Received: 18 Oct 2020 | Revised: 01 Jun 2021 | Accepted: 14 Jun 2021

Electronic Journal of Plant Breeding

Research Note

Performance of maize (*Zea mays* L.) hybrids and association of morpho-physiological traits with grain yield under heat stress and optimal conditions

N. Pavani[1*], P. H. Kuchanur[1], Ayyanagouda Patil[2], B. Arunkumar[1] and P. H. Zaidi[3], M. T. Vinayan[3] and K. Seetharam[3]

[1]Department of Genetics and Plant Breeding, University of Agricultural Sciences, Raichur-584104, Karnataka
[2]Department of Molecular Biology and Agriculture Biotechnology, University of Agricultural Sciences, Raichur-584104, Karnataka.
[3]International Maize and Wheat Improvement Centre (CIMMYT)-Asia, c/o ICRISAT, Patancheru, Hyderabad-502324, Telangana.
***E-Mail:** pavaninalla9@gmail.com

Abstract
Incessant rise in ambient temperature is threatening the sustainability of maize productions, worldwide. Heat stress resilience has emerged as an important trait in maize hybrids. Twelve maize hybrids along with five commercial checks were evaluated for their yielding ability and to know the association of grain yield with its component traits under heat stress and optimal conditions. *Per se* performance indicated that RCRMH 10 for days to 50 per cent anthesis, RCRMH 11 for days to 50 per cent silking, RCRMH 3 and RCRMH 2 for test weight and P3436, RCRMH 4 and RCRMH 2 for grain yield per hectare, were found superior across environments. The association between grain yield per plant and days to 50 per cent anthesis, days to 50 per cent silking and anthesis to silking interval were significantly negative, while, positively significant with chlorophyll content (SPAD) at 55 DAS and number of leaves per plant at the genotypic level under heat stress and optimal conditions.

Key words: Resilience, Heat stress, Association, *Per se* performance and optimal condition

Maize (*Zea mays* L.) is the world's most extensively grown cereal and is the principal staple food in many developing countries. Even though it is adapted to a wide range of environments but, essentially a crop of the warm environment. The production process of maize is highly dependent on prevailing weather conditions. However, reduction in the availability and quality of arable land and water resources, as well as frequent extreme weather conditions can cause many different types of abiotic stresses, such as salinity, drought and extreme temperatures (heat, cold and freezing) (Krasensky and Jonak, 2012). These stresses may be responsible for a yield reduction of over 50% in major crop plants globally (De Zelicourt *et al*., 2016). Higher environmental temperatures negatively affect the maize crop most at anthesis, silking and grain filling reproductive phenophases. Selection based on grain yield alone under heat stress is often misleading, and therefore an approach involving stress-adaptive secondary traits along with grain yield could help in the development of improved, and stable heat stress tolerant cultivars (Noor *et al*., 2019). Plants with severe leaf firing and tassel blasting lose considerable photosynthetic leaf area, produce small ears, and show reduced kernel set and kernel weight. Moderate heat stress occurring at early reproductive stages reduces pollen production, pollination rate, kernel set and kernel weight, resulting in significant yield loss (Chen *et al*., 2012). It is reported that heat tolerant genotypes are likely to tolerate combined drought and heat stress conditions (Tandzi *et al*., 2019) and hence it is important to identify/select maize hybrids that are tolerant to heat stress and also perform better during the rainy season. Grain yield is a complex trait and is collectively influenced by various component characters, besides polygenically inherited and influenced by environmental variation. The correlation studies measure the associations between yield and other traits. For the development and selection of inbred lines for heat stress in tropical maize, information on secondary traits associated with grain yield under heat stress would play a pivotal role. Therefore, the present investigation was carried out to determine the association of traits with grain yield through correlation coefficient under heat stress conditions in tropical maize, besides identifying hybrids tolerant to heat stress with good performance under normal rainy season.

