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National Academy of Agricultural Science (NAAS) Rating : 3. 03

Cellular Membrane Thermostability is Related to Rice (*Oryza sativa.* L) Yield under Heat Stress

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ABSTRACT: *Global warming is predicted to have a general negative effect on plant growth due to the damaging effect of high temperature on plant development. Heat stress induces severe cellular damage in plant species by causing injuries to the cell membrane and changes membrane permeability. Membrane thermo stability (MTS) can be a significant selection criterion for high temperature stress tolerance. MTS is determined by measuring the electrical conductivity of aqueous phase in which leaf tissues exposed to high temperature. This study was conducted to investigate the membrane stability assay measured by two different methods, namely MTS and relative injury (RI). The second objective of this experiment was to determine the genetic variation among genotypes for MTS and RI and their relation with yield attributing traits. A total of 48 rice Recombinant inbred lines along with their parents derived from the cross between IR 64 and N 22 (heat tolerant) were utilized for this study. The estimates of phenotypic and genotypic coefficient of variations were high for all the traits except plant height, relative injury and panicle length. Membrane thermo stability had positive and significant correlation with grain yield per plant. Path analysis revealed that membrane thermostability had direct effect on grain yield per plant and emphasised that selection will be effective through this trait in heat stressed environments.*

Keywords: *Membrane thermostability, relative injury, high temperature tolerance, yield, rice.*

INTRODUCTION

With the development of industrialization, the impact of ongoing climate change on the natural environment deterioration was more and more obviously shown. Due to an increase in mean global temperature, heat stress has become a major disastrous factor that severely affects the crop cultivation and productivity. Fluctuations in temperature occur naturally during plant growth and reproduction. However, extreme variations during hot summer can damage the intermolecular interactions needed for proper growth, thus impairing plant development and seed set. Rice is one of the world's most important crops, particularly in Asia, but increasingly so in Africa and Latin America as well. Rice is extensively grown in irrigated cropping systems, allowing production in the warmer, high radiation post-monsoon and summer months. Rice production has also intensified in rainfed-lowland and dryland (upland) cropping systems, many of which are prone to drought and high temperature (Coffman, 1977). The conclusions of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) published in early 2007 leave no doubt that the Earth's climate is changing in a manner unprecedented in the past 400,000 years. The report corroborated previous scenarios that by 2100 mean planet-wide surface temperatures will rise by 1.4 to 5.8 °C, precipitation will decrease in the sub-tropics, and extreme events will become more frequent (IPCC, 2007). By the end of the 21st century, the earth's climate is predicted to warm by an average of 2 to 4 ^{0}C due to both anthropogenic and natural factors (Eitzinger *et al.*, 2010).

Abiotic stresses are often interrelated, either individually or in combination, they cause

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morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity, and ultimately yield. Heat, drought, cold, and salinity are the major abiotic stresses that induce severe cellular damage in plant species, including crop plants. Fluctuations in temperature occur naturally during plant growth and reproduction. However, extreme variations during hot summers can damage the intermolecular interactions needed for proper growth, thus impairing plant development and seed set. The increasing threat of climate change is already having a substantial impact on agricultural production worldwide as heat waves cause significantly yield losses with great risks for future global food security (Christensen and Christensen, 2007). Of the major forms of abiotic stress plants are exposed to in nature, heat stress has an independent mode of action on the physiology and metabolism of plant cells. Although frequently, heat stress is compounded by additional abiotic stresses such as drought and salt stress, it is important to unravel the independent action and bio- logical consequences of high temperature in order to ameliorate the effects of combined abiotic stress. The susceptibility to high temperatures in plants varies with the stage of plant development, heat stress affecting to certain extent all vegetative and reproductive stages. The observed effects depend on species and genotype, with abundant inter and intra specific variations (Barnabas *et al.,* 2008; Sakata and Higashitani, 2008).

