.78	14.72
Sumati	1.08	0.97	0.59	10.66	10.90	0.87	0.62	0.71	0.89	0.76	14.60
Suraj	1.00	1.00	0.72	11.77	11.92	0.99	0.72	0.73	0.98	0.98	13.28
Tellahamsa	0.97	1.01	0.80	12.45	12.60	1.05	0.78	0.74	1.08	1.11	13.40
Vandana	1.69	0.75	0.31	7.74	8.12	0.56	0.31	0.55	0.57	0.32	17.11
Varadhan	1.29	0.90	0.77	12.17	12.53	0.95	0.62	0.66	1.25	0.91	20.10
WGL14	1.05	0.98	0.75	12.02	12.18	1.00	0.72	0.72	1.04	1.01	14.24
Mean	0.97	1.01	0.74	11.88	12.07	1.00	0.75	0.74	1.03	1.03	13.38
LSD (G) (P<0.05)	0.62	0.23	0.23	1.79	1.88	0.15	0.23	0.17	0.42	0.32	9.85

recorded in ADT43 (0.28), Vandana (0.31), NDR359 (0.44), Jyoti (0.45) and Sampada (0.48) (Table 1).

Geometric Mean Production (GMP)

GMP ranged from 7.40 (ADT43) to 15.09 (GSR310). It was highest in GSR310, Pantdhan4, GSR330, GSR319 and Assanchidiya. Lowest was in ADT43, Vandana, NDR359, Jyoti and Sampada.

Mean Production (MP)

Maximum MP was recorded in GSR310 (15.43), Pantdhan4 (15.07), GSR319 (14.47) and GSR330 (14.45). Minimum MP was in ADT43 (7.98), Vandana (8.12), NDR359 (9.32) and Jyoti (9.45) (Table 1).

Yield Index (YI)

Highest value for YI was noted in Rasi (1.25), Akshayadhan (1.23), HKR47 (1.22), Assanchidiya (1.20) and IR64 (1.20). Lower YI was in ADT43 (0.49), Vandana (0.56), NDR359 (0.77), MTU1001 (0.80) and IR36 (0.80).

Heat Resistance Index (HI)

HI ranged from 1.09 (Rasi) to 0.23 (ADT43). Maximum HI was observed in Rasi (1.09), IR64 (1.07), HKR47 (1.06), Khudaridhan (1.06) and N22 (1.03). Minimum HI was in ADT43 (0.23), Vandana (0.31), IR36 (0.50), MTU1001 (0.52) and Pantdhan18 (0.53).

Yield Stability Index (YSI)

Higher values for YSI were observed in N22 (0.91), IR64 (0.88), Khudaridhan (0.88), HKR47 (0.86) and Rasi (0.86). Lower values were in ADT43 (0.47), Vandana (0.55) and IR36 (0.62) (Table 1).

Modified stress tolerance (K1STI and K2STI)

GSR310, Pantdhan4, GSR319 and GSR330 recorded

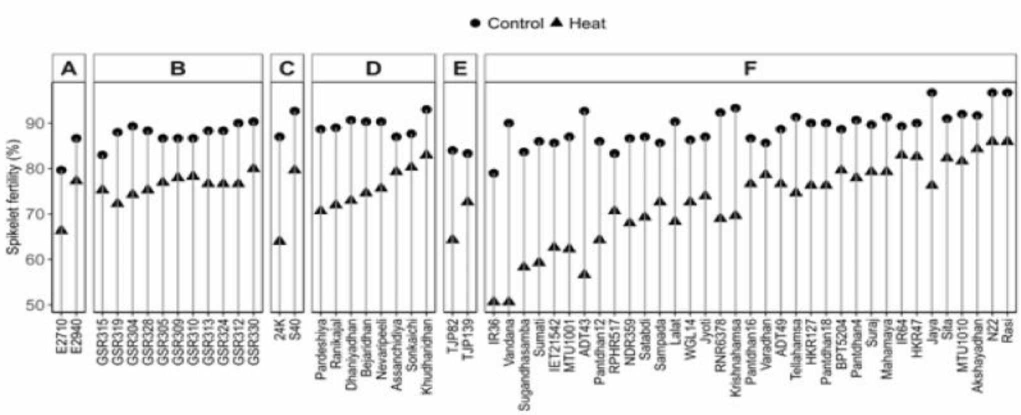

Fig. 2. Effect of high temperature on spikelet fertility (%) of rice genotypes. A- Germplasm lines; B- Green super rice; C- Wild introgression; D- Landrace; E- Tropical Japonica and F- Released varieties.

