Research Article

Evaluation of Local and Multinational Maize Hybrids for Tolerance Against High Temperature using Stress Tolerance Indices

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Abstract | The current study was conducted to evaluate maize hybrids for their high temperature tolerance ability based on their performance as assessed through different high temperature stress indices. Nine maize hybrids were screened under optimal and high temperature stress conditions (late sowing) for three consecutive spring seasons (Spring 2017-18, 2018-19 and 2019-20), laid out under split-split-plot design under RCBD. Results reveled significant differences among stress indices for all three seasons and both conditions. Correlation analysis indicated that some high temperature stress indices i.e., STI, MP, GMP and HARM had a strong positive correlation with kernel yield under normal (Y*p*) and high temperature stress conditions (Y*s*). Biplot analysis further unveiled that two local maize hybrids *i.e.*, YH-5507 and YH-5427 were the most productive, stable and heat tolerant while YH-5532, P-1543 and NK-8711 showed poor performance under high temperature stress conditions as compared to normal sowing. High temperature stress indices could be efficiently used to screen heat tolerant genotypes.

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Keywords | Climate change, Selection, Screening, Biplot analysis, Heat stress

Introduction

Heat stress as a result of high ambient temperature is the one of the most alarming threat to crop production in Pakistan as well as Worldwide. It becomes more severe in spring crop during reproductive stage i.e., anthesis and grain development stages when high ambient temperature coincides with these stages (Ghani *et al.*, 2017; Yousaf *et al.*, 2018; 2019; Riaz *et al.*, 2021). The normal temperature required for reproductive growth of maize crop ranges from 26°C to 31°C (Sánchez *et al.*, 2014). Crop exposure to higher temperature (> 35°C) could significantly reduce maize kernel yield as reported by many researchers (Thornton *et al.*, 2010; Lobell *et al.*, 2011; Deryng *et al.*, 2011; Ghani *et al.*, 2020). Brown (2009) in a global study, reported a 10% reduction in kernel yield for every 1°C above normal temperature (29°C). It is also predicted that 8.1% reduction in kernel yield is expected in Pakistan by 2055 (Iqbal *et al.*, 2011) due to clanging climatic conditions. These studies show that there is an utmost need for the selection

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and development of heat tolerant maize hybrids to cope with deleterious effects of climate change especially high temperature.

High temperature stress could be very fetal to anthesis and grain development stages in maize as a single, severely hot day (above 43°C) could severely reduce kernel yield. Furthermore, high temperature during reproductive stage could also reduce seed setting (51% to 81%), number of kernels per ear, thousand grain weight, pollen viability, silk receptivity, assimilation rate and net photosynthetic rate which ultimate decrease kernel yield (Traore *et al*., 2000; Wahid *et al*., 2007; Yousaf *et al*., 2017; Fonseca *et al*., 2005). The flowering stage in maize – more specifically, anthesis and silking – are more heat sensitive than the grain filling stage, so high temperature stress during the former stages can result in greater reductions in grain yield (Zhang *et al*., 2013). Therefore, improvement of maize hybrids for thermotolerance is one of the most challenge for maize breeders. Selection of maize germplasm for the identification of heat tolerance parents/genotypes is the prerequisite for the development of heat resilient maize hybrids (Abu-Romman, 2016). The most common method for the selection of germplasm is by growing breeding material under optimal and stress conditions and then selecting the lines/genotypes with higher kernel yield (Ehlers and Hall, 1998). Hence, it is pivotal to screen maize hybrids under optimal and stress conditions.

For efficient selection of genotypes under high temperature, several stress related indices have been developed. Among these, STI (Stress Tolerance Index), SSI (Stress Susceptibility Index), Stress Tolerance (TOL), MP (Mean productivity index), GMP (Geometric mean productivity index), HARM (Harmonic mean productivity), GOL (Golden mean), YI (Yield index) and YSI (Yield stability index) (Khalili *et al*., 2012; Grzesiak *et al*., 2019; Zhao *et al*., 2019). These stress indices are based on either stress tolerance or susceptibility of hybrids (Fernandez, 1992). The best selection criteria should identify and discriminate genotypes that have uniform superiority under normal and high temperature stress conditions from those genotypes which are productive under one condition only. TOL could be effectively use to select maize hybrids with high yield potential under high temperature stress conditions. But this criterion does not permit to differentiate between high yielding maize hybrids under high temperature stress conditions from the best performing hybrids under both conditions. Barutcular *et al*. (2016) showed that the genotypes having higher values for SSI and TOL are considered as stress susceptible genotypes and therefore, only suitable for sowing in optimal conditions. Sedri *et al*. (2019) reported that the best index for the selection of maize hybrid under stress conditions must comprised of STI. Many researchers suggested a combination of different stress indices, having significantly positive association with kernel yield under normal and stress conditions, should be utilized to screen genotypes under stress conditions (Grzesiak *et al*., 2019; Zhao *et al*., 2019). The purpose of current investigation was to screen maize hybrids for their heat tolerance, so that most appropriate hybrids can be recommended for sowing in heat prone areas of Pakistan.