The cell membrane is one of the main cellular targets common to different stresses (Levitt 1980). Cell-membrane stability or the reciprocal of cell-membrane injury is a physiological index widely used for the evaluation of drought and temperature tolerance (Sullivan 1972; Sadalla *et al*., 1990a; Reynolds *et al.,* 1994; Fokar *et al*., 1998a). The extent of its damage is commonly used as a measure of tolerance to various stresses in plants such as freezing (Dexter, 1956), heat, drought (Blum and Ebercon, 1981) and salt (Leopold and Willing, 1983). This method was developed for a drought and heat tolerance assay in sorghum and measures the amount of electrolyte leakage from leaf segments (Sullivan, 1972). Bewley (1979) opined that the desiccation tolerance depended on the abilities to limit membrane integrity and membrane bound activities quickly upon rehydration. A scrutiny of meteorological data over past 10 years at Agricultural College and Research Institute, Madurai has revealed that the months of March, April, May, June and July are prone to high temperature stress with the average maximum temperature reaching 37-38^{0}C. Farmers in these regions tend to grow summer rice for varied reasons if they have irrigation facility. This crop will prone to high temperature stress at booting or flowering or grain filling stages. Under this context, the present study was formulated using breeding lines derived from crosses involving heat tolerant donor (N 22). The objective of the study was to assess the genetic variation among genotypes for MTS and RI and their relation to grain yield per plant. The results showed the physiological response of plants to heat stress and attracted a great deal of attention.

MATERIALS AND METHODS

A population of 48 recombinant inbred lines (F_7) developed by crossing IR 64 x N 22 along with their parents were raised during summer, 2013 at Agricultural College and Research Institute. The seedlings were planted in Randomised Block Design with three replications and used to assess the membrane thermo stability, relative injury and their relation to yield contributing traits. Fully expanded leaves of each genotype and parents were taken. The cut leaves were immediately placed into a plastic bag lined with moistened filter paper and transported to the laboratory in a cold box. Thereafter, midribs were removed and leaves were thoroughly washed with de-ionized water and completely hydrated by soaking in de- ionized water for 2 h in a refrigerator. Then, each leaf was cut into one cm circular sections and six sections were put into each vial containing 30 ml of de-ionized water. Half of the vials were used as controls (kept at room temperature, 25^{0}C) and the other vials were subjected to heat treatment (45^{0}C for 12 h) in a hot water bath. After treatment period, both control and heat treated samples were kept refrigerated at 5^{0}C for 12h. Thereafter, the samples were brought to room temperature and conductivity readings of the aqueous phase were taken at 25^{0}C using electrical conductivity meter. The samples were then autoclaved for 15 min (120^{0}C and 0.10 MPa). After the samples cooled to the room temperature a second conductivity reading of the aqueous phase was taken at 25 °C.

Leaf cell membrane thermal stability was estimated using the following equation (Blum and Ebercon, 1981).

I. Membrane Thermal Stability, MTS (%) = $[1- (T_1/T_2)]/ [1- (C_1/C_2)]\ 100$
II. Relative injury, RI (%) = $100- \{[1- (T_1/T_2)]/ [1- (C_1/C_2)]\ 100\}$

Where, C and T refer to electrical conductivity of control and heat treated samples, and the subscript 1 and 2 refer to electrical conductivity reading before and after boiling, respectively.

RESULTS AND DISCUSSION

In rice, extreme maximum temperature is particularly important during flowering which usually lasts for 2-3 weeks. Exposure to high temperature for a few hours can greatly reduce pollen viability and therefore cause yield loss (Mirza, 2003). Hence, there is an urgent need to address high temperature induced yield losses in rice to face a changing climate. Sustained function of cellular membranes under stress is pivotal for processes such as photosynthesis and respiration (Blum, 1988). Heat stress accelerates the kinetic energy and movement of molecules across membranes there by loosening chemical bonds within molecules of biological membranes. This makes the lipid bilayer of biological membranes more fluid by either denaturation of proteins or an increase in unsaturated fatty acids (Savchenko *et al.,* 2002). The integrity and functions of biological membranes are sensitive to high temperature, as heat stress alters the tertiary and quaternary structures of membrane proteins. Such alterations enhance the permeability of membranes, as evident from increased loss of electrolytes. The increased solute leakage, as an indication of decreased membrane thermostability (MTS), has long been used as an indirect measure of heat stress tolerance in diverse plant species.

Mean Performance

Analysis of variance showed significant differences among genotypes for membrane thermostability (MTS) and Relative injury (RI) and all yield contributing traits. With respect to membrane thermostability, the RILs 2, 4, 6, 15, 17, 27, 51, 74, 76, 77, 78, 82, 86, 88, 110, 111, 112, 114, 115, 128, 129, 151, 152, 171, 176 and N22 (Table 1. and Fig 1.) had the highest membrane thermostability and low relative injury values at flowering stage and were inferred to be tolerant to high temperature stress. The thermo tolerance can be attributed due to the ability to maintain their cellular membrane integrity under high temperature conditions. The maintenance of membrane thermostability during severe desiccation is important for normal physiological metabolism to continue under low water potential. Similar findings have also been reported by Shanahan *et al.* (1990); Fokar *et al.* (1998); Ibrahim and Quick (2001); and Singh *et al.* (2005)

