

Exploring stress tolerance indices to identify terminal heat tolerance in spring wheat in Nepal

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Abstract

Terminal heat stress during anthesis and grain filling period accelerates maturity and significantly reduces grain size and weight. A study was performed to explore stress tolerance indices that can judge terminal heat tolerance in spring wheat in Nepal. Ten diverse lines were planted under normal (non-stress) and late (heat stress) sown condition at two locations (Parwanipur and Hardinath) in Nepal. The trial was set up in Alpha Lattice design with two replications in two consecutive crop cycles 2011-12 and 2012-13. Yield traits were recorded and stress susceptibility and tolerant indices were estimated. Correlation analysis showed that yield under stress environment had positive ($r=0.80$) and significant ($p<0.05$) association with that under non-stress environment. Similarly, grain yield under both environments had significant and positive correlation with mean productivity (MP), geometric mean productivity (GMP) and heat tolerance index (HTI) whereas non-significant correlation with stress susceptibility index (SSI) and tolerance index (TOL). The first two principal components explained 97% of the variation. Biplot analysis revealed that stress tolerance indices can be used selection criteria for identification of heat tolerant genotypes. Combined analysis showed that NL 1140 (SSI=0.71) possessed highest tolerance, followed by BL 3978 (SSI=0.79) while NL 1096 (SSI=1.5) appeared least tolerant. The most tolerant line NL 1140 produced mean yield of 3730.5 Kg/ha and 3000.3 Kg/ha under normal and late sown condition, respectively. The HTI of this line was maximum (1.08) among the tested genotypes. NL 1140 and BL 3978 were identified as promising for terminal heat tolerance and can be used directly as well as in the crossing program to heat tolerant genotypes of breed wheat.

Keywords: Stress susceptibility index, Tolerance index

1. Introduction

Temperature is a key environmental factor regulating both the rate of development and growth of crops (Slafer and Rawson, 1994), wheat being no exception. It has been projected that the increase in temperature will have a negative impact on crop production (Porter and Semenov, 2005). By the end of the 21st Century, the earth's climate is predicted to be warmer by an average of 2-4°C (IPCC, 2007), due to both anthropogenic and natural factors (Eitzinger *et al.*, 2010). This increase in temperature has exposed most of the world's crops to heat stress during some stages of their life cycle. The difficulty in precise

prediction of the projected agricultural impacts of climate change further adds to the uncertainty (Watanabe and Kume, 2009). Wheat (*Triticum aestivum*), a temperature sensitive crop, is presently being affected by terminal heat stress on a significant wheat growing area in South Asia with majority being in Eastern Gangetic Plains (Joshi *et al.*, 2007a). Globally, terminal heat stressed wheat is reported to be on 36 Mha area (40% of the temperate environment) (Hays *et al.*, 2007). The current trends in Nepal, India and other neighboring countries indicate that the 'cool period' for wheat crop is shrinking, while the threat of terminal heat stress is increasing (Joshi *et al.*, 2007b).

In wheat, temperature above 30°C after anthesis decreases the rate of grain filling (Stone and Nicolas, 1995). It was also predicted that an increase of 1°C temperature will result in 4-5 million tons (3-4%) of loss in wheat production (Wardlaw *et al.*, 1989). Terminal heat stress prevails in around half of the wheat growing area of Nepal, all in Terai (plain) area. This area faces western hot winds accompanied by sudden rise in temperature (Maximum and Minimum) starting from mid March and leads to shriveling of grains. Using the factor (3-4% loss per 1°C above 15-20°C), it can be easily understood that most commercially sown wheat cultivars lose approximately 40% of their yield potential when exposed to 32-38°C temperature at the crucial grain formation stage.

