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Research Article

Evaluation of Grain Yield of Heat Stress Resilient Maize Hybrids in Nepal

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Abstract

Midhills, foot hills and river basin areas of are generally under spring maize cultivation. These areas along with the areas from Terai and Inner Terai where spring and early summer maize are grown are the most affected from heat stress. Identification and selection of suitable varieties and traits for high temperature tolerance is vital to produce heat resilient genotypes.With a view to identify high yielding heat stress resilient maize hybrids, genotypes received from International Maize and Wheat Improvement Centre (CIMMYT) were evaluated in alpha lattice design with two to three replications at Rampur, Nepalgunj and Surkhet in 2013/014, 2014/015 and 2015/016. Total 57 trials consisting of 7764 maize hyrbids were evaluated under heat stress conditions. At Nepalgunj and Surkhet, trials were planted in March/April. Out of the tested genotypes, 24 hybrids were found promising based on grain yield, plant and ear height. These 24 hybrids along with four National Maize Research Program (NMRP) developed and two multi-national companies' hybrids as checks were tested in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur in 2014/015. Out of these 24 hybrids, eight were selected and tested during 2015/016 in Dumarwana, Nijgadh, Nawalparasi, Anandapur and Rampur. Based on results combined over years and locations CAH-151 (8629 kg ha^{-1}) and CAH-153 (8955 kg ha^{-1}) were registered for general cultivation as Rampur Hybrid-8 and Rampur Hybrid-10, respectively. Other promising hybrids were CAH-1511 (8800 kg ha^{-1}) followed by CAH-1515 (8678 kg ha^{-1}), RML-95/RML-96 (8486 kg ha^{-1}), CAH-1513 (8258 kg ha^{-1}) and RML-86/RML-96 (7544 kg ha^{-1}), respectively. Stability analysis revealed that CAH-151, CAH-153, CAH-1515, CAH-1511 and RML-95/RML-96 are stable hybrids having good performance.

Keywords: Maize hybrid; heat resilient; stability

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Introduction

Maize is the second most important crop in terms of area (891583 ha) and production (2231517 t) with productivity of 2503 kg ha^{-1} (MoAD, 2017). Out of the total maize area; 8.76, 72.29 and 18.95% belong to mountain, hills and Terai with productivity of 2075, 2461 and 2725 kg ha^{-1}, respectively. The average productivity of improved maize is 2547 kg ha^{-1} compared to local (1754 kg ha^{-1}). Seed replacement rate (SRR) of maize is quite low (9.5%). As envisioned in National Seed Vision 2013-2025 (SQCC, 2013) by 2025, projected SRR for maize is about 31.57% with average productivity of 3.33 t ha^{-1}. Heat stress reduces grain yield due to a decline in harvest index (Craufurd *et al.*, 2002; Ferris *et al.*, 1998).

The reasons for low maize yield in Nepal are high temperature, drought, stalk rot infestation, maize borer and shoot fly infestation, poor crop management, high input rates and use of low quality, substandard seed. Heat and drought stress have emerged as a common problem worldwide which can reduce maize crop productivity (Ali *et al.*,2015).Heat stress in the flowering and grain filling periods due to elevated temperatures drastically affect crop productivity. A record drop in maize production was reported in many maize-growing areas of the world (Van der Velde *et al.*, 2010).It is predicted that maize yield might be reduced up 70 % due to increasing temperatures (Khodarahmpour *et al.*,2011)

Rise in temperature (above 38^0C) reduces the pollen viability and silk receptivity resulting in poor seeds set and reduced yield. Spring maize planted in maize–rice system is estimated to be about 15.5% of the total maize area are mostly affected by heat stress, and yield losses may reach up to 75% (Koirala *et al.*, 2013) in Nepal. Mainly anthesis and silking of these maize coincide with high temperatures which cause leaf firing and tassel blast resulting poor pollination.

Among the different measures to increase maize production under adverse climatic conditions, development of high temperature tolerant maize varieties is good option to increase and maize production under heat stress condition (Shrestha *et al.*, 2014). Therefore, this study was carried out to evaluate and identify heat stress resilient maize hybrids.

Materials and Methods

Genetic Materials and Experimental Sites

Heat stress resilient maize hybrids received from Heat Tolerant Maize for Asia (HTMA) - CIMMYT were experimented at National Maize Research Program (NMRP), Rampur; Regional Agricultural Research Sstation (RARS), Nepalgunj and Agriculture Resrarch Station (ARS), Surkhet during 2013/014, 2014/015 and 2015/016. Total eight, three and one experiments consisting of 1682 genotypes were tested at NMRP Rampur, RARS Nepalgunj and ARS Surkhet, respectively during 2013/014 (Table 1). Similarly, nine experiments consisted of 1535 hybrids at NMRP Rampur and ten experiments each at RARS Nepalgunj and surkhet consisting 1710 and 1205 genotypes, respectively were evaluated in 2014/015 (Table 2). Likewise, in 2015/016 at NMRP Rampur and RARS Nepalgunj nine and seven experiments with 812 and 820 genotypes, respectively were evaluated (Table 3). Thus, total 57 experiments consisting of 7764 genotypes were tested under this project in Nepal. Rampur was considered as normal (favorable), and Nepalgunj and Surkhet as heat stress environments. At RARS Nepalgunj and Surkhet planting was managed in such a way that maximum temperature coincided with anthesis and silking stages of the crop based on previous years meteorological data. Out of the tested 7764 genotypes from 2013/014 to 2015/016, 24 hybrids were found promising based on grain yield, plant and ear heights. These 24 hybrids along with four NMRP developed and two multi-national companies' hybrids as checks were experimented in multilocation trials at Dumarwana, Nijgadh, Nawalparasi (Keureni) and Rampur in 2014/015 (Table 4). Further more, among these 24 hybrids, eight were selected and tested in multilocation trials again in 2015/016 at Dumarwana, Nijgadh, Nawalparasi, (Gaindakot-5, Sitalnagar), and Rampur with one additional site Anandapur in Chitwan (Table 5).

