SAARC J. Agric., 19(1): 27-43 (2021) *DOI: https://doi.org/10.3329/sja.v19i1.54776*

FIELD EVALUATION OF HEAT STRESS-RESILIENT MAIZE HYBRIDS FOR IMPROVED AND STABLE MAIZE PRODUCTION IN NEPAL

K.B. Koirala[1*], M.P. Tripathi[1], K. Seetharam[2], M.T. Vinayan[2] and P.H. Zaidi[2]

[1]National Maize Research Program (NMRP), Rampur, Chitwan, Nepal
[2]CIMMYT Asia Maize Program, ICRISAT campus, Patancheru, Hyderabad, India

ABSTRACT

In recent years, National Maize Research Program (NMRP) aimed a paradigm shift from open-pollinated varieties (OPVs) towards hybrid maize to achieve self-sufficiency in maize for food, feed, and hybrid seed within the country. In this mission, it is necessary to identify and deploy high-yielding stress-resilient maize hybrids that can cope with climate change effects, including heat stress. Under the project "Heat Tolerant Maize for Asia (HTMA)", NMRP introduced the hybrids that performed better in previous years in different environments from International Maize and Wheat Improvement Center (CIMMYT) Hyderabad for multi-location on-farm testing. Fifteen genotypes were evaluated at two locations, two sites in Madi, Chitwan, and one in Ghorahi, Dang, along with Rampur Hybrid-8 as a heat-tolerant check, and RML-86/RML-96 and RML-95/RML-96 as normal checks. Randomized complete block design (RCBD) was used with three replicates during the spring of 2016/17. Likewise, another 20 and 18 promising hybrids were demonstrated during the winter of 2016/17 and 2017/18, respectively, in different hybrid growing pockets considering a site – a replication. Grain yield and yield attributing traits at all locations were recorded. From the across-site data analysis, selected heat-tolerant hybrids from the experiment were CAH1432, ZH15405, ZH141592, and CAH1715 which were statistically at par with promising normal hybrid RML-86/RML-96 and superior to already released heat-tolerant Rampur Hybrid-8. In 2016/17, ZH138098, ZH1620, and VH121062 were farmers' preferred heat-tolerant hybrids. In 2017/18, Rampur Hybrid-10, ZH141592, CAH1715, and ZH15440 were preferred by farmers. The selected best-bet are taken forward for official release/registration followed by commercialization through a public-private partnership with Nepali seed companies/cooperatives.

Keywords: Anthesis-silking interval, Heat stress, Hybrid, Resilient, Single cross

[*] Corresponding author: koiralakb15@gmail.com

Received: 11.10.2020 *Accepted: 22.04.2021*

INTRODUCTION

Maize plays a vital role in global grain production due to its high yield potential, and it is expected to become the world's number one cereal in the future (Gong et al., 2015). It is the second cereal in terms of area (958,150 ha), production (2,893,987 t), and productivity (3.02 t ha^{-1}) (MoF, 2021), with the highest per capita consumption per day (98 g) among the South Asian countries (Ranum et al., 2014) in Nepal. There is a wide gap between the actual (2.84 t ha^{-1}) and potential yield (6.50 t ha^{-1}) of maize at the farmers' level (Koirala et al., 2020a). The aggressive intervention of high-yielding climate-resilient hybrids is of the utmost importance to meet the current high demand for maize, and also to narrow down the gap between farmers' harvest and potential yields. Hybrids and open-pollinated varieties (OPVs) occupy 12–15, and 85–88% of the total maize area in the country, respectively (Koirala et al., 2020b; 2020c). The potential yield of maize cannot be achieved only by area expansion, and popularization of OPVs, without promoting high-yielding hybrids, as stated in National Seed Vision (NSV) and Agriculture Development Strategy (ADS) (SQCC, 2013; ADS, 2015). The overall maize seed replacement rate of 17.83% (Memoire, 2017) should be reached to 33% by 2025 (SQCC, 2013). To meet the demand for hybrid maize, NSV envisaged the development and promotion of twelve and five maize hybrids by the public and private sectors, respectively, by 2025.