Variability Studies

Knowledge on genetic variability of the available population which is partitioned from the environmental effect is very essential for any crop improvement programme as it will increase the efficiency of selection. Since, the parameters like phenotypic variance, genotypic variance and genetic advance for various characters are expressed in their respective units; we go for a standard measure. Hence, we give due consideration towards phenotypic and genotypic coefficient of variation, heritability and genetic advance as per cent of mean for the selection criterion. Coefficient of variation measures the range of variability available in the breeding material handled for various characters. The estimates of phenotypic and genotypic coefficient of variations (Table 2 and Fig 2) were high for, grain yield per plant (36.54 and 36.47), productive tillers per plant (29.96 and 29.88 respectively), membrane thermostability (27.52 and 27.42 respectively) and number of spikelets per panicle and spikelet fertility (22.43 and 22.36 respectively). Moderate phenotypic and genotypic coefficients of variations were exhibited for plant height (19.48 and 19.39 respectively), relative injury (18.62 and 18.22 respectively) and panicle length (13.52 and 13.43 cm respectively). A close proximity between the PCV and GCV for the traits indicated less influence of environment. So, the expression of these traits is mainly due to genetic constitution of the population. All the seven traits *viz.,* plant height, number of productive tillers per plant, panicle length, spikelet fertility, membrane thermostability, relative injury and grain yield per plant had high heritability indicated that the characters to be under genetic control. Even though heritability estimates provide an indication of the relative value of selection based on the phenotypic expression, heritability and genetic advance when considered together, gives more reliable information in predicting the result of selection. Because heritability could be even 100 per cent when the genotypic variance is of small or large value, the genetic progress will be larger only when the genotypic variance is of large value (Allard, 1960). In the present study, it has been found that number of productive tillers per plant (56.28) had exhibited high genetic advance followed by membrane thermostability (45.80), grain yield per plant (44.98), spikelet fertility (40.93), plant height (39.78), panicle length (27.49) and relative injury (26.14). These traits also exhibited a high value for heritability indicating that, they are under the control of additive gene action and directional selection could be profitably applied

Table 1
Mean Performance of Recombinant Inbred Lines for Membrane thermo Stability, Relative Injury and Yield Contributing Traits