NMRP Rampur has humid and subtropical climate with cool winter (2-3ºC) and hot summer (43ºC). The annual rainfall is over 1500 mm with a distinct monsoon period (>75% of annual rainfall) from mid-June to mid-September. The soil texture of NMRP Rampur is sandy loam having 5.43 pH value with 3.95% organic matter and 0.15% nitrogen content. Similarly, available phosphorus, potassiun, boron and zinc in the soil is 33.76, 145.29, 0.17 and 1.58 (ppm), respectively. At RARS Nepalgunj, average annual rainfall is 1000-1500 mm. However, delayed onset and early termination of monsoon is a regular feature, causing occasional failure of crops. The maximum and minimum temperatures are 46ºC and 5.4ºC respectively, with relative humidity ranging from 27 to 94%. Humidity remains low in most parts of the year. Soils of the station have sandy to silty loam, poor in organic carbon and available N but medium in available P_2O_5 and K_2O; pH varies from 7.2-7.5. Bara district falls under subtropical region of Nepal. The average maximum temperature ranges from 22.7ºC to 34.52ºC and minimum temperature ranges from 8.54ºC to 25.9ºC with an average annual rainfall of 1550 mm. The rainfall distribution is not uniform across the year, 84% of the total rainfall is received from June to September. Likewise, ARS Surkhet has subtropical climate with average annual rainfall of 747 mm, of which 80% occurs between June and September. Temperature ranges from 7.9^0C to 36.9^0C in the month of January and June, respectively. The soil of the station is sandy loam in texture and acidic in reaction with pH value from 5.3-5.8.

Table 1: Experimental details of heat stress resilient maize genotypes evaluated at NMRP Rampur, RARS Nepalgunj and ARS Surkhet during 2013/014.

SN	Trial code	Replication	No. entries	Date		Location
				Planting	Harvesting	
1	HTMAHT-46	2	35	12.09.2013	28.01.2014	NMRP, Rampur
2	HTMAHT-86	3	10	12.09.2013	28.01.2014	NMRP, Rampur
3	HTMAHT-66	2	15	12.09.2013	28.01.2014	NMRP, Rampur
4	HTMAHT-56	2	215	12.09.2013	28.01.2014	NMRP, Rampur
5	HTMAHT-76	2	205	13.09.2013	29.01.2014	NMRP, Rampur
6	HTAMHT-16	2	195	13.09.2013	29.01.2014	NMRP, Rampur
7	HTAMHT-36	2	120	13.09.2013	29.01.2014	NMRP, Rampur
8	AEYH-17	2	100	13.09.2013	29.01.2014	NMRP, Rampur
Sub-total (Rampur)			895			
9	13S-HSHT-15	2	155	02.04.2013	08.08.2013	RARS Nepalgunj
10	HTAM-HT-15	2	300	02.04.2013	08.08.2013	RARS Nepalgunj
11	HTAM-HT-25	2	300	02.04.2013	08.08.2013	RARS Nepalgunj
Sub-total (Nepalgunj)			755			
12	CCAFS-HT-14	3	32	25.03.2013	18.07.2013	ARS Surkhet
Sub-total (Surkhet)			32			
Total (2013)			1682			

Table 2: Experimental details of heat stress resilient maize genotypes evaluated at NMRP Rampur, RARS Nepalgunj and ARS Surkhet during 2014/015.

SN	Trial code	Replication	No. entries	Date		Location
				Planting	Harvesting	
1	ABHSHT-114	2	20	02.04.2014	30.07.2014	NMRP, Rampur
2	MPSEWATC-13	2	145	03.04.2014	30.07.2014	NMRP, Rampur
3	MPSEWATC-23	2	140	06.04.2014	27.07.2014	NMRP, Rampur
4	MPSEWBTC-13	2	170	03.04.2014	29.07.2014	NMRP, Rampur
5	MPSEWBTC-23	2	170	06.04.2014	28.07.2014	NMRP, Rampur
6	MPSEYATC-11	2	240	02.04.2014	28.07.2014	NMRP, Rampur
7	MPSEYATC-21	2	240	06.04.2014	31.07.2014	NMRP, Rampur
8	MPSEYBTC-11	2	205	06.04.2014	29.07.2014	NMRP, Rampur
9	MPSEYBTC-21	2	205	03.04.2014	31.07.2014	NMRP, Rampur
Sub-total (Rampur)			1535			
10	EHSTC-112	2	90	14.04.2014	17.08.2014	RARS Nepalgunj
11	EHSTC-312	2	105	12.04.2014	13.08.2014	RARS Nepalgunj
12	MPSEWATC-112	2	145	14.04.2014	14.08.2014	RARS Nepalgunj
13	MPSEWATC-212	2	140	20.04.2014	22.08.2014	RARS Nepalgunj
14	MPSEWBTC-112	2	170	12.04.2014	13.08.2014	RARS Nepalgunj
15	MPSEWBTC-212	2	170	20.04.2014	25.08.2014	RARS Nepalgunj
16	MPSEYATC-13	2	240	12.04.2014	12.08.2014	RARS Nepalgunj
17	MPSEYATC-23	2	240	12.04.2014	13.08.2014	RARS Nepalgunj
18	MPSEYBTC-13	2	205	14.04.2014	16.08.2014	RARS Nepalgunj
19	MPSEYBTC-23	2	205	19.04.2014	19.08.2014	RARS Nepalgunj
Sub-total (Nepalgunj)			1710			
20	ABHSHT-16	2	20	13.04.2014	27.07.2014	ARS Surkhet
21	EHSTC-34	2	105	13.04.2014	05.08.2014	ARS Surkhet
22	HTMAHT-86	2	155	12.04.2014	01.08.2014	ARS Surkhet
23	HTMAHT-96	2	155	12.04.2014	31.07.2014	ARS Surkhet
24	HTMAHT-106	2	100	13.04.2014	08.08.2014	ARS Surkhet
25	HTMAHT-116	2	45	13.04.2014	27.07.2014	ARS Surkhet
26	MPSEWATC-11	2	145	13.04.2014	05.08.2014	ARS Surkhet
27	MPSEWATC-21	2	140	12.04.2014	26.07.2014	ARS Surkhet
28	MPSEWBTC-11	2	170	12.04.2014	10.08.2014	ARS Surkhet
29	MPSEWBTC-21	2	170	12.04.2014	11.08.2014	ARS Surkhet
Sub-total (Surkhet)			1205			
Total (2014)			4450			

Table 3: Experimental details of heat stress resilient maize genotypes evaluated at NMRP Rampur and RARS Nepalgunj during 2015/016