Materials and Methods

Experimental material and site

The test material used in the study was comprised of nine (09) maize hybrids including six (06) local *i.e*., YH-5427, YH-5482, YH-5213, YH-5532, YH-5507 and YH-1898 and three (03) multinational hybrids i.e., P-1543, DK-6724 and NK-8711 of well-known companies *i.e*., Cortiva, Bayer and Syngenta, respectively. Among local hybrids, YH-1898 and YH-5427 were the approved hybrids for general cultivation in all over Punjab province while other four maize hybrids i.e., YH-5482, YH-5213, YH-5532 and YH-5507 were the elite maize hybrids that are in the process of evaluation. All these hybrids were assessed under optimal and high temperature stress conditions for three consecutive spring seasons i.e., 2017-18, 2018-19 and 2019-20, respectively at Maize and Millets Research Institute (MMRI), Yusafwala-Sahiwal, Pakistan.

Experimental design and layout

Nine (09) maize hybrids we cultivated using RCBD with three replicates for three consecutive spring seasons (2017-18, 2018-19 and 2019-20). For each season, sowing was done on two different dates; first set of hybrids was sown as normal sowing in 2nd week of February and second set of same hybrids was sown on 3rd week of March as late sowing (high temperature stress conditions). In late sowing (high temperature stress) conditions, reproductive stage of crop coincides with high temperature (>40 °C), which was significantly higher from optimum temperature (32-34°C) required for fertilization, seed setting and

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kernel yield. For every testing season, experimental design, genetic material, replications and sowing dates were same. Each entry/hybrid was sown in 12 m^2 sized plot, having 15 cm plant to plant and 75 cm row-to-row distance, respectively. Two seed per hill were planted with the help of dibbler and seedling stage, thinned to single seedling per hill to ensure optimum plant population per hectare. For proper crop growth and development, 270 kg/ha nitrogen, 110 kg/ha phosphorus and 60 kg/ha potash were applied under both normal and high temperature stress conditions, respectively. Other agronomic/management practices like application of pre-emergence herbicides and use of pesticide was carried out to insure proper plant health.

Data recording

Data was recorded for several morphological, phenological, physiological and kernel quality traits for all hybrids. Kernels per ears (NE) and 1000 kernel weight (TKW) were recorded after harvesting of entries and drying in sunlight to insure 15% kernel moisture. Net photosynthetic rate (Pn) was measured through Infrared Gas Analyzer (IRGA), using a handheld photosynthetic system CI-340. The data was recorded during the grain development in 10 random ear leaves per hybrid between 10:00 am and 12:00 am. Kernel quality analysis was accomplished by near infrared spectrometry (NIR-Inframatic 9200, Parten Instruments, Sweden) to measure kernel protein content percentage (Pro) and kernel oil content percentage (Oil). Grain yield (Kg/hectare) was calculated through the following formula as described by Tandzi and Mutengwa (2020);

$$\text{Grain Yield (Kg ha} - 1) = \frac{\text{Fresh ear weight (Kg/plot)} \times (100 - \text{Moisture Contents}) \times 0.8}{(100 - 15) \times \textit{Area Harvested/plot}} \times 10000$$

Determination of Stress Indices

High temperature stress indices were calculated from kernel yield of normal (Y_p) and high temperature stress conditions (Y_s) as used by Grzesiak *et al.* (2019) and Zhao *et al.* (2019).

Stress Tolerance Index (STI) = $(Y_s \times Y_p)/(Y_p)2$

Stress Susceptibility Index (SSI) = $2(Y_s \times Y_p)/(Y_p+Y_s)$

Stress Tolerance (TOL) = Y_p-Y_s

Mean productivity index (MP) = $(Y_p+Y_s)/2$

Geometric mean productivity index (GMP) = $\sqrt{Yp + Ys}$

Harmonic mean productivity index (HARM) = $2(Y_s \times Y_p)/(Y_p+Y_s)$

Golden mean (GOL) = $[1- (Y_s/Y_p)]/ [1- (Y_s/Y_p)]$

Yield index (YI) = $Y_s/Y_{\underline{s}}$

Yield stability index (YSI) = Y_s/Y_p

Where;

Y_p = Normal Kernel yield under normal conditions

Y_s = Kernel yield under high temperature stress conditions

Data analysis

The data was subjected for statistical analysis using Statistix 8.1 and XLSTAT 16.0 statistical packages. Analysis of variance and correlation coefficient analysis was executed according to Steel *et al.* (1997). Furthermore, first two principal components (PCs) were used to plot different biplots based on the high temperature stress indices under optimal and stress conditions for three successive Spring seasons (Sneath and Sokal, 1973). Microsoft Excel (Version 2019) was also utilized for the presentation of data in graphical form.

