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Selection indices for identifying heat tolerant of maize (*Zea mays*)

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ABSTRACT

Drought and heat stress have become the most prevailing problems for maize (*Zea mays* L.) crop production. Therefore, development of stress tolerance has become an essential goal in a breeding programme. Hence, an experiment was conducted at Punjab Agricultural University, Ludhiana, Punjab to identify heat tolerant DH lines in maize during spring season, 2016 and 2017. A total of 32 DH lines were evaluated under heat stress and non-stress conditions. Five stress tolerance indices such as Tolerance Index (TOL), Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Susceptibility Index (SSI) and Stress Tolerance Index (STI) were calculated based on grain yield under heat stress (Ys) and non-stress conditions (Yp). Grain yield under stress condition showed a negative significant association with TOL and SSI while positive significant correlation with MP, GMP and STI. Similarly, grain yield under non stress condition showed positive significant association with TOL, MP, GMP and STI. Based on two years data and using MP, GMP and STI, DH line DH_4_23 and DH_4_47 were found to be the most heat tolerant. These lines may be used as a potential source for heat stress tolerance and can be further used in heat stress tolerant breeding programme.

Keywords: Correlation, Heat stress, Stress tolerance indices, Zea mays

Maize (*Zea mays* L.) is the third dominant cereal crop after rice and wheat across the world. It is routinely consumed by humans, and is used as feed for animals along with serving as raw material for industries, for production of starch, oil, protein, food sweetener and alcohol. In South Asia, millions of smallholders grow maize for their income and livelihood. Therefore, the demand for maize has significantly increased in recent years due to many factors, including changing food habits resulting in rapidly growing poultry sector. But the average maize yield in South Asia is still only 2.9 tonnes per hectare (FAOSTAT 2016). Hence the ever increasing demand for maize can be achieved through intensification of current maize production systems, such as expansion of maize cultivation areas during the spring season in several countries of Asia (Dass *et al.* 2010).

Spring maize is grown during the hotter months of the year (Feb–May) and is invariably exposed to prolonged high temperature regimes (or heat stress) during most of the critical crop growth period, starting from the late vegetative stage to early grain filling. Exposure to temperatures above 35°C for a prolonged period is considered unfavourable for crop growth and beyond 40°C, particularly during flowering and grain filling can have severe impact on grain yields (Rincon and Lopez 2006, Tesfaye *et al.* 2016). Rise in temperature beyond threshold, reduces the pollen viability and silk receptivity, resulting in poor seed set and reduced grain yield (Johnson 2000).

Breeding for heat stress tolerance in maize has limited success, primarily because selection in stress tolerance breeding programmes is often based on grain yield *per se*, which could be misleading in stressed trials due to its low heritability estimates. Different indices, viz. stress tolerance (TOL), mean productivity (MP), stress susceptibility index (SSI), tress tolerance index (STI) and Geometric mean productivity (GMP) have been used for screening stress tolerant genotypes and these indices are based either on stress tolerance or susceptibility of genotypes (Fernandez 1992). Therefore, the present study was carried out to identify heat stress tolerant DH lines using different stress tolerance indices.

MATERIALS AND METHODS

Present study was carried out at Punjab Agricultural University, Ludhiana, Punjab during spring season of 2016 and 2017. Thirty two DH lines derived from one bi-parental pedigree population (VL1030/VL1036) and test-crossed with a heat susceptible tester line (CML-474) were evaluated using randomized complete block design with 2 replications, under 2 different planting dates: 1st week of February (non-stress) and 1st week of March to ensure maximal heat stress

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during flowering and grain formation stages (April/May months). Each entry was represented by a single row of 3 m length with a spacing of 65 cm between rows. Minimum and maximum air temperature at the time of pollination during 2016 were 19.6°C and 36.6°C; similarly, during 2017 were 20.0°C and 36.9°C, respectively. Grain yield was recorded in terms of ear weight per plot immediately after crop harvest and converted to tonnes per hectare at 15% grain moisture content and 80% shelling percentage.