Driven by climate change effects, heat stress is becoming an eminent constraint of maize production in all the major maize-producing regions, including Nepal. If the current trends of global warming continue until 2050, the production and productivity of maize will be decreased by 17% in South Asia (CIMMYT, 2016). Shrestha and his colleagues (1999) predicted the warming trend after 1977 from 0.06 to 0.12°C $year^{-1}$ in most of the middle mountain and Himalayan regions of Nepal. Malla (2008) reported an average rise in temperature of 0.06°C $year^{-1}$ from 1975 to 2006. Nevertheless, the average temperature in Nepal has been increased at an annual rate of 0.06°C between 1977 and 2000, with a 0.04°C and 0.08°C increase in Terai and the Himalayas, respectively (Synnott, 2012). The expected mean annual temperatures of 1.3–3.8°C by 2060 and 1.8–5.8°C by 2090 and reduced annual precipitation of 10 to 20% can affect Nepal's agriculture sector (CIF, 2018).

The development of heat-resilient variety(ies) is an appropriate option to combat the negative impacts of climate change (Acharya and Bhatta, 2013). Heat-stress to maize is exposure to temperatures above a threshold level for a period that causes irreversible damage to growth and development, which is a function of the intensity, duration, and rate of increase in temperature (Zaidi et al., 2016). The most critical period to heat stress that is highly susceptible is from tassel emergence to early grain-filling (Vinayan et al., 2020). Spring maize, planted in the maize-rice system is estimated to be about 15.5% of the total maize in Nepal. Yield loss of spring and early summer maize reaches up to 75% due to heat-stress (Koirala et al., 2017b) causing leaf firing, silk damage, and tassel blast, which depends on the crop's stage, severity, and duration of stress (Monsanto, 2012). Anthesis and silking of the crop when coinciding with a temperature above 38°C leads to leaf firing and tassel blast resulting in poor pollination, and barren ears which are the critical period to determine grain yield. Lobell and Burke (2010) reported reduced higher maize yields with a 2°C rise in temperature than the reduction created by precipitation dropped more than 20%. Likewise, 13% yield reduction due to an increase in temperature by 2°C was also recorded (Rowhani et al., 2011).

However, heat stress-tolerant (HST) hybrids compared to current/normal commercial varieties could minimize yield loss by 36 and 93%, and 33 and 86% under rainfed and irrigated conditions by 2030 and 2050, respectively (Tesfaye et al., 2017). Thus, ever-increasing food/feed demand can be met only by developing climate-resilient maize hybrids. Therefore, the objectives of this study were to identify, evaluate, and deploy high-yielding HST hybrids in different agro-ecological domains of Nepal to increase maize production and productivity in the public-private partnership model.

MATERIALS AND METHODS

The project entitled "Heat stress-tolerant maize for Asia (HTMA)" was launched by CIMMYT and funded by the USAID under the Feed the Future (FTF) initiative using a public-private partnership approach in Nepal, India, Bangladesh, Pakistan, and the USA in 2012, and now is in the second phase. The experimental materials consisted of HST single cross hybrids selected from various trials conducted in the past. The trial set comprised fifteen single cross hybrids, including Rampur Hybrid-8, RML-86/RML-96, and RML-95/RML-96 as checks were evaluated at two sites in Madi, Chitwan; and one in Ghorahi, Dang, by using RCBD with three replications during the spring of 2016/17. Likewise, NMRP conducted two demonstration sets of 20 and 18 promising hybrids along with P3533, P3535, P3396, and DKC9081 as commercial checks in different pockets of Chitwan (Madi, Rampur, and Narayanpur), Sarlahi (Sagarnath-1 and Sagarnath-2), Jhapa, Bara, and Banke districts considering a site as replication during the winter of 2016/17 and 2017/18, respectively. To shorten the longer period of 10–12 years to release a variety and to fulfill the immediate demand for hybrids of Nepali farmers, emphasis has been given to the fast-track variety release process. Therefore, multi-environment testing was emphasized rather than tested for many years. During two years period, eight locations were used including experiments and demonstrations. Madi in Chitwan and Sagarnath in sarlahi district are potential pockets for hybrids, therefore two sites in Madi for experimentation in 2016/17, and two sites for demonstration in 2016/17 and 2017/18 in Sagarnath were used. Table 1 highlights the geographical description of experimental/demonstration sites.