Metrological Conditions during the trial

The research trials were conducted in three consecutive spring seasons *i.e.*, 2017-18, 2018-19 and 2019-20. For all these sowing seasons, normal set of hybrids was sown in the mid of February and harvested in the month of May-June. However, late sown set (High temperature stress) maize hybrids were planted in mid of March while harvested in the month of July. For each season, lowest day and night temperatures were recorded in the month of February while highest average day and night temperature were recorded in the month of June and July, which coincided with the flowering and grain development stages of maize crop. Under normal sowing, average minimum temperature remained 18.9°C while average maximum temperature was recorded as 35.7 °C. However, an increase of about 4 °C was observed in both average minimum (22.5°C) and maximum (39.1°C) temperature in late sown (high temperature stress) conditions (Figure 1). The average maximum temperature during reproductive stage under high temperature stress conditions was recorded 41.7 °C which was detrimental to pollen viability, fertilization, seed setting and ultimately kernel yield in maize.

Results and Discussion

Analysis of Variance (ANOVA)

Results obtained from combined ANOVA unveiled the presence of significant ($P < 0.01$) difference between

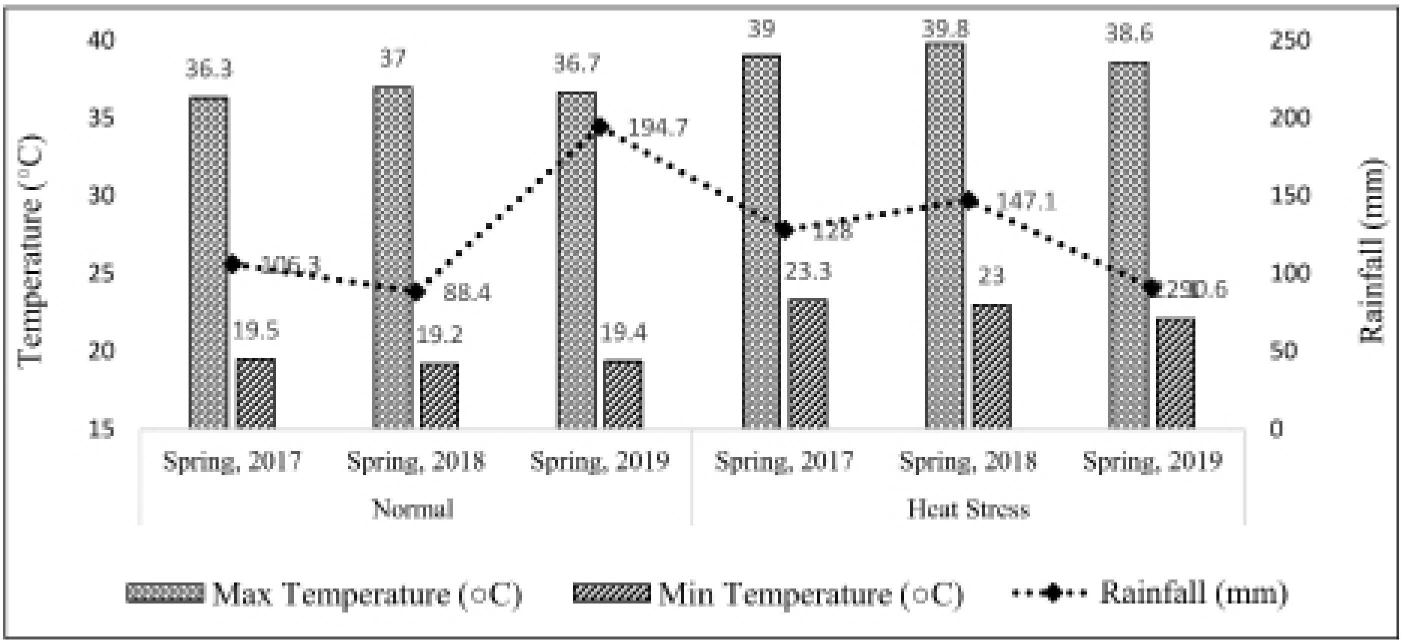

Figure 1: *Three Years Metrological data of normal and heat sown maize hybrids.*

Table 1: *Analysis of variance for kernel yield and quality related traits in maize hybrids for three spring seasons (2017, 2018 and 2019).*