Stress tolerance indices were calculated as:

Tolerance Index (TOL) = Yp – Ys (Rosielle and Hamblin 1981);

Mean Productivity (MP) = Ys + Yp/2 (Rosielle and Hamblin 1981);

Geometric Mean Productivity (GMP) = √Yp.Ys (Fernandez 1992);

Stress Susceptibility Index (SSI) = 1-Ys/Yp/ SI (Fisher and Maurer 1978), where SI, 1–$\overline{Ys}/\overline{Yp}$;

Stress Tolerance Index (STI) = Ys.Yp/ $(\overline{Ys})^2$ (Fernandez 1992), where Ys and Yp being the yield of genotypes evaluated under stress and non-stress condition; $\overline{Ys}$ and $\overline{Yp}$ being the mean of overall genotypes evaluated under stress and non-stress condition.

Analysis of variance and adjusted means for randomized complete block design were performed for pooled data, using the *Proc GLM* procedure in SAS 9.3 (SAS Institute 2011) and genotypic correlation coefficients was analyse using multi environment trial analysis with R (META-R) (Alvarado *et al.* 2015).

RESULTS AND DISCUSSION

According to the meteorological data (Department of Meteorological, PAU, Ludhiana, India), late sown genotypes (natural heat stress) coincided with high temperature during plant developmental and pollination stages. High temperature affects the days of anthesis and silking, resulting in prolonged of anthesis-silking interval under stress condition (Table 1). Under stress condition, grain yield was low as compared to non-stress condition, means high temperatures during pollination had greater impact on grain yield of maize. Among the DH lines, DH_4_12 followed by DH_4_23, DH_4_44, DH_4_49 and DH_4_8, showed higher grain yield under non-stress conditions whereas, DH_4_42 showed lowest yield under non-stress condition (Table 1). In heat stress condition, DH_4_23, DH_4_47, DH_4_49 and DH_4_12 showed higher grain yield while DH_4_9 recorded lowest grain yield (Table 1). The analysis of variance showed significant variation among the DH lines (Table 2).

Perpetual increase in environmental temperature is threatening sustainability of maize productions, worldwide (Naveed *et al.* 2016). The major decreases in crop yield have been affected by increased temperatures and heat waves (Hoffmann *et al.* 2006, Figueiredo *et al.* 2015). Under stress conditions, anthesis-silking interval was found high and grain yield was low compared to non-stress conditions. Farooq *et al.* (2011) reported that increased temperature hastens the phenological stages of wheat development and reduces the duration of the grain filling stages, resulting in decreased grain yield and quality. Wiegand and Cuellar (1981) reported that 1°C rise from mean daily air temperatures (15.8–27.7°C) during wheat development reduces the grain filling period by 3.1 days and weight per grain by 2.8 mg approximately.

Based on TOL and SSI indices, DH_4_23, DH_4_47 and DH_4_49 were observed to be the most stress tolerant among the DH lines. A low TOL and SSI indices indicates higher tolerance to stress. Considering GMP and STI indices, DH_4_12, DH_4_8, DH_4_49, DH_4_44 and DH_4_47 were found to be more stress tolerant among DH lines under study. DH lines such as DH_4_12, DH_4_8, DH_4_44, DH_4_49, DH_4_14 and DH_4_47 showed more tolerance based on MP index. The stress tolerant genotype had a positive correlation between grain yield and selection indices, viz. GMP, STI and MPI.

Higher TOL and SSI value indicates increased sensitivity to a given stress. Hence, lower TOL and SSI are desired under stress conditions. Selection based on TOL favours genotypes with low yield potential under non-stress conditions and high yield under stress conditions (Fernandez 1992) and genotypes with low TOL are quite more stable under stress-prone environments (Hossian and Silva 2012, Hossian *et al.* 2012). Similarly, selection based on SSI genotypes with low GY under non-stress and high GY under stress conditions are considerable for selection (Nouri *et al.* 2011, Ali *et al.* 2016). Ankit *et al.* (2013) and Singh *et al.* (2015) reported that wheat genotypes with higher SSI and TOL values were susceptible to stress and with lower value of SSI and TOL were tolerant to stress. Moghaddam and Hadizadeh (2002) suggested that STI is more useful for selection of maize genotypes tolerant to stress than SSI. STI and GMP and has to be used to select hybrids with high yield under stress and non-stress conditions, while as SSI identifies genotypes yielding well under stress conditions (Khalili *et al.* 2004, Souri *et al.* 2005, Karami *et al.* 2006).