S. No.	*Genotypes (RIL No.)*	*PHT*	*NPT*	*PL*	*SF*	*MTS*	*RI*	*YLD(g)*
1	1	124.17	17.71	29.365*	96.665*	54.29	45.71*	22.81
2	2	135.96	33.940*	29.085*	86.25	63.17*	36.83*	31.66*
3	4	174.09	30.720*	28.850*	95.075*	62.59*	37.41*	30.14*
4	6	151.88	28.290*	31.245*	71.89	61.25*	38.75*	26.17
5	9	150.18	18.705	28.240*	88.745	38.65	61.35	21.49
6	15	111.03*	35.645*	25.535	67.9	68.74*	31.26*	35.35*
7	17	117.58*	31.745*	27.920*	87.295	72.50*	27.50*	36.65*
8	19	94.43*	26.22	25.73	73.32	38	62	21.26
9	27	135.44	24.53	27.885*	92.825*	58.41*	41.59*	21.68
10	51	126.82	23.465	30.440*	93.830*	58.99*	41.01*	20.15
11	52	116.92*	26.01	23.95	90.885	36.45	63.55	23.49
12	57	106.12*	22.615	28.470*	94.830*	48.86	51.14	25.18
13	61	130.23	21.825	21.385	83.82	50.18	49.82*	23.01
14	66	132.13	26.15	28.530*	91.325	35.43	64.57	26
15	67	106.38*	31.190*	23.43	88.375	30.34	69.66	23.37
16	74	83.33*	35.035*	24.24	95.320*	60.11*	39.89*	20.48
17	76	71.83*	33.935*	23.68	94.780*	60.30*	39.70*	24.54
18	77	120.88	30.795*	27.830*	92.985*	70.46*	29.54*	41.14*
19	78	110.88*	27.095	22.325	93.485*	60.69*	39.32*	36.66*
20	82	136.3	19.935	32.380*	91.99*	61.63*	38.37*	30.83*
21	86	84. 89*	36.930*	25.38	96.660*	61.21*	38.79*	25.24
22	88	150.74	21.065	29.740*	91.335	61.40*	38.60*	28.18
23	110	123.76	47.050*	25.215	91.545	72.24*	27.77*	42.96*
24	111	103.39*	25.76	23.17	86.97	62.34*	37.67*	22.25
25	112	81.64*	25.69	19.67	96.125*	56.33*	43.67*	32.68*
26	114	98.58*	37.710*	25.595	94.675*	72.86*	27.14*	40.78*
27	115	105.42*	30.910*	24.42	95.290*	58.92*	41.08*	23.31
28	126	107.25*	28.195	25.52	94.355*	49.61	50.40*	21.51
29	128	127.96	29.115*	28.195*	93.090*	60.24*	39.76*	30.93*
30	129	123.47	37.535*	28.425*	88.105	61.32*	38.68*	35.78*
31	145	76.67*	28.605*	21.525	91.905*	47.46	52.54	30.23*
32	151	119.39	33.510*	31.585*	93.150*	72.00*	28.00*	44.22*
33	152	106.43*	33.030*	20.61	97.825*	61.95*	38.05*	27.59
34	154	136.53	22.285	26.35	93.380*	51.75	48.25*	45.22*
35	157	122.32	29.750*	25.505	93.765*	51.11	48.89*	25.28
36	159	104.53*	39.790*	25.42	94.555*	52.59	47.41*	41.47*
37	166	127.43	48.765*	26.38	95.950*	51.76	48.24*	37.44*
38	169	122.31	30.370*	24.525	93.160*	51.53	48.47*	25.18
39	171	104.42*	25.505	21.37	92.415*	62.77*	37.23*	22.53
40	175	135.33	18.375	31.680*	85.21	52.37	47.63*	20.28
41	176	108.81*	21.6	24.63	83.285	60.37*	39.63*	22.49
42	194	95.12*	20.62	20.205	95.365*	42.74	57.26	20.53
43	212	106.07*	22.335	26.680*	93.805*	44.77	55.23	23.58
44	214	94.51*	20.53	21.4	89.04	38.53	61.47	24.46
45	284	92.24*	11.465	26.155	60.35	35.21	64.79	19.81
46	285	137.78	20.825	36.605*	95.470*	55.24*	44.76*	27.33
47	286	167.02	23.88	26.255	87.78	48.3	51.7	25.27
48	289	110.14*	31.920*	24.71	90.365	45.05	54.95	19.4
49	N 22	75.83*	20.785	22.715	80.965	57.76*	42.24*	20.37
	Mean	116.051	27.669	26.21	90.001	54.11	50.25	27.96
	SE (5%)	1.507	0.466	0.288	1.654	0.68	0.618	0.688
	CD	4.283	1.324	0.819	4.699	1.93	1.756	1.955

* Significant at 5 per cent level

PHT: Plant height, NPT: Number of productive tillers per plant, PL: Panicle length, SF: Spikelet fertility, MTS: Membrane Thermostability, RI: Relative Injury, YLD: Grain yield per plant, RIL NO: Recombinant Inbred Line Number