SN	Trial code	Replication	No. entries	Date		Location
				Planting	Harvesting	
1	ATTC-15	2	20	18.03.2015	04.07.2015	Nepalgunj
2	ATTC-215	2	30	19.03.2015	04.07.2015	Nepalgunj
3	AS2BH-42	3	20	16.03.2015	05.07.2015	Nepalgunj
4	AS2BH-52	3	12	17.03.2015	07.07.2015	Nepalgunj
5	AS2BH-62	3	40	18.03.2015	08.07.2015	Nepalgunj
6	AS2BH-72	3	15	18.03.2015	08.07.2015	Nepalgunj
7	AS3BMHR-15	3	10	17.03.2015	07.07.2015	Nepalgunj
8	MPS3TC-111	2	330	17.03.2015	06.07.2015	Nepalgunj
9	MPS3TC-211	2	335	17.03.2015	09.07.2015	Nepalgunj
Sub-total (Nepalgunj)			812			
10	AS2BR-15	3	10	06.03.2015	06.07.2015	Rampur
11	AS2BR-25	3	10	06.03.2015	06.07.2015	Rampur
12	AS3BMHS-117	3	15	06.03.2015	07.07.2015	Rampur
13	AS3BEHS-118	3	10	06.03.2015	07.07.2015	Rampur
14	MPS3TC-15	2	115	06.03.2015	08.07.2015	Rampur
15	MPS3TC-23	2	325	07.03.2015	09-10.07.2015	Rampur
16	MPS3TC-25	2	335	07.03.2015	11-112.07.2015	Rampur
Sub-total (Rampur)			820			
Total (2015)			1632			

Table 4: On-farm multilocation testing of selected hybrids at various locations during 2014/015

Trial	No. entries	Date		Location
		Planting	Harvesting	
On-farm multilocation testing	30	16.11.2014	07.05.2015	NMRP, Rampur
On-farm multilocation testing	30	05.11.2014	16.04.2015	Dumarwana, Bara
On-farm multilocation testing	30	04.11.2014	17.04.2015	Nijgadh, Bara
On-farm multilocation testing	30	22.11.2014	12.05.2015	Keureni, Nawalparasi

Table 5: On-farm multilocation testing of selected hybrids at various locations during 2015/016.

Trial	No. entries	Date		Location
		Planting	Harvesting	
On-farm multilocation testing	10	20.11.2015	20.05. 2016	NMRP, Rampur
On-farm multilocation testing	10	16.11.2015	13.05. 2016	Dumarwana, Bara
On-farm multilocation testing	10	15.11.2015	13.05. 2016	Nijgadh, Bara
On-farm multilocation testing	10	02.12.2015	28.04. 2016	Gaindakot-5, Nawalparasi
On-farm multilocation testing	10	20.11.2015	15.05. 2016	Anandapur, Chitwan

Table 6: CIMMYT code and pedigree of genotypes tested in multilocation trials during 2014/2015.

SN	Genotype (Stock ID)	CIMMYT Code	Pedigree	CAH No.	Demo name
1	Z478-2	ZH151	CAL151/ZL152825	CAH-151	ZH151
2	Z478-3	ZH152	VL1012835/ZL152825		
3	Z478-5	ZH15237	CAL1514/ZL152825	CAH-153	ZH111948-1
4	Z478-4	ZH15240	CIL12102/ZL152825		
5	Z478-8	ZH15236	CAL14113/ZL152824		
6	Z480-1	ZH15443	ZL152846/ZL152841		
7	Z478-9	ZH15238	CIL1218/ZL152824		
8	Z480-2	ZH15444	VL1032/ZL1312		
9	Z478-10	ZH15241	CIL1218/ZL152826		
10	Z433-11	ZH111765	CAL1412/CIL1221	CAH-158	ZH111765
11	Z433-99	ZH111737	CAL157/CIL1221		
12	Z464-5	ZH137097	CAL1513/CAL1412		
13	Z376-30	ZH114233	VL108305/CIL12180	CAH-1521	ZH114233

Table 6: CIMMYT code and pedigree of genotypes tested in multilocation trials during 2014/2015. (Contd.)

SN	Genotype (Stock ID)	CIMMYT Code	Pedigree	CAH No.	Demo name
14	Z466-4	ZH15239	CAL158/ZL152825		
15	Z466-3	ZH15414	CAL14137/ZL152825	CAH-1511	ZH111948-2
16	Z466-1	ZH15448	CAL1733/ZL152825		
17	Z376-2	ZH116072	CZL0713/CIL12180		
18	Z376-5	VH11129	CAL1465/CIL12180	CAH-1513	ZH11129
19	Z376-6	ZH137855	CAL159/CIL12180		
20	Z376-8	ZH137856	CZL0718/CIL12180	CAH-1515	ZH137856
21	Z376-9	ZH116108	CAL1510/CIL12180		
22	Z376-26	ZH111698	CAL1441/CIL12180		
23	Z376-34	ZH116078	CAL1511/CIL12180		
24	Z376-51	ZH111471	CAL1512/CIL12180		
25	900M Gold	Monsanto India Ltd., Mumbai, India			
26	30V92	Pioneer HI Pvt. Ltd., Hyderabad, India			
27	Rampur Hybrid-4		RML-32/RML-17		
28	RML-95/RML-96		RML-95/RML-96		
29	RML-86/RML-96		RML-86/RML-96		
30	Rampur Hybrid-2		RML-4/NML-2		

Table 7: Geographical description of experimental locations.

Location	Longitude	Latitude	Elevation (m) (m.a.s.l)
NMRP Rampur	84º20′20.9″E	27º39′0.3″N	228
RARS Nepalgunj	81º37′E	28º 06″ N	181
ARS Surkhet	81º47″E	28º30″N	580
Dumarwana (Bara)	85º1′8.5″E	27º7′55.7″N	124
Nijgadh (bara)	85º10′32.5″E	27º12′11.8″N	169
Keureni (Nawalparasi)	84º12′31.44″E	27º40′22.77″N	178
Gaindakot, Sitalnagar (Nawalparasi)	84º23′21.1″E	27º41′42.5″N	193
Anandapur (Chitwan)	84º23′13.7″E	27º40′12.1″N	194