The most desirable stress tolerant criterion can be determined by studying the correlation between Ys, Yp and quantitative indices of stress tolerance (Table 3). Grain yield (Ys) under heat stress showed a strong positive and significant association with MP, GMP and STI whereas, TOL and SSI showed a negative and significant correlation. It indicates that high MP, GMP and STI indices and low TOL, SSI indices show high grain yield. These results are in agreement with Khodarahmpour *et al.* (2011). They explained that grain yield (Yp) under non-stress conditions showed positive and significant correlation with TOL, MP, GMP, SSI and STI. This correlation study showed that MP, GMP and STI appeared to be a better predictor of Ys and Yp than TOL and SSI. The relationships observed between both Yp and Ys, and MP was consistent with those reported by Fernandez (1992) in mungbean and Farshadfar and Sutka (2002) in maize.

Grain yield (Ys) under heat stress showed a strong positive and significant association with MP, GMP and STI

Table 1 Pooled performance of the 31 DH lines for yield related traits

Genotype	Non-stress condition				Stress condition			
	Yp	AD	SD	ASI	Ys	AD	SD	ASI
DH_4_12	8.30	71.93	73.42	1.40	5.41	64.67	67.18	2.90
DH_4_13	5.29	69.71	71.46	1.95	4.71	71.60	73.03	2.65
DH_4_14	6.88	69.71	70.97	1.54	4.54	70.70	72.35	2.70
DH_4_19	5.83	71.51	72.93	1.40	3.56	74.73	78.66	3.20
DH_4_20	5.30	71.37	72.77	1.40	1.75	72.04	74.60	2.90
DH_4_22	5.34	69.01	70.16	1.54	3.60	66.01	70.78	3.39
DH_4_23	8.04	70.82	73.26	2.36	6.27	68.02	69.88	2.75
DH_4_24	5.38	69.57	70.81	1.54	4.23	64.89	66.50	2.70
DH_4_25	6.75	71.93	73.75	1.68	4.81	71.82	75.06	3.05
DH_4_27	6.44	71.37	73.09	1.68	4.04	71.82	72.80	2.56
DH_4_28	6.59	70.68	72.60	1.95	2.87	72.71	75.28	2.90
DH_4_3	5.22	70.96	72.93	1.95	3.15	66.90	71.90	3.44
DH_4_30	4.47	70.68	72.28	1.68	3.77	65.11	68.30	3.05
DH_4_32	5.90	70.82	72.77	1.95	4.15	70.70	72.58	2.75
DH_4_34	5.07	71.37	74.07	2.50	3.70	75.40	78.88	3.10
DH_4_35	5.54	72.07	74.89	2.50	2.87	75.62	79.11	3.10
DH_4_36	5.52	70.40	72.28	1.95	3.03	74.05	76.63	2.90
DH_4_37	6.25	71.65	73.75	1.95	4.12	75.84	78.66	2.95
DH_4_38	5.88	70.40	71.95	1.68	4.23	65.56	67.18	2.70
DH_4_39	5.74	70.96	74.40	3.19	4.10	73.83	76.86	3.00
DH_4_4	4.54	70.26	72.60	2.36	3.43	70.70	76.18	3.54
DH_4_42	3.75	72.90	75.21	1.95	3.31	74.95	76.18	2.61
DH_4_44	7.53	70.96	72.44	1.54	4.44	66.01	69.65	3.15
DH_4_45	4.82	69.98	71.79	1.95	3.01	71.82	78.21	3.74
DH_4_46	5.98	72.21	74.40	1.95	4.68	70.48	73.03	2.90
DH_4_47	6.71	70.26	72.11	1.95	5.91	64.67	66.73	2.80
DH_4_49	7.12	71.51	73.09	1.54	5.68	67.80	68.98	2.61
DH_4_53	4.75	70.40	72.11	1.82	1.67	67.80	71.23	3.10
DH_4_54	5.63	71.23	72.93	1.68	3.18	65.78	71.00	3.49
DH_4_8	7.65	70.12	71.95	1.95	4.91	65.34	68.08	2.95
DH_4_9	6.51	71.23	73.58	2.23	1.47	81.65	86.54	3.39

Yp, Yield under non stress condition; Ys, Yield under stress condition; AD, Days to 50% anthesis; SD, Days to 50% sliking; ASI, Anthesis-silking interval.