Table 1. Geographical description of experimental/demonstration sites at different parts of the country for the period of 2016/17 and 2017/18

Location	Longitude	Latitude	Elevation (masl)
Maharanijhoda, Jhapa	87°42’15”E	26°34’41”N	103
Sagarnath, Sarlahi	85°40’14”E	26°58’43”N	130
Dumarwana, Bara	85°02”58”E	27°07’41”N	126
Narayanpur, Chitwan	84°23’21”E	27°38’58”N	198
Madi, Chitwan	84°21’47”E	27°25’42”N	253
Rampur, Chitwan	84°20’20.9″E	27°39′0.3″N	228
Ghorahi, Dang	82°28’38”E	28°02’13”N	657
Khajura, Banke	81°35’23”E	28°06’48”N	181

The plot size of an individual entry in the experiment was 12m^2, consisting of four rows of 5-m long, whereas the plot size was 30m^2, which is ten rows of 5-m long in demonstration sets. The row-to-row and plant-to-plant distances were 60 and 25 cm, respectively, both in experiments and demonstrations. Farmyard manure (FYM) @15 t ha^{-1} in combination with chemical fertilizer @180:60:40 N:P_2O_5:K_2O kg ha^{-1} was applied. CIMMYT's procedures (CIMMYT, 1985) were adopted to measure days to 50% anthesis and silking, plant and ear heights, field weight, and other parameters as given below:

Days to 50% anthesis: The number of days from planting until the date which 50% of the plants in a plot are shedding pollen.

Days to 50% silking: The number of days from planting until 50% of the plants in a plot has silks 2-3 cm long.

Anthesis-silking interval (ASI): This is the interval in days between days to 50% silking and days to 50% anthesis.

Plant height: The distance in cm from the plant base to the point where the tassel starts to branch. Measurement is taken from five randomly selected plants.

Ear height: The distance from the plant base to the node bearing the uppermost ear in cm. For convenience, the same five plants whose plant height was measured are used to measure this trait,

Ear position: Ear height divided by plant height showing the point of ear placement in the plant.

Field weight: Weight of the ears harvested from central rows in kilograms to one decimal place.

Moisture content (%): Ten ears are selected from each plot, two central kernel rows on each one is removed, grains are mixed, and with this sample, moisture percentage is determined in the grain at harvest. We have to delay the harvest of maize until its moisture content is low (15-25%). Doing so, the grain is much easier to shell for moisture content determination and most moisture meters are more accurate at low moisture levels.

Grain yield: Field weight was converted into grain yield (t ha^{-1}) by adjusting 80% shelling recovery and 15% moisture level using the following formula adopted by Koirala et al. (2017c).

$$\text{Grain yield (kg/ha)} = \frac{\text{F.W. (kg plot}^{-1}\text{) x (100-M.C.) x SP x10,000}}{\text{85 x Net harvested area (m}^2\text{)}}$$

Where,

F.W.= Fresh weight of harvested ears in kg per plot

M.C.= Grain moisture content in percent at harvest

SP= Shelling percent

85= Grain moisture adjusted to 15%

Except for grain yield, mean values combined over locations/sites have been presented in the tables.

Statistical analysis: The data were recorded and analyzed using ADEL-R software. The significant differences between genotypes were calculated using the least significant difference (LSD) test at 1% or 5% level of significance, respectively (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Experiment

There was a difference among the genotypes for days to 50% anthesis at Ghorahi, Dang, during spring 2016/17. Three hybrids, such as ZH15405, ZH15272, and Rampur Hybrid-8 flowered three days earlier than average days to flowering of 62 days, whereas genotypes RML-95/RML-96 and ZH1615 flowered 5−6 days later. Genotypes varied for the average plant and ear height. Plant height ranged from 151 cm of CAH1432 to 195 cm of CAH1715, whereas ear height ranged from 53 cm of ZH1615 to 85 cm of ZH1611. The ear position of the tested hybrids ranged from 0.33 of ZH1615 to 0.48 of ZH1611 when combined over locations. The grain yield of the tested hybrids at individual locations did not differ significantly ($P>0.05$), however, significant differences among the genotypes were recorded when data were averaged over locations ($P<0.05$). The mean grain yield ranged from 4.3 to 6.45 t ha^{-1} (Table 2).