The experimental material consisted of 10 single cross hybrids, two three-way hybrids developed in collaboration with CIMMYT-Asia Regional Programme, ICRISAT campus, Patancheru, Hyderabad under Heat Tolerant Maize for South Asia through public private partnership (HTMA) project and five commercial hybrids as checks (**Table 1**). The evaluation of maize hybrids was carried out at Main Agricultural Research Station, Raichur (Karnataka) situated at 16° 15' N latitude and 77° 20' E longitude with an altitude of 389 m above mean sea level, during the 2018 summer and *Kharif* seasons. The experiments were conducted in randomized block design with three replications for each season. Each replicated entry had a plot size of four rows of 4 m length. The genotypes were planted with a spacing of 60 cm between rows and 20 cm between plants. After thorough land preparation, furrows were opened and seeds were hand dibbled at the rate of two seeds per hill and later (10 days after sowing) thinned to retain one seedling per hill.

Table 1. List of drought stress tolerant hybrids and checks used for stability analysis

S. No.	Hybrids	Duration	Remarks
1	BGMH-1	Medium	Tolerant to drought
2	BGMH-2	Medium	Tolerant to drought
3	RCRMH-3	Medium	Tolerant to heat
4	RCRMH-4	Medium	Tolerant to drought
5	RCRMH-5	Medium	Tolerant to drought
6	RCRMH-6	Medium	Tolerant to drought
7	RCRMH-9	Medium	Tolerant to heat
8	RCRMH-10	Early	Three way hybrid, tolerant to heat
9	RCRMH-11	Early	Three way hybrid, tolerant to heat
10	RCRMH-12	Medium	Tolerant to drought
11	RCRMH-13	Medium	Tolerant to heat
12	RCRMH-14	Medium	Tolerant to heat
	Checks		
1	900MG	Late	High yielding hybrid from Monsanto Ltd
2	NK6240	Late	High yielding hybrid from Syngenta Ltd
3	P3436	Medium	A drought tolerant hybrid from Pioneer Ltd
4	P3550	Medium	A drought and heat tolerant hybrid from Pioneer Ltd
5	RCRMH-2	Medium	A heat tolerant hybrid released by UAS, Raichur

Table 2. Meteorological data recorded during the cropping period (2018) at MARS, Raichur.

Main Agricultural Research Station, Raichur				
Months	Temperature (°C)		Rainfall (mm)	Relative humidity (%)
	Max (°C)	Min (°C)		
March	37.1	22.9	0.0	41.9
April	39.1	26.5	4.4	42.2
May	39.3	27.5	14.2	49.1
June	35.6	25.1	8.8	60.1
July	35.5	23.9	31.6	67.0
August	32.5	23.2	52.5	70.8
September	33.5	23.2	77.1	65.0
October	33.4	21.6	27.5	58.6
November	32.2	19.8	0.0	51.4
December	30.4	18.5	0.0	62.1

The recommended agronomic practices were adopted timely to raise a healthy crop in each season. The weather parameters recorded at the experimental site indicated that the experiment conducted during summer was under heat stress as the T_{max} and T_{min} recorded were above the values prescribed for the optimal growth of maize (**Table 2**).

During the course of an investigation, observations were recorded on the following traits *viz.,* plant height, ear height, the number of grains per cob on randomly selected five plants. Characters, days to 50% anthesis, days 50% silk emergence and grain yield at 12.5% moisture per plot were recorded on a plot basis. Test weight was measured by counting 100 grains from the bulk of each plot after shelling and weighed in grams at 12.5% moisture. Anthesis to silking interval (ASI) was calculated by subtracting the number of days taken for 50% anthesis from the number of days taken to 50% silk emergence. Grain yield per plant (g) was calculated by dividing the grain yield per plot by a total number of plants in the plot - Soil Plant Analyses Development (SPAD), Normalized Difference Vegetation Index (NDVI), Relative water content (RWC), the number of leaves (NL) were recorded on five randomly selected plants from each entry from the three replications. The mean data of five plants were computed and statistically analysed using Windostat 9.2. The phenotypic and genotypic correlation coefficients for grain yield and its related characters were calculated as per the method suggested by Al-Jibouri *et al.* (1958).