SOV	DF	KE	TKW	Pn	Pro	Oil	GY
Replications	2	18.9	5.2	2.30	0.1896	0.00296	29821.5
Hybrids	8	57414..1**	7552.6**	153.88**	20.6125**	4.0275**	10860000**
Years	2	3788.6**	7214**	241.40**	0.5817**	0.2066**	25950000**
Treatment	1	99062**	11960.9**	1009.50**	1.8689**	1.1755**	110400000**
Hybrid*Year	16	8544.8**	476.7**	22.83**	0.1098NS	0.0591*	2030920**
Hybrid*Treatment	8	3724.7**	558.5**	80.40**	0.1239NS	0.0180NS	2631676**
Year*Treatment	2	12005.8**	7472.9**	274.61**	0.7772**	0.0155NS	6609754**

*Significant changes are highlighted by an asterisk (*); *P ≤ 0.05, **P ≤ 0.01; ns: non-significant; KE: Kernels per ear; TKW: Thousand Kernel Weight (g); Pn: Net Photosynthetic Rate (µmole m^{-2} s^{-1}); Pro: Kernel Protein Content percentage (%); Oil: Kernel Oil Content percentage (%); GY: Grain Yield per hater (kg ha^{-1})*

maize hybrids for kernel yield and associated parameters under normal and stress conditions (Table 1). A high genetic divergence among maize hybrids was observed that allow suitable hybrids selection under normal and high temperature stress conditions. Similar results were reported by Saeed *et al.* (2018), Yousaf *et al.* (2018) and Shehzad *et al.* 2019, which revealed the presence of significant variations among maize hybrids under high temperature stress conditions. Among nine maize hybrids, two local maize hybrids YH-5507 and YH-5427 produced high kernel yield under both normal and high temperature stress conditions (Figure 2). NK-8711, P-1543 and DK-6724 had higher kernel yield under normal sowing conditions, but produce lower kernel yield under high temperature stress conditions. However, the interaction between hybrids and treatments (sowing conditions) for quality traits *i.e.*, kernel protein content percentage and kernel oil content percentage were non-significant. Similarly, Hybrid vs Year interaction for kernel protein content percentage and Year vs Treatment interaction for kernel oil content percentage were also non-significant. Yousaf *et al.* (2018) and Khalid *et al.* (2020) also reported the significance of locally developed maize hybrids for high temperature stress tolerance and showed that maize hybrids developed from heat tolerant/adaptive inbred lines were comparatively more productive than imported, exotic hybrids under high temperature stress conditions.

Correlation coefficient analysis for the nine stress indices and kernel yield under normal and high temperature stress conditions in nine maize hybrids

Selection for the best and most effective stress related indices as the selection criterion to discriminate desirable hybrids was determined through correlation