Table 8: Weather data of NMRP Rampur during crop growing season 2013/014

Month	Mean daily temperature (ºC)		Total rainfall (mm)	Relative humidity (%)
	Maximum	Minimum		
September (2013)	30.06	29.30	13	29.68
October	27.33	26.21	0.40	27.77
November	21.73	20.17	0.00	20.95
December	17.40	16.66	0.00	17.07
January (2014)	18.53	16.19	0.30	17.36
Average (crop season)	23.01	21.71		22.57
Total (crop season)			13.70	

Table 9: Weather data of NMRP Rampur during crop growing season 2014/015

Month	Mean daily temperature (ºC)		Total rainfall (mm)	Relative humidity (%)
	Maximum	Minimum		
April (2014)	33.66	21.46	0.13	66.53
May	37.06	23.85	3.23	73.80
June	35.26	26.91	12.98	92.39
July	33.66	26.75	517.00	87.00
August	32.95	26.38	795.70	85.74
September	32.57	25.33	206.56	86.40
October	31.44	21.12	85.00	86.06
November	28.13	15.82	0.00	74.56
December	22.29	11.64	9.50	75.64
January (2015)	21.44	11.35	14.00	73.56
February	24.95	13.10	40.90	70.54
March	29.05	20.19	43.70	71.52
April	32.50	20.85	21.00	75.35
May	35.63	25.23	198.50	77.85
Average (crop season)	30.76	20.71		78.35
Total (crop season)			1948.20	

Table 10: Weather data of NMRP Rampur during crop growing season 2015/016

Month	Mean daily temperature (ºC)		Total rainfall (mm)	Relative humidity (%)
	Maximum	Minimum		
November (2015)	28.18	14.28	0.00	76.20
December	23.22	8.72	7.70	75.80
January (2016)	22.20	7.50	1.10	90.03
February	27.29	10.48	36.20	81.29
March	32.13	14.57	1.90	65.79
April	37.68	19.58	305.20	59.46
May	34.31	18.58	257.90	68.62
Average (crop season)	29.29	13.39		73.88
Total (crop season)			610.00	

Table 11: Weather data of RARS Nepalgunj during crop growing season 2013/014

Month	Mean daily temperature (ºC)		Total rainfall (mm)
	Maximum	Minimum	
April (2013)	36.04	18.44	0.50
May	38.98	24.43	12.80
June	32.86	24.97	324.00
July	33.11	27.01	228.50
August up to 8	34.27	27.73	229.20
Average (crop season)	35.05	24.52	
Total (crop season)			795

Experimental Design and Cultural Practices

Experiments were conducted in alpha lattice design with 2-3 replications depending upon trials in 2013/014 and 2014/015. Plot size was 4m long single row and replicated twice except in HTMAHT-86 and CCAFS-HT-14 which were replicated thrice. Row-to-row and plant-to-plant spacing was maintained at 75 cm and 25 cm, respectively. Two seeds per hill were planted and thinned to single plant during first weeding. Fertilizer was applied @120:60:40 N:P:K kg ha^{-1}. In multilocation trials during 2014/015 and 2015/016, plot size was 10 rows of five metre long. One location was considered as a replication. Row-to-row and plant-to-plant distance was maintained at 60 cm and 25 cm, respectively. Two seeds per hill were planted and thinned to single plant during first weeding. Fertilizer was applied @180:60:40 N:P:K kg ha^{-1}. In all the years of experimentation, half of the N and full dose of P_2O_5 and K_2O were applied as basal dose. The remaining half dose of N was applied in two splits at knee-high and pre-tasseling/silking stages. Other agronomic practices were carried out as per recommended.

Data Recording and Measurements

Grain yield, plant and ear heights were recorded. Grain yield was estimated using formula adopted by Shrestha *et al.* (2015) by adjusting the grain moisture at 15% and converted to the grain yield kg per hectare.

Plant height is the distance from the base of the plant to the top of the plant from where tassel starts branching. It was measured as an average of the randomly taken five plants. This was recorded after 2-3 weeks of flowering until just prior to harvesting. Ear height was measured at the same time from those plants which were used for plant height. It is the distance from base of the plant to the uppermost ear bearing node.

Statistical Analysis

The statistical analysis was done using computer software MSTATC version 1.2 (Freed, 1990) applying 5% level of significance for various trials from 2013/014 to 2015/016. Stability analysis was carried out using GEA_R version 2.0.

Results and Discussion

A huge number of genotypes (7764) were evaluated. The results of multilocation trials conducted during 2014/015 and 2015/016 have been presented and discussed. Different techniques are being applied to evaluate and select heat tolerant germplasm in maize (Molin *et al.*, 2013; Carvalho *et al.*, 2004). The grain yield (Hussain *et al.*, 2006) have been extensively used by researchers to evaluate maize germplasm under heat stress.Based on three years' results hybrids namely Z478-2, Z478-3, Z478-5, Z478-4, Z478-8, Z480-1, Z478-9, Z480-2, Z478-10, Z433-11, Z433-99, Z464- 5, Z376-30, Z466-4, Z466-3, Z466-1, Z376-2, Z376-5, Z376-6, Z376-8, Z376-9, Z376-26, Z376-34 and Z376-51 performed better and were found heat stress resilient. These hybrids performed better both in optimal and heat stress environments. Thus, were selected for multilocation testing purpose. The results of one location were considered as one replication. In 2014/015 when results combined over locations for grain yield, significant differences were observed. The grain yield ranged from 6378 (Z480-2) to 9673 kg ha^{-1}. RML-95/RML-96 produced the highest grain yield followed by Rampur hybrid-4 (9483 kg^{-1}), Z478-3 (9393 kg ha^{-1}), Z478-4 (9315 kg ha^{-1}), Z478-2 (CAH-151) (9315 kg ha^{-1}) and Z376-34 (9315 kg ha^{-1}). These varieties performed better than multinational companies' hybrids 900M Gold (8385 kg ha^{-1}) and 30V92 (8258 kg ha^{-1}). The

ranking of the varieties based on grain yield differed from location to location (Table 12). Based on grain yield and stakeholders feedbacks in farmers' field day, eight hybrids were selected for multilocation testing in 2015/016. Non-significant results were observed for grain yield in 2015/016 (Table 13). Results for grain yield were statistically at par for genotypes and, genotype by environment interactions when combined over years and locations, however it was highly significant for locations (Table 14).