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

	Yp	Ys	SSI	RHI	STI	GMP	MP	YI	HI	YSI	K1	K2	SSPI
Yp	1.00												
Ys	0.71	1.00											
SSI	0.11	-0.61***	1.00										
RHI	-0.11	0.61***	-1.00	1.00									
STI	0.92***	0.92***	-0.27	0.27	1.00								
GMP	0.91***	0.94***	-0.31	0.31	1.00	1.00							
MP	0.93***	0.92***	-0.25	0.25	1.00	1.00	1.00						
YI	0.71***	1.00***	-0.61	0.61	0.92	0.94	0.92	1.00					
HI	0.37**	0.91***	-0.87	0.87	0.69	0.72	0.68	0.91	1.00				
YSI	-0.11	0.61***	-1.00	1.00	0.27	0.31	0.25	0.61	0.87	1.00			
K1	1.00***	0.68***	0.14	-0.14	0.91	0.88	0.91	0.68	0.33	-0.14	1.00		
K2	0.71***	0.99***	-0.59	0.59	0.93	0.94	0.91	0.99	0.91	0.59	0.68	1.00	
SSPI	0.50***	-0.26	0.90	-0.90	0.13	0.09	0.15	-0.26	-0.62	-0.90	0.53	-0.24	1.00

(n-2)= 58, * =($p<0.05$), ** = ($p<0.01$), *** = ($p<0.001$)

highest K1STI. Jyoti, Vandana, NDR359, ADT43 and Sampada recorded lowest K1STI. Maximum values for K2STI were noted in Rasi, Akshayadhan, HKR47, Assanchidiya and IR64; least in ADT43, Vandana, NDR359, MTU1001 and IR36.

Stress Susceptibility Percentage Index (SSPI)

Maximum values for SSPI was in Pantdhan4 (23.45), GSR310 (23.21), GSR319 (21.30) and ADT43 (21.18). However, minimum values were in N22 (4.43), IR64 (5.92), Ranikajal (6.82), RNR6378 (6.94) and 24K (6.94) (Table 1).

Correlation analysis

Correlation analysis between Ys, Yp and other tolerance and susceptibility indices showed a negative but significant correlation of SSI with Ys and non-significant between SSPI and Ys. The remaining indices were positively and significantly correlated with Ys. STI, GMP, MP, YI, HI, K1 and K2 were significantly and positively correlated to yield under both stress and non-stress conditions and could be considered as good selection indices (Table 2).

Ranking method

The genotypes Rasi, HKR47, IR64, Khudaridhan, Akshayadhan and N22 exhibited the highest mean rank and a lower standard deviation of rank, hence they can be identified as heat tolerant genotypes. Genotypes ADT43, Vandana, IR36, MTU1001, ADT49 and Krishnahamsa as susceptible to high temperature stress (Table 3).

In the present investigation a mean 17.0 % reduction in spikelet fertility was recorded which was mainly due to lesser production of pollen grains and poor dehiscence of the anther when exposed to high temperature and hence lower number of germinating pollen on the stigmatic surface leading to reduction in the filled grains in the panicle and yield (Prasad et al., 2006; Matsui et al., 2001). Hurkman et al. (2009) also reported an increase in the sterile spikelets when rice was exposed to a high temperature (>33°C) at heading stage.

High temperature is reported as one of the most important causes for reduction in yield mostly by affecting the phonological development processes in plant (Giaveno and Ferrero, 2003). In this study, under stress *i.e.*, 2nd sowing there was a reduction in yield in all the tested genotypes mainly due to the inhibition in grain filling process which was also reported by Ma et al. (2009), but, the extent of reduction, however, varied among the genotypes. Exposure to high temperature led to considerable reduction in both spikelet fertility and grain yield in rice as reported by Cao et al. (2008), Sailaja et al. (2015), Mohammed and Tarpley (2010) and Poli et al. (2013). Heat-induced yield reduction was also documented in many other cultivated crops such as pulses (*e.g.*, chickpea, cowpea) and oil yielding crops (mustard, canola) (Tubiello et al., 2007; Ahamed et al., 2010; Hatfield et al., 2011; Zhang et al., 2013). Similarly, in the present investigation also reduction in grain yield was noted among all the tested genotypes.