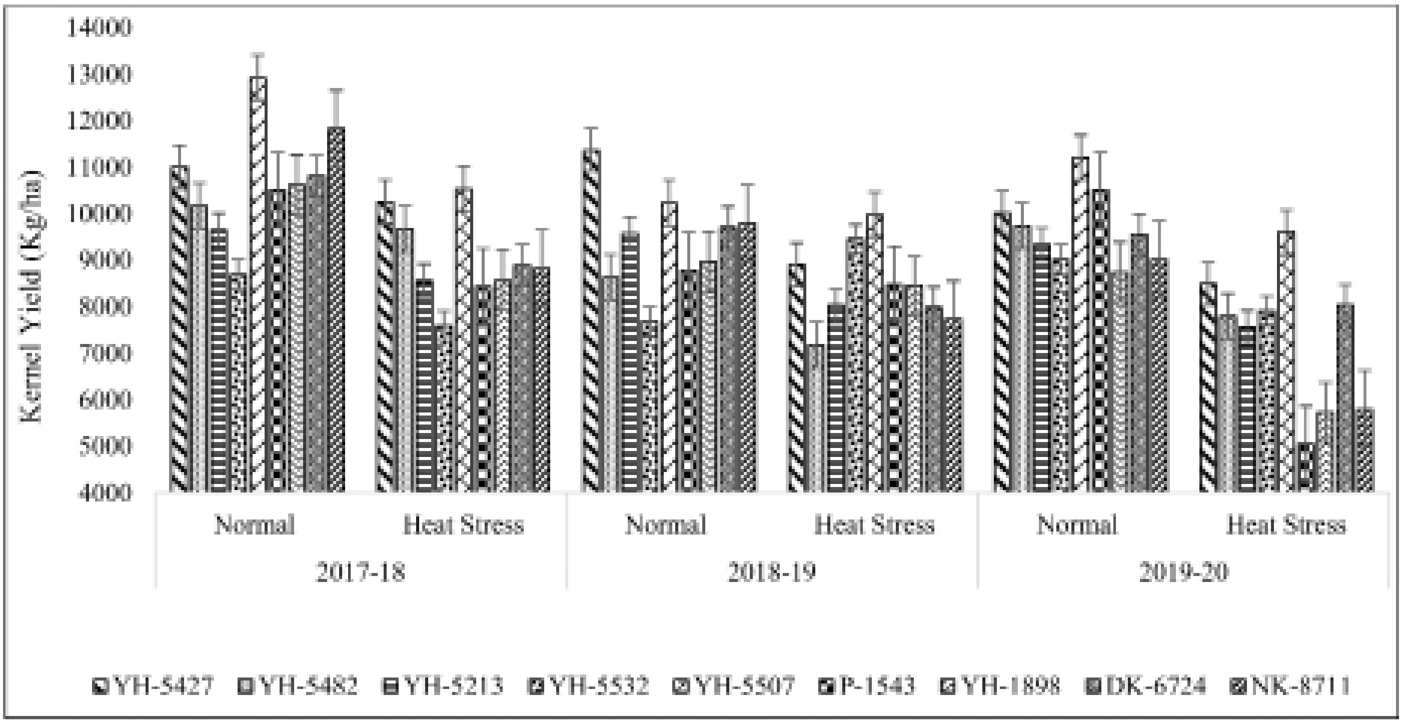

Figure 2: *Three year's averages of kernel yield of corn hybrids under normal and high temperature stress conditions.*

coefficients analysis between nine different stress tolerance indices of kernel yield under normal (*Yp*) and high temperature stress conditions (*Ys*) for three spring seasons (Table 2). Correlation coefficient analysis revealed that *Yp* had a significantly positive correlation with STI (0.934*, 0.794* and 0.664), MP (0.947, 0.802 and 0.725), GMP (0.936*, 0.792* and 0.639) and HARM (0.924*, 0.781* and 0.565) for three spring seasons, 2017-18, 2018-19 and 2019-20, respectively (Table 2). Similarly, *Ys* was found to be positively related to STI (0.921*, 0.697* and 0.955*), MP (0.910*, 0.689* and 0.930*), GMP (0.923*, 0.700* and 967*), HARM (0.935*, 0.710* and 0.967*) and YI (1.000*, 1.000* and 1.000*) (Table 2). Four stress indices *i.e.* STI, MP, GMP and HARM proved their worth in identification of superior and productive hybrids under optimal and stress conditions. These indices were the most appropriate indices for the selection of highly productive and stress tolerant maize hybrids because of their significant positive correlation with kernel yield. Similar findings were also described by Khodarahmpour *et al.* (2011) and Moradi *et al.* (2012) in maize. Kamrani *et al.* (2018) suggested that high yielding and heat tolerant hybrids could be designated on the basis of STI, MP, GMP and HARMS.

It was also observed that correlation between Yp and Ys was also positive for under all three seasons but was significant only under spring-2017 suggesting that high yielding maize hybrids could be selected on the basis of their kernel yield under both conditions as shown by Zhao *et al.* (2019). It further suggested that indirect selection of heat tolerant maize hybrids could be done in accordance with the results found under normal condition. Aghaei-Sarbarze *et al.* (2009) also showed hybrids with higher kernel yield also had good heat tolerance under stress condition.

Phenotypes for the nine stress tolerance indices and kernel yield under normal and high temperature stress conditions in nine maize hybrids

Kernel yield was used to calculate heat tolerance indices in nine maize hybrids under normal and high temperature stress (Table 3). Maize hybrids *i.e.*, NK-8711, P-1543 and YH-1898 had highest value for TOL and SSI in three seasons especially in Spring-2017 and Spring-2019, respectively. All these hybrids had high kernel yield under normal condition while low yields under high temperature stress and thus, were selected as stress susceptible hybrids. The average lowermost value of tolerance index for three seasons was observed in YH-5482 and YH-5532, which depict their lower yield under both conditions due to low differences in their kernel yield under both conditions. Similar findings were reported by Khodarahmpour *et al.* (2011) and Zhao *et al.* (2019) who showed a strong negative correlation of TOL with Y*s*. It is reported that low TOL value is correlated with lower susceptibility to high temperature stress and selection based on TOL will potentially lead to the

Table 2: *Correlation between different stress indices in corn hybrids for three consecutive spring seasons (Spring 2017, 2018 and 2019).*