Generally, different genotypes behave differently because of differences in gene responses or in their potential performance in different environments (Brandiej, 1994). The G × E interaction analysis has been previously done to evaluate genotypes in multi-environment trials of maize (Choukan, 2011; Fan *et al.*, 2007). Based on stability analysis, Hybrids namely CAH-1515 (=1515), CAH-1511 (=1511), CAH-153 (=153), CAH-1151 (=1151) and RML-95/RML-96 (=95 × 96) were found to be stable and good performers (Fig. 1).

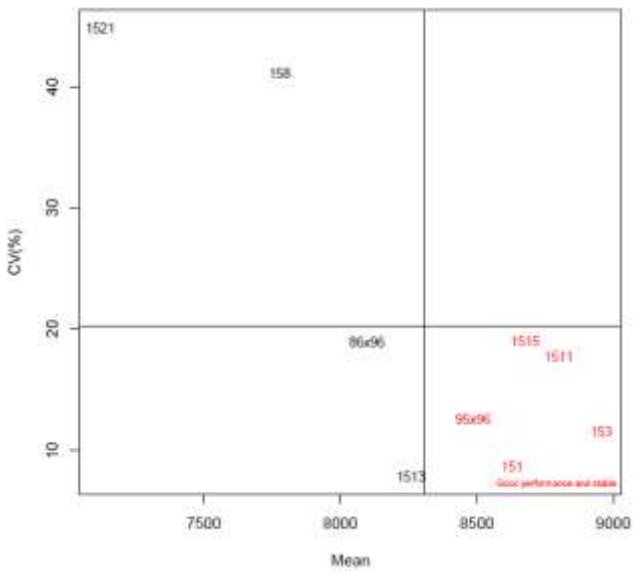

Fig. 1: Stability of heat stress resilient hybrids across the tested locations during 2014/015 and 2015/016.

Table 12: Mean grain yield (kg ha^{-1}) of HTMA hybrids in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur during 2014/015

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Rampur	Combined	Rank
1	Z478-2 (CAH-151)	10650	8980	8020	9000	9163	5
2	Z478-3	9490	9380	10060	8640	9393	3
3	Z478-5 (CAH-155)	9990	8740	8870	8120	8930	8
4	Z478-4	9570	9860	10090	7740	9315	4
5	Z478-8	9920	6650	8010	5950	7633	24
6	Z480-1	11370	7410	4090	5710	7145	25
7	Z478-9	6000	10590	5130	5170	6723	29
8	Z480-2	6810	6470	6910	5320	6378	30
9	Z478-10	7130	6320	8410	5510	6843	27
10	Z433-11 (CAH-158)	10440	6760	12290	2890	8095	22
11	Z433-99	10270	5770	11420	6270	8433	16
12	Z464-5	8810	6070	11270	6240	8098	21
13	Z376-30 (CAH-1521)	8410	3670	9680	5380	6785	28
14	Z466-4	7950	7640	6240	6340	7043	26
15	Z466-3 (CAH-1511)	11210	6830	9030	7110	8545	14
16	Z466-1	10610	7390	7730	8910	8660	11
17	Z376-2	9860	6360	9380	7970	8393	18
18	Z376-5 (CAH-1513)	10620	7840	5410	7250	7780	23
19	Z376-6	10070	7960	7630	8560	8555	13
20	Z376-8 (CAH-1515)	10160	7330	9040	7550	8520	15
21	Z376-9	11380	7900	8790	7920	8998	7
22	Z376-26	10110	9470	8500	8540	9155	6
23	Z376-34	8450	9670	7100	8450	8418	17
24	Z376-51	8250	8720	10470	7050	8623	12
25	900M Gold	9350	7690	7710	8790	8385	19
26	30V92	8570	10420	9090	4950	8258	20
27	Rampur Hybrid-4	10640	11370	7650	8270	9483	2
28	RML-95/RML-96	11150	11040	9040	7460	9673	1
29	RML-86/RML-96	9740	7630	10940	7430	8935	9
30	Rampur Hybrid-2	10710	8740	9170	6320	8735	10
Grand mean		9590	8022	8572	7027	8303	
Minimum		6000	3670	4090	2890	6378	
Maximum		11380	11370	12290	9000	9673	
F-test						*	
LSD (0.05)						2200	
CV (%)						18.9	

Table 13: Average grain yield (kg ha^{-1}) of heat stress resilient maize hybrids tested in multilocation trials at Dumarwana, Nijgadh, Nawalparasi, Anandapur and Rampur during 2015/016

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Anandapur	Rampur	combined
1	CAH-158	6500	4600	11700	7600	4800	7040
2	CAH-1521	7100	2900	12300	11000	4300	7520
3	CAH-1513	7500	8400	11300	9500	2000	7740
4	CAH-1515	7500	7000	12800	9400	3500	8040
5	CAH-151	7100	6800	11100	8000	3900	7380
6	CAH-153	8100	7700	11900	7000	6400	8220
7	ZH114228	6200	8500	13400	9000	5600	8540
8	CAH-1511	8100	8000	12100	6800	5100	8020
9	RML-95/RML-96	7700	5100	9500	8700	3500	6900
10	RML-86/RML-96	7400	5500	9100	9700	3500	7040
Grand mean		7218	6127	11300	8500	4055	7576
Minimum		6200	2900	9100	6800	2000	6900
Maximum		8100	8500	13400	11000	6400	8540
F-test							ns
CV (%)							17.9

Table 14: Mean grain yield of HTMA hybrids in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur (combined data over locations and years) 2014/015-2015/016

SN	Genotypes	Grain yield, kg/ha												Combined over locations & year
		Dumarwana			Njgadh			Nawalparasi			Rampur			
		2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	
6	CAH-153	9990	8100	9045	8740	7700	8220	8870	11900	10385	8120	8220	8170	8955
7	CAH-1511	11210	8100	9655	6830	8000	7415	9030	12100	10565	7110	8020	7565	8800
4	CAH-1515	10160	7500	8830	7330	7000	7165	9040	12800	10920	7550	8040	7795	8678
5	CAH-151	10650	7100	8875	8980	6800	7890	8020	11100	9560	9000	7380	8190	8629
8	RML-95/RML-96	11150	7700	9425	11040	5100	8070	9040	9500	9270	7460	6900	7180	8486
3	CAH-1513	10620	7500	9060	7840	8400	8120	5410	11300	8355	7250	7740	7495	8258
9	RML-86/RML-96	9740	7400	10263	7444	8854	7647	6222	6934	9147	11311	10229	6910	7544
1	CAH-158	10440	6500	8410	6500	7755	3670	2900	3285	5410	9100	8355	2890	6900
2	CAH-1521	8410	7100	11210	8100	9655	11040	8400	8220	12290	12800	11995	9000	8220
Grand mean		10263	7444	9419	8089	7696	7693	7437	9682	9545	8856	8542	7244	8274
Minimum		8410	6500	8410	6500	5100	3670	2900	3285	5410	7110	6900	2890	6900
Maximum		11210	8100	11210	11040	9655	11040	9040	12800	12290	12800	11995	9000	8955
F-test:Genotype (G														ns
F-test:Location (L)														**
F-test:G × L														ns
LSD (0.05):G														1876
LSD (0.05):L														1251
LSD (0.05):G x L														3753
CV (%)														22.2