The mean performance of 12 hybrids and five checks along with the general mean for 12 characters are presented in **Tables 3 and 4**. Among the hybrids evaluated, hybrid RCRMH-10 was found early for days to 50 per cent anthesis (48.33) and days to 50 per cent silking (59.24). While, BGMH-2 and NK6240 were found late for 50 per cent anthesis (62.67) and days to 50 per cent silking (61.22), respectively, under heat stress. Hybrid, RCRMH-4 and NK6240, respectively, recorded minimum (1.00 days) and maximum (4.33 days) days for anthesis to the silking interval**.** Hybrid, RCRMH-12 recorded maximum plant height (155.66 cm). Previously, Divya (2018) identified three hybrids *viz.*, ZH16899, ZH16843 and ZH16869 that registered better performance for plant height under heat stress from her study. Among the test entries, hybrid RCRMH-10 (66.33 cm) had an ideal cob height. In a similar study, Divya (2018) identified three hybrids *viz.,* ZH1630, ZH1645 and ZH16902 having the ideal placement of cob from her study under heat stress. The hybrids RCRMH-10 (399.23) recorded the highest number of grains per cob. Whereas, hybrids RCRMH-14 (37.00 g) and BGMH-1 (23.66 g) have recorded maximum and minimum test weight. While hybrid RCRMH-4 (10141.00 kg/ha)recorded maximum yield as compared to other hybrids. This finding is in confirmation with findings of Angadi (2014), who evaluated 11 maize hybrids and reported that under heat stress, grains per cob ranged from 234 (DMH-117) to 454.66 (DKC-9135) with an overall mean of 322.93. Whereas, grain yield ranged from 2529.44 kg/ ha (Arjun) to 9376.80 kg/ ha (GK-3059) with an overall mean of 5395.68 kg/ ha.

Table 3. ***Per se*** **performance of hybrids for days to 50 per cent anthesis, days to 50 per silking and anthesis to silking interval under heat stress and optimal condition**

Hybrids/ Checks	Days to 50 per cent anthesis			Days to 50 per cent silking			Anthesis to silking interval (days)		
	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean
BGMH-1	57.67	54.00	55.83	61.19	56.70	58.94	4.00	2.67	3.33
BGMH-2	62.67	53.67	58.17	61.11	57.30	59.20	2.67	3.67	3.17
RCRMH-3	60.00	53.00	56.50	60.19	57.00	58.59	2.00	4.00	3.00
RCRMH-4	61.33	54.67	58.00	60.07	56.70	58.38	0.00	2.00	1.00
RCRMH-5	60.00	54.00	57.00	59.98	56.30	58.14	2.33	2.33	2.33
RCRMH-6	56.33	53.33	54.83	59.79	57.00	58.39	5.00	3.67	4.33
RCRMH-9	60.67	53.67	57.17	59.67	56.30	57.98	3.67	2.67	3.17
RCRMH-10#	48.33	50.00	49.16	59.24	51.70	55.47	2.67	1.67	2.17
RCRMH-11#	*	50.00	50.00	*	51.00	51.00	*	1.00	1.00
RCRMH-12	51.33	53.33	52.33	60.07	55.70	57.88	3.00	2.33	2.66
RCRMH-13	59.67	53.67	56.67	60.70	56.70	58.70	2.33	3.00	2.66
RCRMH-14	53.67	50.33	52.00	60.54	52.00	56.27	2.33	1.67	2.00
Checks									
900MG	56.67	53.00	54.83	60.58	56.30	58.44	2.00	3.33	2.66
NK6240	59.67	51.33	55.50	61.22	53.30	57.26	4.33	2.00	3.16
P3436	59.00	52.33	55.66	59.83	55.70	57.76	3.00	3.33	3.16
P3550	55.33	53.33	54.33	57.67	55.30	56.48	2.33	2.00	2.16
RCRMH-2	56.67	55.00	55.83	60.27	57.00	58.63	2.33	2.00	2.16
Mean	57.44	52.86		60.13	55.41	57.77	2.75	2.55	
LSD (0.05)	3.36	1.94		3.00	2.23		2.39	1.55	
CV (%)	3.50	2.21		2.99	2.42		52.22	36.65	