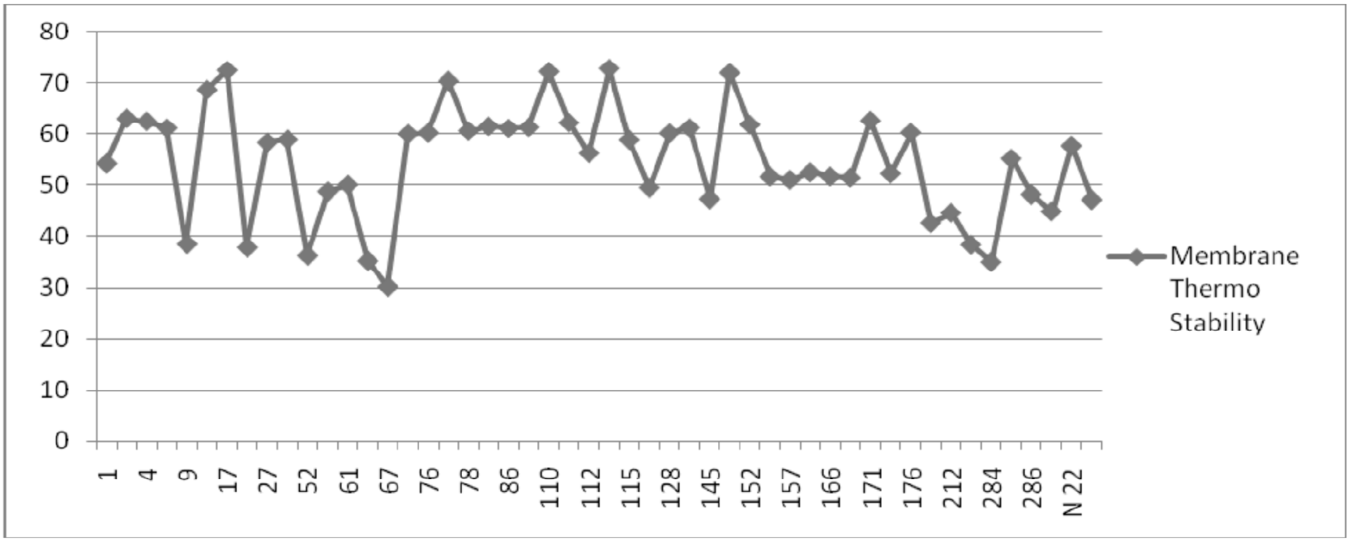

Figure 1: Frequency Distribution of Membrane thermo Stability for 48 Recombinant Inbred Lines Derived from Cross between IR 64 and N 22

Table 2
Genetic Variability Parameters for Membrane thermo Stability (MTS), Relative Injury (RI) and Yield Contributing Traits

Characters	*GCV*	*PCV*	*Heritability(%)*	*Genetic Advance as per cent of mean*
Plant height	19.39	19.48	69.11	39.78
Number of productive tillers	29.88	29.96	89.25	56.28
Panicle length	13.43	13.52	78.68	27.49
Spikelet fertility	22.36	22.43	80.92	40.93
Membrane thermostability	27.42	27.52	89.23	45.80
Relative injury	18.22	18.62	89.38	26.14
Grain yield per plant	36.47	36.54	70.60	44.98

PCV: Phenotypic coefficient of variation, GCV: Genotypic coefficient of variation.

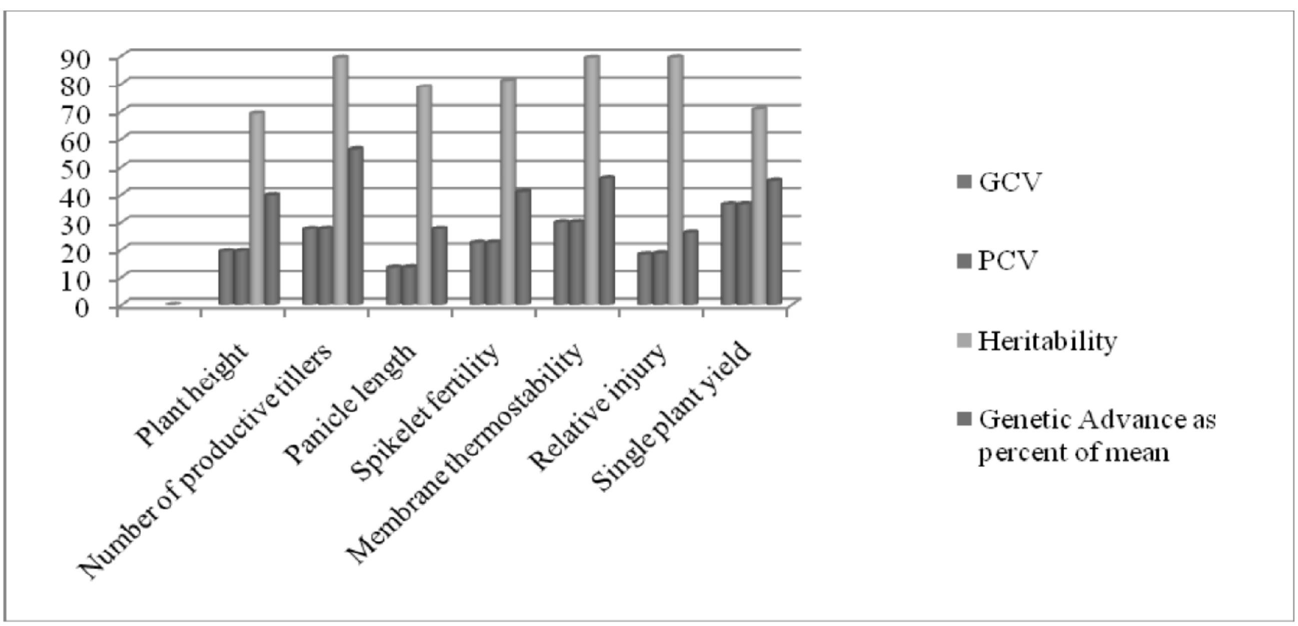

Figure 2: Genetic Variability Parameters for Membrane thermo Stability (MTS), Relative Injury (RI) and Yield Contributing Traits

on these traits for desired genetic improvement. The genetic variations in heat tolerance in grain sorghum (Sullivan and Ross, 1979), soybean (Martineau *et al*., 1979b), various turf grass species (Wallner *et al*., 1982), dry beans (Schaff *et al*., 1987), vegetables (Kuo 1992) and spring wheat (Fokar *et al*., 1998a) were studied using cell membrane thermo stability as one of the component traits. It is also observed that, all those characters with high genotypic coefficient of variation also had high heritability and high genetic advance as per cent of mean. In addition, the characters *viz.*, panicle length, relative injury and plant height have high heritability and genetic advance as per cent of mean but have moderate genotypic coefficient of variation. So, these characters can also be used for selection if they have a positive correlation with yield.