Based on the results of this project two hybrids namely CAH-151 and CAH-153 have been released for commercial cultivation as Rampur hybrid-8 and Rampur hybrid-10 for Terai regions of Nepal. The development of germplasm adapted to high temperature stress has been a key strategy for increasing grain yield (Fischer and Palmer, 1984).

A lot of information on agronomic and physiological traits for high temperature tolerance in maize is available (Steven *et al.*, 2002; Sinsawat *et al.*, 2004). The final plant height reflects the growth behavior of a crop, besides genetic characteristics, availability of essential nutrients, space, water and environmental condition under which it is grown. Increase in temperature affects the plant growth which ultimately influences the plant height. In 2014/015, Plant height of the tested genotypes were found highly significant and ranged from 125 to 191cm. The lowest plant height was recorded in Z478-9 (125 cm) followed by Z478-10 (139 cm), Z478-8 (145 cm), Z480-2 (151 cm) and Z480-1 (153 cm) (Table 15). In 2015/016, plant height among the tested hybrids differed significantly. The lowest plant height was recorded in CAH-1513 (158 cm) followed by RML-86/RML-96 (165 cm), CAH-1515 (170 cm), RML-95/RML-96 (171 cm) and CAH-153 (173 cm). It might be due to genetic difference among different maize hybrids and efficient utilization of high temperature to increase the plant growth (Bakker and Van Uffelen, 1998). Hybrid CAH-158 was the tallest (194 cm) among the tested hybrids (Table 16).The ranking of varieties based on plant height was more or less similar in both the years and location. Genotypic variation was evident for plant height when combined over years and locations. Similarly, highly significant differences were observed for locations. Genotype × Environment interactions were found non-significant. Plant height of the genotypes ranged from 157 cm (CAH-1513) to 194 cm (CAH-158). Results have been summarized in Table 17.

Table 15: Average plant height (cm) of heat stress resilient maize hybrids in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur during 2014/015

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Rampur	Combined	Rank
1	Z478-2 (CAH-151)	145	130	180	215	168	14
2	Z478-3	155	150	215	210	183	28
3	Z478-5 (CAH-155)	145	140	205	195	171	19
4	Z478-4	165	155	205	180	176	25
5	Z478-8	125	120	165	170	145	3
6	Z480-1	130	125	185	170	153	6
7	Z478-9	120	110	150	120	125	1
8	Z480-2	145	135	160	165	151	5
9	Z478-10	130	125	170	130	139	2
10	Z433-11 (CAH-158)	190	160	205	210	191	30
11	Z433-99	175	160	190	190	179	26
12	Z464-5	145	150	165	165	156	7
13	Z376-30 (CAH-1521)	175	140	200	185	175	24
14	Z466-4	145	140	155	150	148	4
15	Z466-3 (CAH-1511)	160	170	190	175	174	22
16	Z466-1	160	125	165	185	159	10
17	Z376-2	180	150	180	180	173	21
18	Z376-5 (CAH-1513)	155	155	160	155	156	8
19	Z376-6	150	140	195	230	179	27
20	Z376-8 (CAH-1515)	150	130	185	175	160	11
21	Z376-9	165	140	210	115	158	9
22	Z376-26	150	135	185	210	170	17
23	Z376-34	155	160	170	160	161	12
24	Z376-51	155	145	180	170	163	13
25	900M Gold	165	140	195	230	183	29
26	30V92	155	140	200	180	169	16
27	Rampur Hybrid-4	135	175	200	175	171	20
28	RML-95/RML-96	140	160	205	165	168	15
29	RML-86/RML-96	140	150	215	175	170	18
30	Rampur Hybrid-2	175	125	210	185	174	23
Grand mean		153	143	186	177	165	
Minimum		120	110	150	115	125	
Maximum		190	175	215	230	191	
F-test						**	
CV (%)						10.1	
LSD(0.05)						23.5	

Table 16: Average plant height (cm) of heat stress resilient maize hybrids tested in multilocation trials at Dumarwana, Nijgadh, Nawalparasi, Anandapur and Rampur during 2015/016

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Anandapur	Rampur	combined	Rank
1	CAH-158	204	180	210	188	190	194	10
2	CAH-1521	195	182	220	184	180	192	9
3	CAH-1513	170	150	180	160	130	158	1
4	CAH-1515	160	165	180	194	150	170	3
5	CAH-151	185	200	210	205	150	190	8
6	CAH-153	170	190	190	150	165	173	5
7	ZH114228	190	170	200	145	160	173	6
8	CAH-1511	168	185	190	173	170	177	7
9	RML-95/RML-96	170	170	180	172	165	171	4
10	RML-86/RML-96	152	165	180	184	145	165	2
Minimum		152	150	180	145	130	158	
Maximum		204	200	220	205	190	194	
Grand mean		177	176	195	175	160	176	
F-test							**	
CV (%)							7.3	
LSD (0.05)							16.4	

Table 17: Mean plant height of HTMA hybrids in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur (combined data over locations and years) 2014/015-2015/016

SN	Genotypes	Plant height, cm												Combined over locations & years (DMRT)
		Dumarwana			Njgadh			Nawalparasi			Rampur			
		2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	
3	CAH-1513	155	170	163	155	150	153	160	180	170	155	130	143	157c
4	CAH-1515	150	160	155	130	165	148	185	180	183	175	150	163	1612c
9	RML-86/RML-96	140	152	146	150	165	158	215	180	198	175	145	160	165bc
8	RML-95/RML-96	140	170	155	160	170	165	205	180	193	165	165	165	169bc
6	CAH-153	145	170	158	140	190	165	205	190	198	195	165	180	175abc
7	CAH-1511	160	168	164	170	185	178	190	190	190	175	170	173	176abc
5	CAH-151	145	185	165	130	200	165	180	210	195	215	150	183	177abc
2	CAH-1521	175	195	185	140	182	161	200	220	210	185	180	183	185ab
1	CAH-158	190	204	197	160	180	170	205	210	208	210	190	200	194a
Grand mean		156	175	165	148	176	162	194	193	194	183	161	172	173
Minimum		140	152	146	130	150	148	160	180	170	155	130	143	157
Maximum		190	204	197	170	200	178	215	220	210	215	190	200	194
F-test:Genotype (G)														*
F-test:Location (L)														**
F-test:G × L														ns
LSD (0.05):G														19.51
LSD (0.05):L														13.01
CV (%)														11

Table 18: Average ear height (cm) of heat stress resilient maize hybrids tested in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur during 2014/015.