* **-** not included for evaluation, **#** - Three-way hybrids

https://doi.org/10.37992/2021.1203.144

4. *Per se* performance of hybrids for morphological traits under heat stress and optimal conditions

Hybrids/ Checks	Plant height (cm)			Cob height(cm)			Number of grains per cob			Test weight (g)			Grain yield (kg/ha)		
	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean	Summer	*Kharif*	Mean
BGMH-1	126.66	156	141.33	69.66	92	80.83	381.4	503.4	442.4	23.66	29.33	26.49	7214.2	6005.2	6609.7
BGMH-2	139	148.33	143.66	74.33	94.66	84.49	297.41	447.06	372.23	32.66	35.66	34.16	7518.2	6623.7	7070.9
RCRMH-3	150.33	181	165.66	78.33	109	93.66	289.46	369	329.23	34.66	40.33	37.49	8850.2	7047.2	7948.7
RCRMH-4	134	181	157.5	71.33	97.33	84.33	305.86	448.66	377.26	34.66	35	34.83	10041	8588.6	9314.6
RCRMH-5	130	169	149.5	74	102.66	88.33	383.4	571.26	477.33	24.33	26.66	25.49	7712.7	7042.7	7377.7
RCRMH-6	111.66	172	141.83	68.33	104.33	86.33	389.83	650.93	520.38	27.33	35	31.16	8036.5	9553.6	8795
RCRMH-9	130.66	162.33	146.49	67.33	95	81.16	290.51	475.91	383.21	32.66	35	33.83	5237.9	7024.5	6131.2
RCRMH-10#	121.66	160.33	140.99	66.33	81	73.66	399.23	517.86	458.54	32.33	36.33	34.33	6949.4	7756.2	7352.8
RCRMH-11#	*	158	158	*	90	90	*	466.67	466.67	*	33.33	33.33	*	7213.7	7213.7
RCRMH-12	155.66	189.66	172.66	78.66	117	97.83	343.73	517.4	430.56	29.33	31	30.16	8024.8	9760.7	8892.8
RCRMH-13	140	181.66	160.83	74.33	99.66	86.99	322.13	595.26	458.69	29	26.33	27.66	7968.5	7364.5	7666.5
RCRMH-14	120	170.33	145.16	67.66	99.33	83.49	280.76	421.6	351.18	36	37	36.5	7793.6	8790.7	8292.1
Checks															
900MG	129.33	173.66	151.49	72	103	87.5	332.8	581.73	457.26	29	32	30.5	8624.6	9425.7	9025.2
NK6240	163.46	168	165.73	86.33	94.33	90.33	299.26	478.86	389.06	31.66	38	34.83	7237.9	7808.2	7523
P3436	153.66	173.66	163.66	78.66	100	89.33	288.13	431.53	359.83	31.66	35	33.33	9601.8	9484.6	9543.2
P3550	115.66	200.66	158.16	50.86	135.66	93.26	273.46	493.26	383.36	30.33	39.33	34.83	8526.6	9790.3	9158.5
RCRMH-2	144.33	186	165.16	73.66	110.33	91.99	322.56	446	384.28	35.33	39.33	37.33	8642.3	9678.3	9160.3
Mean	135.38	172		71.99	101		325	495.09		30.91	34.39		7998.7	8174.1	
LSD (0.05)	16.595	24.40		8.87	23.14		92.77	95.51		4.109	6.36		1295.07	2378.10	
CV (%)	7.351	8.12		7.39	13.71		17.11	11.60		7.970	11.12		9.92	17.32	