Variables		STI	SSI	TOL	MP	GMP	HARM	GOL	YSI	YI	Yp
SSI	r_{2017}	0.119									
	r_{2018}	0.112									
	r_{2019}	-0.753									
TOL	r_{2017}	0.319	0.978								
	r_{2018}	0.180	0.990								
	r_{2019}	-0.658	0.987								
MP	r_{2017}	0.997	0.152	0.350							
	r_{2018}	0.999	0.120	0.192							
	r_{2019}	0.994	-0.704	-0.596							
GMP	r_{2017}	0.998	0.121	0.320	0.999						
	r_{2018}	0.999	0.108	0.176	0.999						
	r_{2019}	0.998	-0.781	-0.686	0.993						
HARM	r_{2017}	0.998	0.090	0.289	0.998	0.999					
	r_{2018}	0.999	0.096	0.160	0.997	0.999					
	r_{2019}	0.991	-0.833	-0.749	0.977	0.996					
GOL	r_{2017}	0.029	-0.910	-0.850	0.015	0.041	0.068				
	r_{2018}	0.436	-0.061	-0.132	0.402	0.433	0.463				
	r_{2019}	0.773	-0.938	-0.891	0.746	0.798	0.831				
YSI	r_{2017}	-0.119	-1.000	-0.978	-0.152	-0.121	-0.090	0.910			
	r_{2018}	-0.112	-1.000	-0.990	-0.120	-0.108	-0.096	0.061			
	r_{2019}	0.753	-1.000	-0.987	0.704	0.781	0.833	0.938			
YI	r_{2017}	0.921	-0.270	-0.070	0.910	0.923	0.935	0.392	0.270		
	r_{2018}	0.697	-0.631	-0.579	0.689	0.700	0.710	0.431	0.631		
	r_{2019}	0.955	-0.914	-0.849	0.930	0.967	0.986	0.898	0.914		
Yn	r_{2017}	0.934	0.462	0.632	0.947	0.936	0.924	-0.280	-0.462	0.729	
	r_{2018}	0.794	0.685	0.740	0.802	0.792	0.781	0.195	-0.685	0.120	
	r_{2019}	0.664	-0.024	0.121	0.725	0.639	0.565	0.158	0.024	0.422	
Ys	r_{2017}	0.921	-0.270	-0.070	0.910	0.923	0.935	0.392	0.270	1.000	0.729
	r_{2018}	0.697	-0.631	-0.579	0.689	0.700	0.710	0.431	0.631	1.000	0.120
	r_{2019}	0.955	-0.914	-0.849	0.930	0.967	0.986	0.898	0.914	1.000	0.422

Significant Correlation values are highlighted as Bold at P ≤ 0.05, STI: Stress Tolerance Index; SSI: Stress Susceptibility Index; TOL: Stress Tolerance; MP: Mean productivity index; GMP: Geometric mean productivity index; HARM: Harmonic mean productivity index; GOL: Golden mean; YI: Yield index; YSI: Yield stability index, Yp: Kernel yield under normal conditions; Ys: Kernel yield under high temperature stress conditions

development of highly productive genotypes under high temperature stress conditions (Rosielle and Hamblin, 1981). According to STI, two local maize hybrids YH-5507 and YH-5427 were revealed as heat tolerant hybrids and produced highest kernel yields under both conditions. Therefore, STI was able to identify high yielding maize hybrids under high temperature stress conditions. As SSI characterize maize hybrids as heat resilient according to the higher kernel yield under both conditions while TOL characterize maize hybrids as heat tolerant on the basis of lower kernel yield under both sowing conditions. Therefore, it is better to select heat tolerant maize hybrids according to STI rather than TOL. Similar findings were obtained by Zhao *et al*. (2019) who revealed that STI is better index to identify heat tolerant maize hybrids rather than TOL.

The maximum values of MP, GMP and HARM were observed for YH-5507, YH-5427 and DK-6724. These hybrids were identified as the most stable and stress tolerant hybrids under both conditions. Moreover,

Table 3: *Values of different stress indices in corn hybrids for three consecutive spring seasons (Spring 2017, 2018 and 2019).*

Sr. #	Hybrids	STI	SSI	TOL	MP	GMP	HARM	GOL	YSI	YI
Mean values for different high temperature stress indices (Spring, 2017-18)										
1	YH-5427	0.99	0.44	747	10630	10623	10616	28.5	0.93	1.13
2	YH-5482	0.86	0.31	494	9925	9922	9919	40.2	0.95	1.07
3	YH-5213	0.72	0.73	1089	9109	9092	9076	16.7	0.89	0.95
4	YH-5532	0.58	0.82	1106	8142	8123	8104	14.7	0.87	0.84
5	YH-5507	1.19	1.20	2389	11730	11669	11608	9.8	0.82	1.17
6	P-1543	0.78	1.28	2078	9474	9417	9360	9.1	0.80	0.93
7	YH-1898	0.80	1.25	2045	9602	9547	9493	9.4	0.81	0.95
8	DK-6724	0.84	1.15	1921	9858	9811	9764	10.3	0.82	0.98
9	NK-8711	0.91	1.64	3001	10330	10221	10112	6.9	0.75	0.98
Mean values for different high temperature stress indices (Spring, 2018-19)										
1	YH-5427	1.14	2.15	2465	10139	10063	9989	8.2	0.78	1.05
2	YH-5482	0.70	1.67	1456	7909	7875	7842	10.9	0.83	0.85
3	YH-5213	0.87	1.60	1551	8799	8764	8730	11.3	0.84	0.95
4	YH-5532	0.82	2.29	1776	8572	8526	8480	9.7	1.23	1.12
5	YH-5507	1.15	0.24	852	10108	10107	10106	80.2	0.98	1.18
6	P-1543	0.84	0.35	607	8629	8627	8626	56.2	0.97	1.00
7	YH-1898	0.85	0.57	918	8709	8705	8701	33.6	0.94	1.00
8	DK-6724	0.87	1.76	1730	8847	8805	8762	10.2	0.82	0.94
9	NK-8711	0.86	2.08	2062	8771	8710	8650	8.5	0.79	0.91
Mean values for different high temperature stress indices (Spring, 2019-20)										
1	YH-5427	0.91	0.63	1527	9265	9233	9202	12.1	0.85	1.16
2	YH-5482	0.81	0.82	1945	8765	8710	8657	9.0	0.80	1.06
3	YH-5213	0.75	0.79	1781	8455	8407	8361	9.5	0.81	1.03
4	YH-5532	0.76	0.51	1110	8468	8450	8432	15.3	0.88	1.08
5	YH-5507	1.15	0.59	1606	10405	10374	10343	13.0	0.86	1.31
6	P-1543	0.57	2.14	5451	7781	7288	6826	2.9	0.48	0.69
7	YH-1898	0.53	1.42	3005	7241	7083	6929	4.8	0.66	0.78
8	DK-6724	0.82	0.66	1520	8792	8759	8726	11.6	0.84	1.10
9	NK-8711	0.56	1.47	3215	7414	7237	7065	4.6	0.64	0.79