Table 2. Grain yield and other traits of heat stress-tolerant hybrids tested at various sites (Madi-1, Madi-2, and Ghorahi) of Terai, 2016/17 spring

Genotype	AD+	PH	EH	EP	Grain yield, t ha^{-1}			
					Madi-1	Madi-2	Ghorahi	Mean
CAH1432	64	151	61	0.40	6.81	9.25	3.9	6.65
ZH15405	62	153	61	0.40	7.07	6.35	5.8	6.41
ZH141592	63	162	61	0.37	5.73	6.37	6.2	6.10
RML-86/RML-96	66	169	69	0.41	7.24	7.26	3.8	6.10
CAH1715	65	195	78	0.40	6.64	6.27	5.1	6.00
Rampur Hybrid-8	62	191	81	0.43	6.17	6.84	4.5	5.84
ZH1611	63	176	85	0.48	6.12	6.17	5.0	5.76
CAH175	68	177	71	0.40	6.12	6.11	4.8	5.68
CAH1418	68	164	69	0.42	5.99	7.07	3.3	5.45
ZH1615	71	160	53	0.33	7.30	6.41	2.2	5.30
CAH1727	66	181	73	0.40	5.80	5.97	3.6	5.12
ZH15272	62	157	64	0.41	5.65	5.42	4.1	5.06
VH123050	67	167	61	0.37	5.22	5.14	4.6	4.99
ZH15383	63	169	75	0.44	5.17	5.73	3.9	4.93
RML-95/RML-96	70	167	77	0.46	4.50	6.47	3.3	4.76
Minimum	62	151	53	0.33	4.50	5.14	2.20	4.76
Maximum	71	195	85	0.48	7.30	9.25	6.20	6.65
Mean	65	170	70	0.41	6.10	6.45	4.30	5.62
F-test	*	**	**		ns	ns	ns	*
$LSD_{0.05}$	5.6	16.85	10.70		-	-	-	1.51
CV, %	4	5.94	9.20		14.46	12.92	26.8	16.0

AD+: Days to 50% anthesis (data recorded only from Ghorahi), PH: Plant height in cm, EH: Ear height in cm, and EP: Ear position (data recorded from Madi-1, Madi-2, and Ghorahi)

Demonstration

In 2016/17, genotypes differed for days to 50% anthesis (P<0.001), days to 50% silking (P<0.001), plant height (p<0.001), and ear height (P<0.001) when combined over locations (Rampur, Sagarnath-2, Sagarnath-2, Narayanpur and, Madi) (Table 3). Days to 50% anthesis ranged from 94 (ZH1521) to 112 days (ZH1615) when averaged across locations. A similar trend was observed for days to 50% silking that ranged from 97 (ZH1521) to 116 days (ZH1615). Anthesis-silking interval (ASI) ranged from two to four days among the hybrids. Hybrids with shorter mean plant and ear height of 186 and 88 cm and extended plant and ear height of 223 and 115 cm, respectively, were observed at NMRP Rampur and Sagarnath-1 (data not shown). Mean plant height among the hybrids ranged from 166 cm for CAH1432 and VH112337 to 257 cm for P3535 with a demonstration mean value of 202 cm. The ear height ranged from 65 cm (VH112337) to 128 cm (P3535). Ear position was ranged from 0.39 for VH112337 to 0.57 for Rampur Hybrid-6 (Table 3).