* - not included for evaluation, **#** - Three-way hybrids

Under the optimal conditions hybrids evaluated across environments, the hybrids *viz.*, RCRMH-10 (50.00) and RCRMH-11 (50.00) were found early and RCRMH-2 (55.00) was late for days to 50 per cent anthesis. Whereas RCRMH-11 (51.00) and RCRMH-10 (51.70) were found early and BGMH-2 (57.30) was late for days to 50 per cent silking. The hybrids RCRMH-11 (1.00) and RCRMH-3 (4.00), respectively, recorded minimum and maximum days for anthesis to the silking interval**.** The hybrids P3550 (200.60 cm) and RCRMH-12 (189.66 cm) recorded maximum plant height. Whereas, hybrid RCRMH-10 (81 cm) had ideal cob height. The hybrid RCRMH-6 (650.93) registered the highest number of grains per cob. The hybrids*,* RCRMH-3 (40.33 g) and RCRMH-13 (26.33 g), respectively had maximum and minimum test weight. The hybrid P3550 (9790.3 kg/ ha) followed by RCRMH 2 (9678.3) recorded maximum yield as compared to other hybrids. In a similar investigation, Angadi (2014) reported maize hybrids with the lowest (Arjun) and the highest (900M-G) number of grains per cob with an overall mean of 453.80 under optimal conditions.

Among the hybrids evaluated across the environments, hybrid RCRMH-10 (49.16) and BGMH-2 (58.17) was found early and late for days to 50 per cent anthesis. While hybrid RCRMH-11 (51.00) and BGMH-2 (59.20) was found early and late for days to 50 per cent silking. The hybrids, RCRMH-11 and RCRMH-4 (1.00 day) and BGMH-1 (3.33) recorded minimum and maximum days for anthesis to the silking interval, respectively. RCRMH-12 (172.66 cm) recorded a maximum plant height. Among the test entries, hybrid RCRMH-10 (73.66 cm) had an ideal cob height. The hybrid RCRMH-6 (520.38) recorded the highest number of grains per cob. The hybrids *viz.*, RCRMH-3 (37.49 g) and RCRMH-2 (37.33 g) were having maximum test weight, while RCRMH-5 (25.49 g) was found with least 100 grain weight. The hybrids *viz.*, P3436 (9543.17 kg/ha), RCRMH-4 (9314.61 kg/ ha), RCRMH-2 (9160.28 kg/ ha) and P3550 (9158.46 kg/ ha) recorded maximum yield and found desirable as compared to other hybrids in the present study.

In general, the magnitudes of genotypic correlation coefficients were greater than the phenotypic correlation coefficients indicating the importance of genotypic differences in determining the associations. The correlation coefficient between grain yield per plant and days to 50 per cent anthesis (-0.422), days to 50 per cent silking (-0.351), anthesis to silking interval (-0.422) were significantly negative at the genotypic level under heat stress conditions indicating undesirable association (**Table 5**). However, previously, Jodage *et al.* (2017) reported a negative association between grain yield per plant and anthesis to the silking interval at the phenotypic level. Thus, a lesser interval between anthesis and silking interval results in higher yields per plant under heat stress. Plant height registered a highly significant positive correlation at both the levels with grain yield as

Table 5. Phenotypic and genotypic correlation between grain yield and morpho-physiological traits under heat stress