STI: Stress Tolerance Index; SSI: Stress Susceptibility Index; TOL: Stress Tolerance; MP: Mean productivity index; GMP: Geometric mean productivity index; HARM: Harmonic mean productivity index; GOL: Golden mean; YI: Yield index; YSI: Yield stability index

correlation analysis also depicted a strong positive correlation of these indices with kernel yield (Table 2). Another stress index, YSI was found to be positively correlated with kernel yield under high temperature stress conditions (0.270, 0.631 and 0.914*). However, this correlation was significantly negative under normal conditions (-0.462, -0.685* and 0.024). Therefore, YSI is a very valuable index to differentiate heat tolerant hybrids from heat vulnerable hybrids (Mohammadi *et al*., 2010). Nouri *et al*. (2011) also reported the usefulness of YSI index for discriminating maize hybrids in selection of highly stable and less susceptible to high temperature stress conditions.

Biplot analysis for the nine screening indices and kernel yield under normal and stress conditions in nine maize hybrids

Three-dimensional PC1/PC2 biplot graphs were computed between maize hybrids and heat related indices for three sowing seasons to characterize maize hybrids on the basis of kernel yield performance (Figure 3 and 4). In first biplot (Season-2017), which account for 98% of total variation, four hybrids viz., YH-5507, YH-5427, YH-5482 and DK-6724 were included in the Group A, comprised of highly productive and stable maize hybrids under normal and stress conditions (Figure 3). However, YH-5532 and YH-5213