Yield and yield components are known to be effective for evaluation of genotypes under stress

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

Entry	SSI	RHI	STI	GMP	MP	YI	HI	YSI	K1	K2	SSPI	Mean	SDR
Germplasm lines													
E2710	34	34	6	6	9	11	17	34	10	11	34	19	12.5
E2940	24	24	42	41	10	32	29	24	46	34	22	30	10.6
Green Super Rice													
GSR304	51	51	37	37	11	44	51	51	25	43	50	41	13.0
GSR305	36	36	40	40	12	39	39	36	40	38	33	35	8.1
GSR309	44	44	29	29	13	35	44	44	24	33	45	35	10.5
GSR310	9	9	60	60	14	55	33	9	60	55	2	33	24.9
GSR312	18	18	16	16	15	14	11	18	16	16	29	17	4.5
GSR313	35	35	32	31	16	31	32	35	31	31	36	31	5.5
GSR315	29	29	52	52	17	46	41	29	53	46	21	38	13.1
GSR319	12	12	57	57	18	47	30	12	58	47	3	32	21.5
GSR324	53	53	39	39	19	45	54	53	26	45	51	43	11.8
GSR328	8	8	51	51	20	38	23	8	56	36	5	28	19.6
GSR330	22	22	58	58	21	53	43	22	57	53	10	38	18.6
Wild introgression													
24K	54	54	18	18	1	23	40	54	8	23	57	32	20.6
S40	38	38	48	49	47	49	47	38	45	49	35	44	5.5
Landraces													
Assanchidiya	37	37	56	56	5	57	52	37	55	57	31	44	16.3
Bejaridhan	41	41	13	13	6	17	28	41	7	17	49	25	15.7
Dhaniyadhan	39	39	25	25	8	30	35	39	23	30	38	30	9.6
Khudharidhan	58	58	44	44	29	54	57	58	35	54	54	50	10.1
Nevaripeeli	47	47	49	50	37	52	53	47	41	52	43	47	5.0
Pardeshiya	25	25	24	24	42	24	24	25	33	22	25	27	5.8
Ranikajal	52	52	15	15	43	21	38	52	6	21	58	34	18.7
Sonkaichi	50	50	19	19	51	29	42	50	11	28	52	36	15.6
Tropical Jaoponicas													
TJP139	20	20	21	21	56	19	18	20	28	19	24	24	10.9
TJP82	43	43	35	36	57	40	45	43	29	40	40	41	7.0
Released varieties													
ADT43	1	1	1	1	2	1	1	1	4	1	4	2	1.2
ADT49	14	14	11	9	3	9	7	14	15	9	20	11	4.6
Akshayadhan	49	49	54	54	4	59	55	49	48	59	47	48	15.2
BPT5204	16	16	46	45	7	36	26	16	54	39	11	28	16.2
HKR127	15	15	34	33	22	25	19	15	42	26	13	24	9.5
HKR47	57	57	53	53	23	58	58	57	49	58	48	52	10.3
IET21542	31	31	8	8	24	12	15	31	9	12	37	20	11.1
IR36	3	3	10	12	25	5	3	3	20	5	9	9	7.5
IR64	59	59	45	46	26	56	59	59	30	56	59	50	12.2
Jaya	6	6	30	30	27	18	10	6	47	18	7	19	13.5
Jyoti	48	48	4	4	28	10	21	48	1	10	55	25	21.0
Krishnahamsa	13	13	9	11	30	7	6	13	17	6	17	13	6.9
Lalat	4	4	20	20	31	15	8	4	32	15	8	15	10.3
Mahamaya	19	19	36	35	32	27	22	19	43	27	14	27	9.0
MTU1001	5	5	7	7	33	4	4	5	14	4	15	9	8.8
MTU1010	45	45	43	43	34	50	50	45	38	50	41	44	5.1
N22	60	60	31	32	35	48	56	60	13	48	60	46	15.9
NDR359	32	32	3	3	36	3	9	32	3	3	42	18	16.4
Pantdhan12	27	27	47	47	38	41	36	27	50	41	19	36	10.1
Pantdhan16	28	28	50	48	39	42	37	28	51	42	23	38	9.9
Pantdhan18	11	11	12	10	40	6	5	11	19	7	16	13	9.7
Pantdhan4	7	7	59	59	41	51	31	7	59	51	1	34	24.1
Rasi	56	56	55	55	44	60	60	56	44	60	53	54	5.7

To be continued........