		AD	SD	ASI	PH	CL	CG	TW	SP	SPAD @55 days	SPAD @82 days	NDVI @55 days	NDVI @82 days	NL	GYPP
AD	P	**1.000**	0.919**	-0.177	0.260	-0.009	-0.208	0.006	0.110	0.074	-0.210	0.275	-0.044	0.489**	-0.181
	G	**1.000**	0.976**	0.070	0.302*	0.079	-0.639**	-0.005	0.708**	0.092	-0.170	0.467**	0.098	0.707**	-0.422**
SD	P		**1.000**	0.223	0.255	-0.008	-0.037	-0.098	0.111	0.033	-0.175	0.215	-0.066	0.560**	-0.256
	G		**1.000**	0.292*	0.310*	0.013	-0.375**	-0.180	0.569**	0.080	-0.123	0.596**	-0.044	0.708**	-0.351*
ASI	P			**1.000**	-0.005	0.002	0.422**	-0.264	0.005	-0.101	0.082	-0.144	-0.056	0.190	-0.192
	G			**1.000**	0.091	-0.280	0.658**	-0.779**	-0.492**	-0.0384	0.176	0.661**	-0.621**	0.134	-0.422**
PH	P				**1.000**	0.045	-0.128	0.185	-0.044	0.154	0.141	0.281	0.651*	0.426**	0.332*
	G				**1.000**	0.328*	0.341*	0.265	0.117	0.506**	0.341*	0.868**	0.904**	0.497**	0.450**
CL	P					**1.000**	-0.079	0.315*	-0.325*	0.459**	0.181	-0.040	0.251	0.143	0.226
	G					**1.000**	-0.409**	0.433**	-0.584**	0.247	0.065	0.093	0.399**	0.385**	0.288*
CG	P						**1.000**	0.025	-0.041	-0.102	0.015	0.100	0.126	-0.116	0.031
	G						**1.000**	-0.109	0.024	-0.117	0.802**	0.184	0.449**	-0.153	0.363*
TW	P							**1.000**	-0.236	-0.048	0.129	0.103	0.356*	0.038	0.118
	G							**1.000**	-0.603**	0.368**	0.278	0.468**	0.871**	0.022	0.192
SP	P								**1.000**	-0.101	0.148	0.112	-0.053	0.021	0.121
	G								**1.000**	-0.691**	-0.618**	0.046	0.871**	0.022	0.118
SPAD @55 days	P									**1.000**	0.443**	0.103	0.162	0.094	0.182
	G									**1.000**	0.640**	-0.551**	0.534**	0.505**	0.413**
SPAD @82 days	P										**1.000**	-0.036	0.053	0.001	0.132
	G										**1.000**	-0.796**	0.670**	-0.362**	-0.094
NDVI @55 days	P											**1.000**	0.136	0.211	0.105
	G											**1.000**	0.645**	0.631**	0.307*
NDVI @82 days	P												**1.000**	0.137	0.497**
	G												**1.000**	0.750**	0.173
NL	P													**1.000**	0.151
	G													**1.000**	0.284*

*, ** significant at 0.05 and 0.01 level of probability, respectively.

AD- Days to 50 per cent anthesis; SD- Days to 50 per cent silking; ASI- Anthesis to silking interval; PH- Plant height ; CL- Cob length; CG- Cob girth ; TW- Test weight; SP- Shelling percentage ; GYPP- Grain yield per plant ; GY- Grain yield ; SPAD- Soil Plant Analyses Development; NDVI- Normalized Difference Vegetation Index ; NL- Number of leaves; P- Phenotype; G- Genotype

also reported by Divya (2018). Plants become susceptible to high temperatures after reaching eight-leaf stage**.** Extremely high temperature causes permanent tissue injury to develop leaves and the injured tissues dry out quickly, a phenomenon called leaf firing. Further, under high temperatures, there is a restricted elongation of inter nodes (Hasanuzzaman *et al*., 2013). The association of grain yield per plant was significantly positive with the traits like plant height (0.450), cob length (0.288) and girth (0.363) under heat stress at the genotypic level.

The association of grain yield per plant with chlorophyll content (SPAD) at 55 DAS (0.372, 0.584), SPAD at 82 DAS (0.449, 0.519) and the number of leaves per plant (0.305, 0.767) was significant and positive at both phenotypic and genotypic levels indicating that chlorophyll content and number of leaves per plant would improve grain yield per plant under optimal conditions. The correlation coefficient between grain yield per plant and plant height (0.415 and 0.864), cob length (0.484 and 0.655), shelling percentage (0.317 and 0.843), were significantly positive at both phenotypic and genotypic levels, respectively. While the cob girth (0.464) and test weight (0.480), were significant and positive at the genotypic level indicating the importance of these traits in improving maize yield under optimal conditions (**Table 6**). The observations are in conformity with the findings of Pavan *et al*. (2011) and Angadi *et al*. (2016).

Based on *per se* performance, the hybrids *viz*., RCRMH-10 and RCRMH-11 were identified as early hybrids and RCRMH-3, RCRMH-4 and the check NK6240 were top performing hybrids for test weight across environments. The hybrids RCRMH-4 and P3550, respectively, were found to be superior for yield under heat stress and optimal conditions. Across environments, hybrids *viz*., P3436, RCRMH-4 and RCRMH-2 were identified as the best performers for grain yield per hectare.