ASSOCIATION STUDIES

It has been generally accepted that correlation between different characters represents a coordination of physiological processes, which is often achieved through gene linkages (Mather and Jinks, 1971). Knowledge of the strength and type of association is an important prerequisite for the formulation of breeding strategy. Single plant yield is a complex character influenced by a large number of other component traits. A knowledge of the association between yield and its component traits and also in between the component traits helps in improving the efficiency of selection.

Correlation Analysis

Correlation analysis (Table 3) among yield contributing traits and heat tolerant related traits revealed that genotypic correlation coefficients were higher than their phenotypic correlation coefficients indicating the association is largely due to genetic reason. In the present study number of productive tillers per plant, membrane thermostability and spikelet fertility showed significant positive genotypic and phenotypic correlations with grain yield per plant and it means increase in number of productive tillers per plant, membrane thermostability and spikelet fertility will cause increase in the grain yield per plant upon which emphasis may be given during selection. Negative correlation was observed between relative injury and grain yield per plant.

From the above results, it is evident that traits *viz.*, number of productive tillers per plant, membrane thermostability and spikelet fertility are associated with grain yield per plant and are inter correlated among themselves. It indicated that the selection in any one of these yield attributing traits will lead to increase in other traits, thereby finally enhancing the grain yield per plant. Hence, the traits like number of productive tillers per plant, membrane thermostability and spikelet fertility may be given importance in selection, since this will lead to increase in the grain yield *per se.*

Path Analysis

Complete information about the complex trait yield that is controlled by several other traits either directly or indirectly cannot be given by the correlation coefficient. Hence, the path coefficient analysis would be quite useful as it permits the separation of direct effect from other related traits by partitioning genotypic correlation co-efficient. (Dewey and Lu, 1959).

Path coefficient analysis (Table 4) showed number of productive tillers per plant (0.59524) had the maximum direct effect on yield followed by membrane thermo stability (0.37572) which might be considered in developing breeding strategy for yield improvement in heat stressed environments. Membrane thermostability reliability as an index of heat stress tolerance is supported in several plant species by a good correlation between cell membrane thermo stability and plant performance in the field under high temperature stress. Similar result was obtained by Blum *et al.,* 2001 in RIL population of spring wheat, acquired thermotolerance of spring wheat seedlings in terms of cell membrane thermostability was correlated with yield of RILs grown under hot summer condition in Israel and the results are also akin to the findings of Martineau *et al.* 1979a, Sullivan and Ross 1979, Shanahan *et al.,* 1990, Sadalla *et al*., 1990b, Reynolds *et al*., 1994 and Fokar *et al*. 1998b.

CONCLUSION

Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperature (Wahid and Close, 2007). As plants cannot move, the only option they have to defend themselves from various stressnto make metabolic and structural adjustments. (Yamanouchi *et al*., 2002). At later stages, high temperature may adversely affect photosynthesis, respiration, water relations and membrane stability and also modulate levels of hormones and primary and secondary metabolites. Genetic variability in the stress response has been suggested to be mainly due to the differential expression of stress response genes (Krishanan *et al*.,

Table 3
Genotypic and Phenotypic Correlation Coefficients for Membrane thermo Stability (MTS), Relative Injury (RI) and Yield Contributing Traits

Characters		*PHT*	*NPT*	*PL*	*SF*	*MTS*	*RI*	*YLD*
PHT	P	1.000	-0.098	0.609**	0.010	0.150	-0.124	0.140
	G	1.000	-0.099	0.616**	0.010	0.151	-0.127	0.142
NPT	P		1.000	-0.155	0.246**	0.441**	-0.163	0.695**
	G		1.000	-0.157	0.256**	0.445**	-0.164	0.698**
PL	P			1.000	-0.034	0.226	-0.149	0.146
	G			1.000	-0.041	0.230	-0.150	0.147
SF	P				1.000	0.304**	-0.228	0.326**
	G				1.000	0.312**	-0.243*	0.333**
MTS	P					1.000	-0.518**	0.593**
	G					1.000	-0.522**	0.596**
RI	P						1.000	-0.168
	G						1.000	-0.168