Continued........

RNR6378	55	55	22	22	45	33	49	55	12	32	56	40	16.1
RPHR517	17	17	27	27	46	22	20	17	39	24	18	25	9.6
Sampada	42	42	5	5	48	8	16	42	5	8	44	24	19.0
Satabdi	46	46	26	26	49	34	46	46	22	37	46	39	10.0
Sita	40	40	41	42	50	43	48	40	36	44	39	42	4.0
Sugandhasamba	21	21	17	17	52	16	13	21	21	14	26	22	10.7
Sumati	23	23	14	14	53	13	12	23	18	13	27	21	11.8
Suraj	30	30	23	23	54	26	27	30	27	25	32	30	8.6
Tellahamsa	33	33	38	38	55	37	34	33	37	35	30	37	6.6
Vandana	2	2	2	2	58	2	2	2	2	2	12	8	16.9
Varadhan	10	10	33	34	59	20	14	10	52	20	6	24	18.0
WGL14	26	26	28	28	60	28	25	26	34	29	28	31	10.0

conditions and computing the yield-based indices are essential for the identification of tolerant genotypes that could be used in applied breeding programs. Yield-based indices have been used for screening large germplasm of many crops for abiotic stresses like drought, salinity and high temperature. Several yield-based indices have been identified and their relationship with yield under control and stress has been studied (Farshadfar et al., 2012b; Golabadi et al., 2006)

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. Mehrabi et al. (2011) suggested corn hybrids with high yield may be obtained based on GMP and STI indices. In the present study, also a highly positive significant correlation was obtained and hence the genotypes possessing a higher GMP 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.

It has been reported that the best indices are those which have high correlation with grain yield in both normal and stress conditions (Naghavi et al. 2013). Jafari et al. (2009) found that indices STI and GMP showed the highest correlation with grain yield under both normal and stress conditions, and hence can be used as best indices in the plant breeding programs to identify maize hybrids tolerant to drought stress. In our study, positive and significant correlation was obtained between STI, GMP and Ys, Yp according to which GSR310, Pantdhan4, GSR330, GSR319 were identified as tolerant and ADT43, Vandana, NDR359, Jyoti and Sampada as susceptible genotypes. Khalili et al. (2012), Farshadfar and Elyasi (2012) and Farshadfar et al. (2012a, b) suggested that modified STI indices such as K1STI, K2STI, can be used as the most suitable indicators for screening drought-tolerant cultivars. Similarly, in this study under high temperature stress, a strong positive association between K1STI and Ys, Yp was noted. Porch (2006) using stress indices screened 14 genotypes of common bean (Phaseolus vulgaris) for high temperatures in both greenhouse and field. In this evaluation, indices, STI and GM were found to be effective for selecting genotypes with greater yield potential under heat stress conditions. The above statement is in agreement with the results of the present study and hence using the above indices screening can be done and tolerant genotypes can be identified.

Naghavi et al. (2013) computed drought indices and correlated with Ys and Yp and followed the ranking method by which drought tolerant corn cultivars were identified. In the present investigation, genotypes were ranked according to their indices and the genotypes having the highest mean rank and a lower standard deviation of rank, were identified as heat-tolerant genotypes. Multilocation trials conducted under All India Coordinated Rice Improvement Project on screening for high temperature tolerance showed strong association between yield-based indices with Yp and Ys. Most of the tolerance indices showed strong positive association and the susceptibility indices showed a strong negative association. GMP, K2STI and YI showed highly significant positive association with Ys and these indices were useful in selecting genotypes for heat tolerance (IIRR Annual Progress Report, 2015).

CONCLUSION

In this study, out of the computed 11 indices STI, GMP, MP, YI, K1STI, K2STI were selected as most effective and suitable stress indices for identifying tolerant rice genotypes with high yield potential under high temperature conditions as correlation analysis revealed that these indices were significantly correlated under both Ys and Yp. When a large germplasm is available computing these yield based indices would help in preliminary screening for high temperature tolerant genotypes.

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