Table 6. Phenotypic and genotypic correlation between grain yield and morpho-physiological traits under optimal condition

		AD	SD	ASI	PH	CL	CG	TW	SP	SPAD @55 Days	SPAD @82 Days	NDVI @55 days	NDVI @82 days	NL	RWC @ 48 days	RWC@ 71 days	GYPP
AD	P	**1.000**	0.862**	0.116	-0.054	0.195	-0.176	-0.143	-0.032	-0.151	-0.587**	0.043	0.240	-0.013	0.180	0.067	-0.047
	G	**1.000**	0.974**	0.553**	0.457**	0.391**	-0.822**	-0.363*	-0.898**	-0.301	-0.237	-0.659**	-0.888**	0.105	-0.543**	0.541**	-0.162
SD	P		**1.000**	0.602**	-0.021	0.121	-0.138	-0.121	-0.019	-0.219	-0.060	0.103	0.298*	0.023	0.087	0.031	-0.089
	G		**1.000**	0.736**	0.267	0.284*	-0.873**	-0.376**	-0.157	-0.401**	-0.321*	-0.477**	-0.602**	0.165	-0.240	0.467**	0.467**
ASI	P			**1.000**	0.040	-0.068	0.006	-0.012	0.013	-0.191	-0.026	0.134	0.206	0.066	-0.112	-0.044	-0.101
	G			**1.000**	-0.364*	-0.119	-0.716**	-0.284*	0.908**	-0.549**	-0.449**	-0.823**	-0.581**	0.281	0.704**	0.094	-0.698**
PH	P				**1.000**	0.307**	0.115	0.168	-0.134	0.215	0.373**	0.254	0.195	0.411**	0.145	-0.046	0.415**
	G				**1.000**	0.576**	0.693**	0.197	0.700**	0.455**	0.844**	-0.332*	-0.843**	0.877**	-0.947**	0.004	0.864**
CL	P					**1.000**	0.066	0.264	0.264	0.454**	0.340*	0.136	0.080	0.289*	-0.073	0.037	0.484**
	G					**1.000**	0.589**	-0.004	0.884**	0.576**	0.220	-0.207	-0.365*	0.398**	-0.814**	0.632**	0.655**
CG	P						**1.000**	0.081	0.096	-0.019	0.173	-0.153	-0.017	0.044	0.132	0.215	0.232
	G						**1.000**	0.594**	0.701**	0.351*	0.607**	0.066	-0.687**	0.307*	-0.978**	0.197	0.464**
TW	P							**1.000**	0.097	0.314	0.098	0.148	-0.007	0.335*	-0.066	-0.029	0.292
	G							**1.000**	-0.579**	0.116	-0.205	-0.164	-0.082	0.678**	-0.421**	0.440**	0.480**
SP	P								**1.000**	0.026	0.456**	-0.116	0.026	0.139	-0.056	0.080	0.317*
	G								**1.000**	1.009	-0.742**	0.511**	0.864**	0.814**	0.975**	-0.970**	0.843**
SPAD @55 Days	P									**1.000**	0.456**	-0.116	0.026	0.139	-0.056	0.080	0.372**
	G									**1.000**	0.920**	0.274	0.171	0.426**	0.916**	0.070	0.584**
SPAD @82 days	P										**1.000**	-0.037	0.062	0.048	0.077	-0.189	0.449**
	G										**1.000**	0.448**	-0.393**	0.515**	-0.818**	-0.275	0.519**
NDVI @55 days	P											**1.000**	0.016	0.044	0.074	-0.017	-0.075
	G											**1.000**	-0.330*	-0.936**	-0.818**	0.207	-0.170
NDVI @82 days	P												**1.000**	0.317**	0.250	0.059	-0.035
	G												**1.000**	-0.795**	0.898**	-0.620**	-0.155
NL	P													**1.000**	0.050	0.096**	0.305*
	G													**1.000**	-0.929**	-0.089	0.767**
RWC @48 days	P														**1.000**	0.047	0.197
	G														**1.000**	-0.932**	-0.859**
RWC @71 days	P															**1.000**	-0.202
	G															**1.000**	-0.161