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Rampur	Combined	Rank
1	Z478-2 (CAH-151)	35	60	80	110	71	13
2	Z478-3	65	55	115	90	81	23
3	Z478-5 (CAH-155)	60	55	90	90	74	14
4	Z478-4	65	60	100	80	76	18
5	Z478-8	55	50	70	80	64	6
6	Z480-1	55	55	65	85	65	8
7	Z478-9	50	50	65	50	54	3
8	Z480-2	70	60	75	65	68	9
9	Z478-10	65	65	90	60	70	10
10	Z433-11 (CAH-158)	100	90	115	120	106	30
11	Z433-99	90	80	100	130	100	29
12	Z464-5	75	90	70	70	76	19
13	Z376-30 (CAH-1521)	70	80	90	85	81	24
14	Z466-4	50	70	50	40	53	2
15	Z466-3 (CAH-1511)	50	70	60	60	60	5
16	Z466-1	60	25	70	50	51	1
17	Z376-2	80	60	90	50	70	11
18	Z376-5 (CAH-1513)	65	70	50	40	56	4
19	Z376-6	60	70	85	90	76	20
20	Z376-8 (CAH-1515)	60	50	100	70	70	12
21	Z376-9	65	65	80	90	75	15
22	Z376-26	60	55	105	90	78	22
23	Z376-34	70	70	90	70	75	16
24	Z376-51	50	65	80	60	64	7
25	900M Gold	70	60	90	130	88	27
26	30V92	60	60	100	80	75	17
27	Rampur Hybrid-4	65	80	70	90	76	21
28	RML-95/RML-96	80	55	100	100	84	25
29	RML-86/RML-96	55	70	120	90	84	26
30	Rampur Hybrid-2	85	75	105	125	98	28
Grand mean		65	64	86	82	74	
Minimum		35	25	50	40	51	
Maximum		100	90	120	130	106	
F-test						**	
CV (%)						19.6	
LSD(0.05)						20.3	

Table 19: Average ear height (cm) of heat stress resilient maize hybrids tested in multilocation trials at Dumarwana, Nijgadh, Nawalparasi, Anandapur and Rampur during 2015/016

SN	Genotypes	Dumarwana	Nijgadh	Nawalparasi	Anandapur	Rampur	Combined	Rank
1	CAH-158	145	110	140	100	120	123	10
2	CAH-1521	105	112	90	100	90	99	9
3	CAH-1513	75	82	110	65	70	80	5
4	CAH-1515	65	80	70	100	60	75	3
5	CAH-151	70	100	110	120	60	92	8
6	CAH-153	72	70	90	90	50	74	1
7	ZH114228	60	65	95	80	70	74	2
8	CAH-1511	80	92	60	85	60	75	4
9	RML-95/RML-96	120	90	80	70	80	88	6
10	RML-86/RML-96	92	80	120	80	75	89	7
	Minimum	60	65	60	65	50	74	
	Maximum	145	112	140	120	120	123	
	Grand mean	91	88	97	90	75	89	
	F-test						**	
	CV (%)						18.7	
	LSD (0.05)						20.9	

Table 20: Mean ear height of HTMA hybrids in multilocation trials at Dumarwana, Nijgadh, Nawalparasi and Rampur (combined data over locations and years) 2014/015-2015/016

		Ear height, cm												Combined over locations & years (DMRT)
		Dumarwana			Njgadh			Nawalparasi			Rampur			
SN	Genotypes	2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	2015	2016	Combined	
1	CAH-1511	50	80	65	70	92	81	60	60	60	60	60	60	67d
2	CAH-1515	60	65	63	50	80	65	100	70	85	70	60	65	69cd
3	CAH-1513	65	75	70	70	82	76	50	110	80	40	70	55	70bcd
4	CAH-153	60	72	66	55	70	63	90	90	90	90	50	70	72bcd
5	CAH-151	35	70	53	60	100	80	80	110	95	110	60	85	78bcd
6	RML-86/RML-96	55	92	74	70	80	75	120	120	120	90	75	83	88bc
7	RML-95/RML-96	80	120	100	55	90	73	100	80	90	100	80	90	88bc
8	CAH1521	70	105	88	80	112	96	90	90	90	85	90	88	90b
9	CAH-158	100	145	123	90	110	100	115	140	128	120	120	120	118a
Grand mean		64	92	78	67	91	79	89	97	93	85	74	79	82
Minimum		35	65	53	50	70	63	50	60	60	40	50	55	67
Maximum		100	145	123	90	112	100	120	140	128	120	120	120	118
F-test:Genotype (G)														**
F-test:Location (L)														*
F-test:G × L														ns
LSD (0.05):G														17.89
LSD (0.05):L														11.93
CV (%)														21.4

In 2014/015, ear height of the tested genotypes were found highly significant and ranged from 51 to 106 cm. The lowest ear height was recorded in Z466-1 (51 cm) followed by Z466-4 (53 cm), Z478-9 (54 cm), Z376-5 (CAH-1513) (56 cm) and Z466-3 (CAH-1511) (60 cm) (Table 18). Highly significant variations were recorded for ear height among the tested hybrids in 2015/016. The lowest ear height was recorded in CAH-153 and ZH114228 (74 cm) followed by CAH-1515 and CAH-1511 (75 cm), RML-95/RML-96 (88 cm) and RML-86/RML-96 (89 cm). Hybrid CAH-158 was the genotype having the highest (123 cm) ear highest among the tested hybrids (Table 19). Genotypic variation was evident for ear height when combined over years and locations. Similarly, significant differences were observed for locations.