Table 3. Combined quantitative traits of heat stress-resilient hybrids demonstrated at various sites (Rampur, Sagarnath-1, Sagarnath-2, Narayanpur, and Madi) in Terai condition, 2016/17 winter

Genotype	AD	SD	ASI	PH	EH	EP
VH112337	107	110	3	166	65	0.39
ZH141592	107	109	2	196	95	0.48
ZH1521	94	97	3	193	94	0.49
CAH178	107	109	2	183	88	0.48
ZH138038	102	105	3	172	91	0.53
Rampur Hybrid-10	107	109	2	203	102	0.50
CAH1715	111	114	3	236	120	0.51
CAH177	98	101	3	211	114	0.54
CAH153	111	115	4	215	113	0.53
CAH1719	108	110	2	208	94	0.45
CAH175	98	102	4	200	101	0.51
Rampur Hybrid-8	111	113	2	21	110	0.51
ZH1505	107	110	3	202	103	0.51
CAH1432	98	102	4	166	78	0.47
ZH1611	104	107	3	221	121	0.55
ZH1615	112	116	4	203	99	0.49
P3533	108	111	3	227	122	0.54
P3535	107	110	3	257	128	0.50
Rampur Hybrid-4	111	114	3	175	92	0.53
Rampur Hybrid-6	109	113	4	182	104	0.57
Minimum	94	97	2	166	65	0.39
Maximum	112	116	4	257	128	0.57
Mean	106	109	3	202	102	0.50
F-test	**	**		**	**	
$LSD_{0.05}$	1.7	1.9		21.1	13.7	
CV, %	1.3	1.4		8.3	10.7	

AD: Days to 50% anthesis, SD: Days to 50% silking, ASI: Anthesis-silking interval, PH: Plant height in cm, EH: Ear height in cm, EP: Ear position

The mean grain yield differed during the winter of 2016/17 significantly ($P<0.05$) among the hybrids when combined over locations. The mean grain yield was 6.69 t ha^{-1}. The grain yield among the locations varied from 3.88 t ha^{-1} (Narayanpur site; $P>0.05$) to 6.82 t ha^{-1} in Madi ($P>0.05$). The highest mean grain yield of 10.11 t ha^{-1} was recorded at Sagarnath-1 ($P>0.05$) (Table 4).

Table 4. Grain yield (t ha^{-1}) of heat stress-tolerant maize hybrids demonstrated at various locations (Rampur, Sagarnath-1, Sagarnath-2, Narayanpur, and Madi) in Terai, 2016/17 winter

Genotype	Rampur	Sagarnath-1	Sagarnath-2	Narayanpur	Madi	Mean
P3535	6.33	11.00	8.09	2.82	10.55	7.76
CAH1719	8.83	10.15	6.75	4.63	7.49	7.57
CAH178	6.60	10.74	6.30	4.65	8.36	7.33
CAH1432	4.47	12.57	7.23	3.83	7.93	7.21
P3533	3.20	12.00	9.37	4.33	6.60	7.10
Rampur Hybrid-8	6.23	10.10	7.68	4.16	6.77	6.99
ZH1611	5.12	9.28	8.27	4.61	7.51	6.96
ZH1505	5.56	10.92	6.68	3.89	7.63	6.94
ZH1615	5.73	10.32	6.62	4.62	6.99	6.86
Rampur Hybrid-10	7.69	10.04	6.23	4.32	5.80	6.82
CAH153	6.08	9.30	7.98	3.59	7.01	6.79
ZH1521	6.93	9.90	6.27	3.15	7.36	6.72
Rampur Hybrid-6	7.71	9.42	5.41	4.17	6.68	6.68
CAH1715	8.31	9.51	4.56	4.67	5.82	6.57
ZH138038	5.27	11.25	5.50	3.88	6.90	6.56
CAH177	6.82	11.14	4.76	3.22	5.95	6.38
CAH175	6.71	9.10	5.55	3.37	6.84	6.31
ZH141592	5.10	9.46	6.32	3.39	5.03	5.86
Rampur Hybrid-4	4.07	7.48	7.62	3.40	5.23	5.56
VH112337	4.70	8.68	5.87	3.09	3.54	5.18
Minimum	3.20	7.48	4.56	2.82	3.540	5.18
Maximum	8.83	12.57	9.37	4.67	10.55	7.76
Mean	6.07	10.11	6.68	3.88	6.82	6.69
F-test						*
$LSD_{0.05}$						1.48
CV, %						18.1

The hybrids set for demonstration purposes also differed for days to 50% anthesis ($P<0.05$), days to 50% silking ($P<0.05$), and plant height ($P<0.05$) across Terai when data combined over locations in winter 2017/18. The days to 50% anthesis varied from 112 days of ZH15286 and ZH138077 to 126 days of CAH1723 with a mean of 118 days. The days to 50% silking ranged from 115 to 129 days with a mean value of 121 days. The minimum plant height of 179 cm was measured for ZH1718, whereas the maximum plant height of 211 cm was attained by DKC9081 with a mean value of 194 cm when combined over locations (Table 5).