The long term weather parameters of Terai in Nepal indicate that the winter season is getting a bit delayed and shorter while, warm summer days are becoming longer. This type of change in temperature regime could be detrimental to wheat cultivation in the whole Indo Gangetic region including Nepal Terai. Long duration wheat varieties are already suffering due to early heat during grain filling period. Wheat crop growth is highly dependent to temperature regimes and an abrupt change in temperature tends to speed up the growth and vegetative stage shifts to reproductive one within short period of time resulting in low yield. Under such situations, wheat varieties with shorter maturity or fast grain filling rate would be desirable (Mondal *et al.*, 2013). Therefore, breeding for high-temperature tolerant wheat lines having disease resistance and stay green trait that are capable of producing enough endosperm, bold grains within short grain filling duration should be developed for climate

resilience. This has been one of the major objectives around the world in light of increased global warming.

Yield and its components in stress condition, are still the most effective tools for stress evaluation (Ozkan *et al.*, 1998). Therefore understanding parameters that can judge heat stress and development of heat tolerant wheat cultivars are of paramount importance. Genetic diversity for heat tolerance in wheat is well established (Al-Khatib and Paulsen, 1990; Reynolds *et al.*, 2001; Paliwal *et al.*, 2012). Stress susceptibility indices (SSI) were used to identify tolerant genetic sources for crossing to genotypes with high potential (Mohammad, 2012). Similarly, Paliwal *et al.* (2012) used the trait values from controlled and stressed trails for heat susceptibility index (HSI) of thousand grain weight, HSI of grain filling duration, HSI of grain yield and canopy temperature depression (CTD) to determine heat tolerance. The present investigation was conducted to explore stress tolerance indices that can judge terminal heat tolerance in spring wheat in Nepal and also to identify terminal heat tolerance in agronomically superior background.

2. Material and methods

The experiments were conducted at Regional Agricultural Research Station, Parwanipur (27° 2' North Latitude, 84° 53' East Longitude and 115 masl) and National Rice Research Program, Hardinath (26°49'E latitude and at an altitude of 93 masl) as Coordinated varietal trial for Terai, Tars and lower valleys under irrigated condition. The experimental material consisted of ten spring wheat lines having diverse traits (Table 1).

Table 1. Mean grain yield in stress, non-stress conditions and different stress indices for spring wheat genotypes tested for two years (2011-12 and 2012-13) in Nepal

Genotypes	Pedigree	Yield (NS*)	Yield (LS**)	SSI	TOL	MP	GMP	HTI
NL 1140	WAXWING*2/VIVITSI	3730.50	3000.38	0.71	730.13	3365.44	3340.57	1.08
BL 3978	NL729/BL2015	3838.00	2914.00	0.79	924.00	3376.00	3324.81	1.07
GAUTAM	CHIRYA-3/SIDDHARTHA//NL731	3303.00	2542.75	0.80	760.25	2922.88	2891.60	0.80
RR 21	MIDA-U/K117AII2*TH/3/FN/4*TH/4/AN/5/YT54/N10BIILR	2532.75	1847.38	0.80	685.38	2190.06	2137.43	0.44
NL 1094	KAUZ//ALTER84/AOS/3/PASTOR/4/TILHI	3486.00	2693.38	0.92	792.63	3089.69	3064.16	0.92
NL 1143	WHEAR/VIVITSI/3/C80.1/3*BATAVIA//2*WBLL1	2935.50	2071.25	1.01	864.25	2503.38	2451.99	0.58
NL 1135	PF74354//LD/ALD/4/2*BR12*2/3/	3964.25	2926.50	1.06	1037.75	3445.38	3405.93	1.15
BHRIKUTI	BOW"S"/GH"S"	3432.00	2491.00	1.06	941.00	2961.50	2922.03	0.82
NL 1093	WBLL1*2/TUKURU	3237.50	2176.50	1.30	1061.00	2707.00	2653.73	0.68
NL 1096	REH/HARE//2*BCN/3/CROC-1/AE.SQU(213)	3779.00	2174.00	1.56	1605.00	2976.50	2845.96	0.78

Note: * = Normal sowing and ** = Late sowing

These lines were evaluated for two consecutive crop seasons under two conditions: non stress (Normal sowing: November 15 for 2012 and 2013) and stress (Late sowing: December 5 for 2012 and 2013) using alpha lattice design with two replications. The plot size was 10 rows of 4 m long and 25 cm row to row spacing. Fertilizer and irrigation were applied as per recommendations (Gautam *et al.*, 2011).