AD- Days to 50 per cent anthesis; SD- Days to 50 per cent silking; ASI- Anthesis to silking interval; PH- Plant height ; CL- Cob length; CG- Cob girth; TW- Test weight SP- Shelling percentage GYPP- Grain yield per plant ; GY- Grain yield; SPAD- Soil Plant Analyses Development; NDVI- Normalized Difference Vegetation Index ; RWC- Relative water content (%); NL- Number of leaves; P- Phenotype; G- Genotype

The hybrids *viz.,* RCRMH 2, RCRM 3 and RCRMH 4 could be recommended for cultivation after large scale testing. The grain yield per plant showed a significant and positive correlation with plant height, 100-grain weight, cob length, cob girth, chlorophyll content and number of leaves at genotypic levels and these characters could be used as criteria for selection under heat stress.

ACKNOWLEDGEMENT

The authors are very much thankful to USAID for the financial support to the project ''Heat Stress Tolerant Maize for South Asia (HTMA) through Public Private Partnership'' and CGIAR Research Program on Maize (CRP-Maize).

REFERENCES

Al-Jibouri, H.A., Miller, P.A. and Robinson, H.F. 1958. Genotypic and environmental variances in upland cotton of inter-specific origin. *Agron. J.*, **50**: 633-637. [Cross Ref]

Angadi, S. 2014. Evaluation of maize (*Zea mays* L.) inbred lines and hybrids for heat tolerance. *M.Sc. (Agri.) Thesis*, Univ. Agric. Sci., Raichur, Karnataka (India).

Angadi, S., Kuchanur, P.H., Ayyanagouda Patil, Suma T. C., Umesh Hudedamani, Ameregouda, A. and Kisan, B. 2016. Secondary traits for heat stress tolerance in maize (*Zea mays* L.). National conference on genetics and cytogenetics. UAS, Dharwad, Krantaka, 1-3 February,2016.

Chen, J., Xu, W., Velten, J., Xin, Z. and Stout, J. 2012. Characterization of maize inbred lines for drought and heat tolerance. *J. Soil Water Conserv.*, **67**(5): 354-364. [Cross Ref]

De Zelicourt, A., Colcombet, J. and Hirt, H. 2016. The role of MAPK modules and ABA during abiotic stress signaling. *Trends Plant sci.*, **21**(8): 677-685. [Cross Ref]

Divya.2018. Stability analysis of maize (*Zea mays* L.) hybrids across locations under heat stress for grain yield. *M.Sc. (Agri) Thesis*, Univ. Agric. Sci., Raichur, Karnataka (India).

Hasanuzzaman, M., Nahar, K. and Fujita, M. 2013. Extreme temperature responses, oxidative stress and antioxidant defense in plants. *Abiotic stress-plant responses and applications in agriculture*, **13**: 169-205. [Cross Ref]

Jodage, K., Kuchanur, P. H., Zaidi, P. H., Patil, A., Seetharam. K., Vinayan, M. T. and Arunkumar, B. 2017. Association and path analysis for grain yield and its attributing traits under heat stress condition in tropical maize (*Zea mays* L.). *Electronic J. Pl. Breed*., **8**(1): 336-341. [Cross Ref]

Krasensky, J. and Jonak, C. 2012. Drought, salt, and temperature stress-induced metabolic rearrangements and regulatory networks. *J. Exp. Bot.*, **63**(4): 1593-1608. [Cross Ref]

Noor, J.J., Vinayan, M.T., Umar, S., Devi, P., Iqbal, M., Seetharam, K. and Zaidi, P.H., 2019, Morpho-physiological traits associated with heat stress tolerance in tropical maize (*Zea mays* L.) at reproductive stage. *Aust. J. Crop Sci.,* **13**(4):536-545**.** [Cross Ref]

Pavan, R., Lohithaswa, H. C., Wali, M. C., Gangashetty Prakash and Shekara, B.G., 2011, Correlation and path analysis of grain yield and yield contributing traits in single cross hybrids of maize (*Zea mays* L.). *Electron. J. Plant Breed*., **2**(2): 253-257.

Tandzi, L. N., Bradley, G. and Mutengwa, C., 2019, Morphological responses of maize to drought, heat and combined stresses at seedling stage. *J. Biol. Sci*., **19**(1):7-1. [Cross Ref]