PHT: Plant height, NPT: Number of productive tillers per plant, PL: Panicle length, SF: Spikelet fertility, MTS: Membrane Thermo Stability, RI: Relative Injury, YLD: Grain yield per plant, P: Phenotype, G: Genotype

* Significant at 5 per cent

** Significant at 1 per cent

Table 4
Path Analysis Showing Direct and Indirect Effects of Membrane thermo Stability (MTS), Relative Injury (RI) on Yield Contributing Traits

Characters	*PHT*	*NPT*	*PL*	*SF*	*MTS*	*RI*	*YLD*
PHT	**0.09046**	-0.05897	0.07221	-0.00056	0.05667	-0.01797	0.142
NPT	-0.00896	**0.59524**	-0.01844	-0.01346	0.16713	-0.02320	0.698**
PL	0.05572	-0.09362	**0.11722**	0.00224	0.08649	-0.02124	0.147
SF	0.00092	0.14624	-0.00479	**0.14152**	0.15948	-0.03436	0.333**
MTS	0.01364	0.26478	0.02698	-0.01159	**0.37572**	-0.07388	0.596**
RI	-0.01149	-0.09758	-0.01759	0.01330	-0.19613	**-0.05477**	-0.168

PHT: Plant height, NPT: Number of productive tillers per plant, PL: Panicle length, SF: Spikelet fertility, MTS: Membrane Thermo Stability, RI: Relative Injury, YLD: Grain yield per plant

** Significant at 1 per cent,

Bold diagonal values are direct effects of the respective characters

1989). Genetic variability for membrane thermostability revealed that membrane thermostability showed high positive direct effect alongwith positive genetic correlation on grain yield per plant next to the major yield contributing trait number of productive tillers per plant. Among the 48 RILs the following 25 RILs *viz*., 2, 4, 6, 15, 17, 27, 51, 74, 76, 77, 78, 82, 86, 88, 110,112, 114, 115,128, 129, 151, and 152 had high membrane thermostability, low relative injury and high grain yield per plant. Hence, these genotypes offer scope for direct selection / hybridization or for future elaborate investigations on high temperature tolerance in rice.

REFERENCES

Allard R. W. (1960), Principles of Plant breeding. John Wiley and sons. Inc., USA. 485p.

Barnabas B., Jager K. and Feher A. (2008), The effect of drought and heat stress on reproductive processes in cereals. *Plant Cell and Environment.* 31, 11–38.

Bewley J. D. (1979), Physiological aspects of desiccation tolerance. *Annual Review of Plant Physiology* **30**: 195-238

Blum A. (1988), Plant Breeding for Stress Environments. CRC Press Inc., *Boca Raton, Florida*. pp. 223.

Blum A. and Ebercon A. (1981), Cell membrane stability as a measure of drought and heat tolerance in wheat. *Crop Science* 21: 43-47.

Blum A., Klueva N. and Nguyen H. T. (2001), Wheat cellular thermotolerance is related to yield under heat stress. *Euphytica* 177: 117-123

Christensen J. H. and Christensen O. B. (2007), A summary of the PRUDENCE model projections of changes in European climate by the end of this century. Climate Change 81: 7-30.

Coffman W. R. (1977), Rice varietal development for cropping systems at IRRI. Proceedings of symposium on cropping systems research and development for the Asian rice farmer. *Philippines:* IRRI, 359-371.

Dewey D. R. and Lu K. H. (1959), A correlation and path analysis or components of crested wheat grass seed production. *Agronomy Journal* 51: 521-523.

Dexter S. T. (1956), Evaluation of crop plants for winter hardiness. *Advances in Agronomy* 8: 203-209.

Eitzinger J., Orlandini S., Stefanski R. and Naylor R. E. L. (2010), Climate change and agriculture: introductory editorial. *Journal of Agricultural Science, Cambridge* 148, 499-500.

Forkar M., Blum A. and Nguyen H. T. (1998b), Heat tolerance in spring wheat. II. Grain filling. *Euphytica* 104: 9-15.

Forkar M., Nguyen H. T. and Blum A. (1998a), Heat tolerance in spring wheat. I. Estimating cellular thermostability and its heritability. *Euphytica* 104: 1-8.

Ibrahim A. M. H. and Quick J. S. (2001), Genetic control of high temperature tolerance in wheat as measured by membrane thermo-stability. *Crop Science* 41: 1405-1407.