2.1 Stress indices: Yield and its traits were recorded and the stress susceptibility and tolerance indices were calculated using the formulae:

$$\text{Stress Susceptibility index (SSI)} = [1 - (x_s/sp)] / [1 - (X_s/X_p)]$$

$$\text{Tolerance (TOL)} = x_p - x_s$$

$$\text{Mean Productivity (MP)} = (x_p + x_s) / 2$$

$$\text{Geometric Mean Productivity (GMP)} = \sqrt{x_p \cdot x_s}$$

$$\text{Heat Tolerance Index (HTI)} = (x_s \cdot x_p) / (X_p)^2$$

Where, x_s is the trait value (grain yield kg/ha) of the genotype under stress and x_p is the trait value of the genotype under non stress conditions. X_s and X_p are mean values of the trait of all the genotypes under stress and non-stress conditions, respectively.

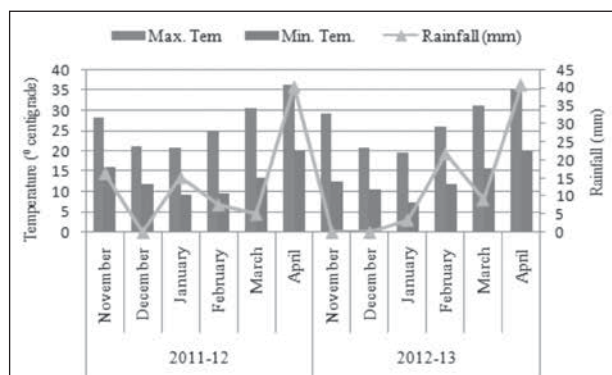


Figure 1. Maximum, minimum temperatures and rainfall during wheat season for Parwanipur, 2011-13.

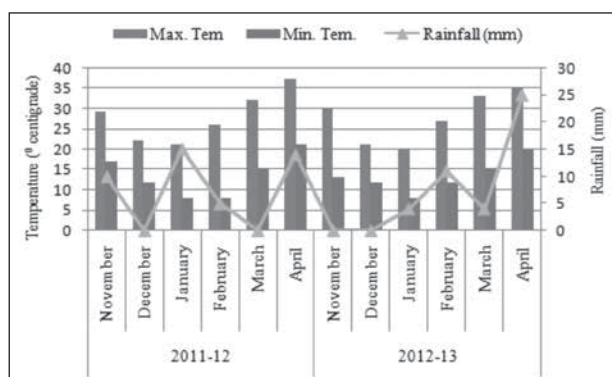


Figure 2. Maximum, minimum temperatures and rainfall during wheat season for Hardinath, 2011-13.

2.2 Statistical Analysis: In addition to estimating stress indices, correlations and principal component analysis was done and biplot and three-dimensional plots drawing were performed using MINITAB 14 and Excels.

The principal component analysis was used to explain all the data variables by minimum number of components. The biplot display of principal component analysis was used to identify suitable stress tolerant indices and stress tolerant genotypes with high grain yield kg/ha.

2.3 Meteorological Information: Daily mean maximum and mean minimum temperatures were recorded for characterization of environments. Mean maximum and minimum temperature for the two experimental sites are presented in Figure 1 and Figure 2.

3. Results and discussion

3.1 Stress indices for wheat genotypes: Combined analysis among the tested wheat lines showed that NL 1140 (SSI=0.71) possessed the highest level of tolerance, followed by BL 3978 (SSI=0.79) while NL 1096 (SSI=1.5) appeared least heat tolerant. The most heat tolerant variety NL 1140 produced mean yield of 3730.5 Kg/ha and 3000.3 Kg/ha under normal and late sown condition respectively. The HTI of this line was highest (1.08) among the tested new wheat genotypes (Table 2). This indicated that NL 1140 and BL 3978 appeared to be promising for terminal heat tolerance. The meteorological information revealed that the temperature during flowering period exceeded 28°C in both the location and still the two lines performed well. Hence, the two lines (NL 1140 and BL 3978) can be used directly as well as in the crossing program to breed more heat tolerant genotypes.