Table 2 Pooled analysis of variance for different stress tolerance indices and yield under heat stress and non-stress conditions in maize DH lines

Source of variation	Degree of freedom	Ys	Yp	TOL	MP	GMP	SSI	STI
Genotypes	30	6.182^{***}	4.657^{***}	4.333^{***}	4.339^{***}	5.297^{***}	0.731^{***}	0.403^{***}
Replication	1	3.864	9.509	25.498	0.303	0.053	0.0002	0.481
Error	60	0.462	0.530	0.855	0.282	0.309	0.270	0.022

***, Significant level at 0.001; Ys, Yield under stress; Yp, Yield under non-stress; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric mean productivity; SSI, Stress susceptibility index; STI, Stress tolerance index.

Table 3 Pooled genotypic correlation coefficients for yield and different stress tolerance indices in maize DH lines

	Ys	Yp	TOL	MP	GMP	SSI	STI
Ys	1.000	0.211	-0.731***	0.833***	0.899***	-0.841***	0.880***
Yp		1.000	0.513**	0.718***	0.597***	0.356*	0.639***
TOL			1.000	-0.230	-0.373*	0.989***	-0.326
MP				1.000	0.980***	-0.397*	0.989***
GMP					1.000	-0.527**	0.992***
SSI						1.000	-0.486**
STI							1.000

*, Significant level at 0.05; **, Significant level at 0.01; ***, Significant level at 0.001; Ys, Yield under stress; Yp, Yield under non-stress; TOL, Tolerance index; MP, Mean productivity; GMP, Geometric mean productivity; SSI, Stress susceptibility index; STI, Stress tolerance index.

indicating that genotypes with higher values of the indices are tolerant to heat stress with higher grain yield. Whereas, TOL and SSI showed significant negatively correlation with grain yield indicating that genotypes with higher indices give lower yields and those with lower indices give higher grain yield under heat stress conditions. Grain yield (Yp) under non stress condition showed a significant positive correlation with all the selection indices under study.

In the present studied, grain yield (Ys) under stress found positive and significant associated with STI, MP and GMP while as TOL and SSI showed a significant negative correlation. These results are in agreement with Khodarahmpour *et al.* (2011). They explained that grain yield (Yp) under non-stress conditions showed a positive and significant correlation with TOL, MP, GMP, SSI and STI. Moghaddam and Hadizadeh (2002) suggested that STI is more useful for selection of maize genotypes tolerant to stress than SSI. STI and GMP has been used to select hybrids with high yield under stress and non-stress conditions, while SSI identifies genotypes yielding well under stress conditions (Khalili *et al.* 2004, Souri *et al.* 2005, Karami *et al.* 2006). Qaing *et al.* (2018) study suggested that there was no consistent association between grain yield under stress and susceptibility index and this index describes only the yield stability under heat stress. This correlation study showed that MP, GMP and STI appeared to be a better predictor of Ys and Yp than TOL and SSI.

Selection based on TOL, MP, GMP, SSI and STI selection indices could help to improve heat tolerance in DH lines. Based on such information, we can strengthen our heat tolerance breeding programme. MP, GMP and STI that showed high positive correlations with grain yield in both stressed and non-stressed conditions can be utilized more efficiently in DH line selection. Based on MP, GMP and STI indices, DH_4_12 DH_4_8, DH_4_49, DH_4_44, DH_4_47 and DH_4_14 were found to be the most tolerant DH lines with consistent high grain yield under stress and non-stress condition.

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