IPCC (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE) (2007), Climate change and its impacts in the near and long term under different scenarios. In Climate Change 2007: Synthesis Report (Eds The Core Writing Team, Pachauri R K & Reisinger A), pp. 43-54. Geneva, Switzerland: IPCC.

Krishanan M., Nguyen H. T. and Burke J. J. (1989), Heat shock protein synthesis and thermotolerance in wheat. *Plant Physiology* 90: 140-145.

Kuo C. G., Chen H. M. and Sun H. C. (1992), Membrane thermostability and heat tolerance of vegetable leaves. In: Kuo CG (ed) Adaptation of food crops to temperature and water stress. Proceedings of International Symposium, Asian Vegetable Research and Development Center, Taiwan : 160-168.

Leopold A. C. and Willing R. P. (1983), Evidence of toxicity effects of salt on membranes. In: Staples RC, Toenniessen GH (eds) Plant improvement for irrigated crop production under increasing saline conditions. John Wiley and Sons, New York : 678-685.

Levitt J. (1980), Responses of plants to environmental stresses, Vol. 2. Academic press, New York.

Martineau J. R., Specht J. E., Williams J. H. and Sullivian C. Y. (1979a), Temperature tolerance in soybeans. I. Evaluation of a technique for assessing cellular membrane thermostability. Crop Science., 19: 75-78.

Martineau J. R., Williams J. H. and Specht J. E. (1979b), Temperature tolerance in soybeans. II. Evaluation of segregating populations for membrane thermostability. Crop Science 19: 79-81.

Mather K. and Jinks J. L. (1971), Biometrical Genetics. Second edition. Chapman and Hall Ltd. London.

Mirza M M Q. (2003), Climate change and extreme weather events: Can countries adapt? *Climate policy* 3: 233-248.

Reynolds M. P., Balota M., Delgado M. I. B., Amani I. and Fischer R. A. (1994), Physiological and morphological traits associated with spring wheat yield under hot, irrigated conditions. *Australian Journal of Plant Physiology* 21: 717-730.

Sadalla M. M., Shanahan J. F., Quick J. S. (1990a), Heat tolerance in winter wheat. I. Hardening and genetic effects on membrane thermostability. *Crop Science* 30: 1243-1247.

Sadalla M. M., Quick J. S. and Shanahan J. F. (1990b), Heat tolerance in winter wheat. II. Membrane thermostability and field performance. *Crop Science* 30: 1248-1251.

Sakata T. and Higashitani A. (2008), Male sterility accompanied with abnormal anther development in plants genes and environmental stresses with special reference to high temperature injury. *International Journal of Plant Development Biology* 2, 42–51.

Savchenko G. E., Klyuchareva E. A., Abrabchik L. M. and Serdyuchenko E. V. (2002), Effect of periodic heat shock on the membrane system of etioplasts. *Russian Journal Plant Physiology*, 49**:** 349–359.

Schaff D. A., Clayberg C. D. and Milliken G. A. (1987), Comparison of TTC and electrical conductivity heat tolerance screening techniques in Phaseolus. *Horticultural Science* 22: 642-645.

Shanahan J. F., Edwards I. B., Quick J. S. and Fenwick R. J. (1990), Membrane thermostability and heat tolerance of spring wheat. *Crop Science* 30: 247-251.

Singh N. B., Singh Y. P. and Singh V. P. N. (2005), Variation in physiological traits in promising wheat varieties under late sown condition. *Indian Journal of Plant Physiology* 10: 171-175.

Sullivan C. Y. (1972), Mechanisms of heat and drought resistance in grain sorghum and method of measurements. In: Rao NGP, House LR (eds) Sorghum in the seventies Oxford and IBH Publ, New Delhi, pp 247-264.

Sullivan C. Y. and Ross W. M. (1979), Selecting for heat and drought resistance in grain sorghum. In: Mussell H, Staples R (eds) stress physiology in crop plants. John Wiley & Sons, New York, pp 263-281.

Wahid A. and Close T. J. (2007), Expression of dehydrins under heat stress and their relationship with water relations of sugarcane leaves. *Biologia Plantarum* 51: 104-109.

Wallner S. J., Bechwar M. R. and Butler J. D. (1982), Measurement of turf grass heat tolerance in vitro. *Journal of American Society for Horticultural Science* 107: 608-611.

Yamanouchi U., Yano M., Lin H., Ashikari M. and Yamada K. (2002), A rice spotted leaf gene, Spl7, encodes a heat stress transcription factor protein. In**:** Proceedings of the National Academy of Sciences, USA 99. pp. 7530–7535.