3.2 Correlation among traits: Correlation analysis showed that yield under stress environment had positive ($r=0.80$) and significant ($p<0.05$) association with that of non-stress environment. Grain yield (Kg/ha) under both environments had significant positive correlation with MP, GMP and HTI while non significant correlation with SSI and TOL (Table 2). These results are in conformity with those of Boussen *et al.* (2010) in durum wheat and Sareen *et al.* (2012) in synthetic wheat lines.

3.3 Principal component and biplot analysis: The first two factors in the principal component analysis explained more than 97% variation (Table 3). The first factor explained 62% variation for grain yield whereas the second factor contributed 35%. The maximum contribution by individual variable for first factor was by GMP followed by HTI. Therefore it reflected high grain yield as well as stress tolerance. Similar result was obtained by Sareen *et al.* (2012) in synthetic wheat lines.

Using principal components, biplot for genotypes and stress indices was drawn (Figure 3). The angles and

Table 2. Correlation coefficients of yield with stress indices under stress and non stress conditions in Nepal

Variables	Yield (NS)	Yield (LS)	SSI	TOL	MP	GMP	HTI
Yield (LS)	0.807*	1					
SSI	0.179	-0.405	1				
TOL	0.445	-0.17	0.913**	1			
MP	0.955**	0.946**	-0.105	0.16	1		
GMP	0.932**	0.965**	-0.162	0.092	0.997**	1	
HTI	0.92**	0.968**	-0.19	0.068	0.992**	0.995**	1

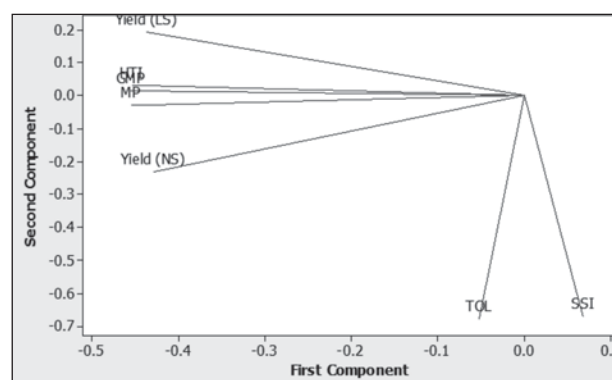
Note: *significant at 0.05, **significant at 0.001

directions between the attribute vectors illustrated the strength and the direction of correlation between any two attributes (Fernandez, 1992). Significant positive correlation was observed between Yield (NS) and MP, MP and GMP, GMP and HTI and HTI and Yield (LS). These observations were in conformity with correlation results indicating that HTI, GMP and MP could be reliable selection criteria for terminal heat tolerance in Nepal as reported by Fernandez (1992), Sareen *et al.*, (2012) and Mohammadi *et al.*, (2011) in other environments.

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**Figure 3.** Biplot for wheat lines and stress indices using first two principal components.**Table 3.** First two principal components for grain yield and stress indices under stress, non-stress conditions in Nepal

Variable	PC1	PC2	PC3
Yield (NS)	-0.405	-0.255	-0.172
Yield (LS)	-0.443	0.094	0.211
SSI	0.117	-0.568	0.036
Tolerance (TOL)	-0.005	-0.569	-0.607
Mean Productivity (MP)	-0.445	-0.093	0.011
Geometric mean productivity (GMP)	-0.448	-0.058	0.104
Heat Tolerance Index (HTI)	-0.448	-0.043	0.114
Eigenvalue	4.9	2.86	0.1969
Variability (%)	0.62	0.35	0.025
Cumulative	0.62	0.97	0.997

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