Genotype × Environment interactions were found non-significant. Ear height of the tested hybrids ranged from 67 cm (CAH-1511) to 118 cm (CAH-158). Results have been presented in Table 20.

Conclusion

It can be inferred from present studies that high level of genetic variability was present among maize hybrids for grain yield under heat stress. Based on three years' efforts, two heat stress resilient single cross hybrids namely Rampur Hybrid-8 (CAH-151) and Rampur Hybrid-10 (CAH-153) have been registered in 2017 (2074 BS) for general cultivation for Terai and inner Terai above 700 m during winter season. Pedigree of Rampur Hybrid-8 (CAH-151) is Z478-2 and Rampur Hybrid-10 (CAH-153) is Z478-5. Parental lines of Rampur Hybrid-8 are ZL26632 (female) and CML-451 (male), and Rampur Hybrid-10 (CAH153) are VL109126 (female) and CML-451(male). The appropriate date of maize sowing in Terai and inner Terai of Nepal ranges from 15th August to 15th October. However, it can be grown before 15th of November, and 1st to 15th February. Other hybrids identified promising were CAH-1511 followed by CAH-1515 , RML-95/RML-96 , CAH-1513 and RML-86/RML-96. Stability analysis revealed that

CAH-151, CAH-153, CAH-1515, CAH-1511 and RML-95/RML-96 are stable hybrids having good performance.

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References

Ali F, Kanwal N, Ahsan M, Ali Q and Niazi NK (2015) Crop improvement through conventional and non-conventional breeding approaches for grain yield and quality traits in *Zea mays*. *Life Sci J* **12**(4s): 38-50.

Bakker JC, Van Uffelen J (1998) The effects of diurnal temperature regimes on growth and yield of sweet pepper. *Netherlands J. Agril. Sci.* **36**: 201-208.

Brandiej E (1994) Genotype × environmental interaction and stability of seed yield of oil rapeseed. *Crop Sci* **18**: 344-353.

Carvalho VP, Ruas CF, Ferreira JM, Moreira RM and Ruas PM (2004) Genetic diversity among maize (*Zea mays* L.) landraces assessed by RAPD markers. *Genet Mol Biol* **27**: 228-236. DOI: 10.1590/S1415-47572004000200017

Choukan R (2011) Genotype, environment and genotype × environment interaction effects on the performance of maize (*Zea mays* L.) inbred lines. *C B Journal* **1**(2): 97-103.

Craufurd PQ, Vara Prasad PV and Summerfield RJ (2002) Dry matter production and rate of change of harvest index at high temperature in peanut. *Crop Science* **42**: 146–151. DOI: 10.2135/cropsci2002.1460

Fan XM, Kang MS, Chen H, Zhang Y, Tan J and Xu C (2007) Yield stability of maize hybrids evaluated in multi-environment trials in Yunnan. China *Agron J* **99**: 220-228. DOI: 10.2134/agronj2006.0144

Ferris R, Ellis RH, Wheeler TR and Hadley P (1998) Effect of high temperature stress at anthesis on grain yield and biomass of field-grown crops of wheat. *Annals of Botany* **82**: 631–639. DOI: 10.1006/anbo.1998.0740

Fischer KS and Palmer AFE (1984) Tropical maize. In Goldsworthy, P. R., & Fisher, N. M. (eds.), The Physiology of Tropical Field Crops. (pp. 213–248). Chichester, England: John Wiley & Sons.

Freed RD (1990) MSTATC version 1.2. MichiganState. Uni., Michigan, USA.

Hussain T, Khan IA, Malik MA and Ali Z (2006) Breeding potential for high temperature tolerance in corn (*Zea mays* L.). *Pak J Bot* **38**: 1185.

Khodarahmpour Z and Choukan R (2011) Genetic Variation of Maize (*Zea mays* L.) Inbred Lines in Heat Stress Condition. *Seed and Plant Improvment Journal* **27**(4): 539-554.

Koirala KB, Pandey YR and Ghimire TB (2013) Road-map for development and deployment of heat resilient maize in Nepal. Paper presented at 1st Annual progress review and planning workshop, held at Hotel Yak and Yeti, Kathmandu, Nepal, 2013.

MoAD (2017) Statistical information on Nepalese agriculture 2072/73 (2015/16). Government of Nepal. Ministry of Agricultural Development. Monitoring, Evaluation and Statistics Division. Agri Statistics Section. Singha Durbar, Kathmandu, Nepal.

Molin D, Coelho CJ, Máximo DS, Ferreira FS, Gardingo JR and Matiello RR (2013) Genetic diversity in the germplasm of tropical maize landraces determined using molecular markers. *Genet Mol Res* **12**: 99-114. DOI: 10.4238/2013.January.22.8

Shrestha J, Gurung DB and Dhital KP (2014) Agronomic performance of maize under high temperature condition. *J Innov Biol* **1**(3): 137-141.

Shrestha J, Koirala K, Katuwal R, Dhami N, Pokhrel B, Ghimire B, Prasai H, Paudel A, Pokhrel K, and KC G (2015).Performance evaluation of quality protein maize genotypes across various maize production agro ecologies of Nepal. *Journal of Maize Research and Development* **1**(1):21-27. DOI: 10.3126/jmrd.v1i1.14241

Sinsawat V, Pandy J, Leipner P, Stamp P and Fracheboud Y (2004) Effect of heat stress on the Photosynthetic apparatus in maize (*Zea mays* L.) grown at control and high temperature. *Environ Exp Bot* **52**: 123-129. 10.1016/j.envexpbot.2004.01.010

SQCC (2013) National Seed Vision 2013-2025. Seed sector development strategy. Government of Nepal. Ministry of Agricultural Development. National Seed Board. Seed Quality Control Centre, Hariharbhawan, Lalitpur, Nepal. 87p.

Steven J, Brandner C, and Salvucci M (2002) Sensitivity of photosynthesis in C4 maize plant to heat stress. *Plant Physiol* **129**: 1773-1780. DOI: 10.1104/pp.002170

Van der Velde M, Wriedt G and Bouraoui F (2010) Estimating irrigation use and effects on maize yield during the 2003 heatwave in France. *Agriculture, ecosystems and environment* **135**(1): 90-97. DOI: 10.1016/j.agee.2009.08.017