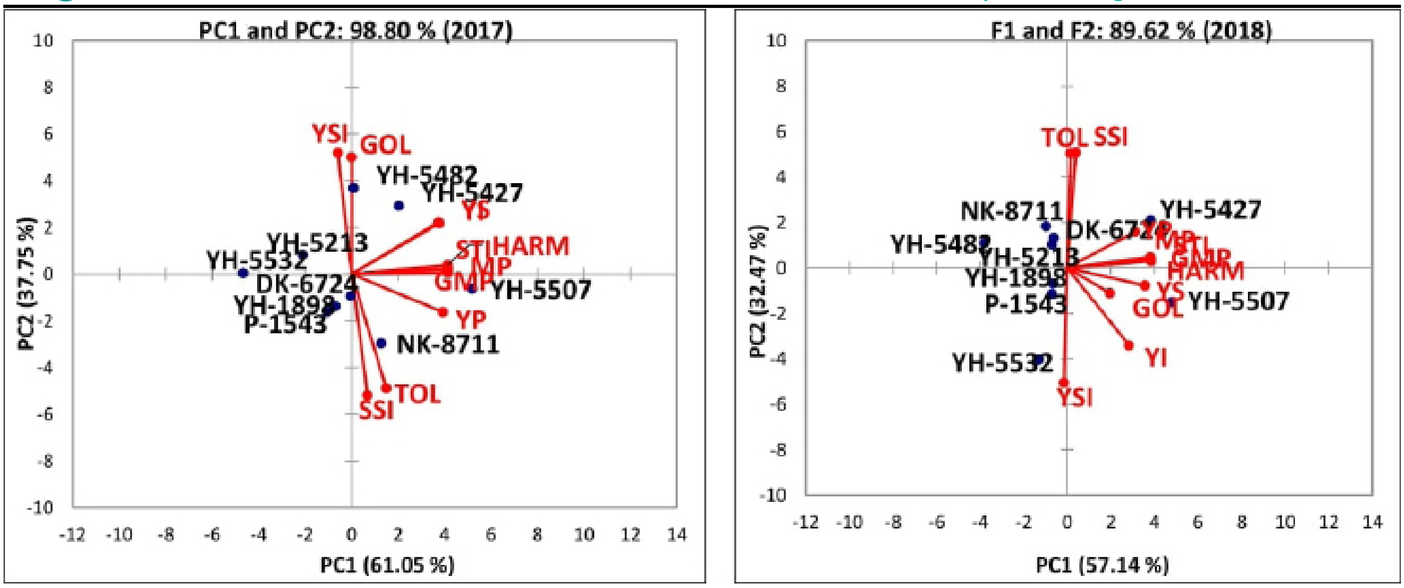

Figure 3: *PC-1 and PC-2 biplot of stress tolerance indices for the year 2017 and 2018.*

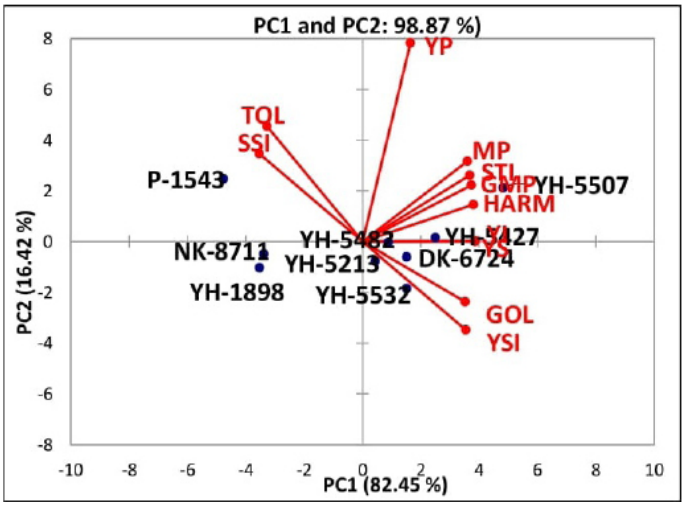

Figure 4: *PC-1 and PC-2 biplot stress tolerance indices for the year 2019.*

were included in the Group D due to their poor performance under both conditions. In second biplot (Season-2018), which account for 89% of total variations, two local maize hybrids YH-5507 and YH-5427 showed the highest productivity and stability while YH-5532, P-1543 and YH-1898 were among the least productive hybrids (Figure 3). Similarly, in the last biplot (Season-2019), which account for 89% of total variation, again YH-5507 and YH-5427 were the highest yielding, stable hybrids but NK-8711, YH-1898 and P-1543 were the least productive hybrids under normal and stress conditions (Figure 4). Conclusively, YH-5507 and YH-5427 were proved to be the most productive, heat tolerant and stable hybrids under optimal and stress conditions because of having higher PC1 values and lower PC2 values as suggested by Zhao *et al.* (2019). Similarly, YH-5532, YH-5213 and NK-8711 were the least productive and heat susceptible hybrids under both conditions having lower PC1 and higher PC2 values. Y*s* had a strong negative correlation with SSI and TOL, as indicated by obtuse angle between their vectors. Many researchers showed a significantly positive correlation between Y*p* and Y*s*, which suggest that high yielding genotypes under optimum conditions are also expected to perform well under high temperature stress (Dorostkar *et al*., 2015; Grzesiak *et al*., 2019; Sedri *et al*., 2019).

Conclusions and Recommendations

High temperature stress is the key factor in abiotic stresses that significantly reduces maize yield especially in heat prone areas of the World. In any breeding program, which aimed to develop heat resilient maize genotypes/hybrids, selection of parents must be founded upon the stress indices, estimated from kernel yield under optimal and stress conditions. In the current study, results revealed a significantly positive association of Y*p* and Y*s* with STI, MP, GMP and HARM. Thus, these indices are the most suitable indices for the selection of hybrids having high kernel yield under both normal and high temperature stress conditions. Maize hybrids i.e., YH-5507 and YH-5427 were the highest yielding and heat tolerant hybrids, therefore should be used in varietal improvement programs aimed to develop stress tolerant genotypes for stress affected areas.

Novelty Statement

This Three-year study is one on its own kind conducted in field conditions to check the tolerance of indigenous and exotic maize hybrids in core maize growing area of Pakistan. This research will be very helpful in selecting the maize hybrids for heat prone areas.

Author's Contribution

MIY, KH, SH, DH, AG, AM, MHB, MAM and MA: Got the idea, managed overall article development, collected observed data.
MUK, AM, SAK and MAS: Gave specialized support, facilitated the experimental work provided supervisory help at every phase of research.
MIY, MAM and AM: Organized write-up and performed data analysis as well as offered technical writing assistance.

Conflict of Interest

The authors have no conflict of interests regarding the publication of this article in Pakistan Journal of Agricultural Research.

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