Table 5. Combined quantitative traits of heat stress-resilient maize hybrids demonstrated at various Terai locations (Maharanijhoda, Sagarnath-1, Sagarnath-2, Dumarwana, Madi, Rampur, and Nepalgunj), 2017/18 winter

Genotype	AD	SD	ASI	PH	EH	EP
ZH141592	116	119	3	184	87	0.47
ZH138077	112	115	3	181	86	0.48
CAH1415	120	122	2	200	93	0.47
RML-95/RML-96	119	121	2	187	99	0.53
ZH15286	112	115	3	194	94	0.48
ZH1718	113	115	2	179	85	0.47
RML-86/RML-96	122	124	2	197	99	0.50
CAH1715	122	124	2	207	103	0.50
ZH15440	121	123	2	196	98	0.50
P3396	117	119	2	207	90	0.43
CAH1424	119	121	2	202	100	0.50
CAH1723	126	129	3	196	99	0.51
DKC9081	117	120	3	211	101	0.48
Rampur Hybrid-10	117	119	2	203	96	0.47
Rampur Hybrid-4/RML-17	122	124	2	186	92	0.49
CAH1722	121	123	2	186	98	0.53
Rampur Hybrid-6/RML-17	120	122	2	181	96	0.53
CAH1725	115	118	3	188	90	0.48
Minimum	112	115	2	179	85	0.43
Maximum	126	129	3	211	103	0.53
Mean	118	121	2.4	194	95	0.49
F-test	*	*		*	ns	
$LSD_{0.05}$	8.5	9.12		20	-	
CV, %	3.42	3.58		10	16	

AD: Days to 50% anthesis, SD: Days to 50% silking, ASI: Anthesis-silking interval, PH: Plant height in cm, EH: Ear height in cm, EP: Ear position

The mean grain yield during 2017/18 varied ($p<0.05$) among genotypes when combined over locations. The mean grain yield was 8.57 t ha^{-1} where DKC9081 had yielded the highest (11.16 t ha^{-1}). Hybrids produced a higher grain yield of 10.72 t ha^{-1} at Khajura, followed by 10.59 t ha^{-1} at Sagarnath-1 and 9.07 t ha^{-1} at Sagarnath-2. HSR hybrids such as Rampur Hybrid-10 (9.52 t ha^{-1}), ZH141592 (9.24 t ha^{-1}), CAH1715 (8.83 t ha^{-1}), and ZH15440 (8.77 t ha^{-1}) were statistically similar ($p>0.05$) to P3396 (10.22 t ha^{-1}) (Table 6).

Table 6. Grain yield (t ha^{-1}) of heat stress-tolerant hybrids demonstrated at various locations in the Terai environment, 2017/18 winter

Genotype	MJ	SS^1	SS^2	DB	MC	RC	NB	Mean
DKC9081	11.85	12.84	10.70	11.60	11.46	5.17	14.49	11.16
P3396	8.11	12.12	9.43	9.20	10.99	6.77	14.93	10.22
Rampur Hybrid-10	8.57	11.99	8.01	9.12	10.15	5.60	13.18	9.52
ZH141592	8.61	14.00	9.28	7.75	7.40	7.57	10.09	9.24
CAH1715	6.56	11.56	9.93	7.41	8.57	6.92	10.90	8.83
ZH15440	4.88	9.20	10.82	7.97	10.05	6.61	11.82	8.76
CAH1415	4.55	11.34	9.85	8.21	8.08	6.00	12.71	8.68
CAH1424	6.19	8.98	9.02	7.82	9.98	4.76	12.99	8.53
RML-95/RML-96	6.92	10.39	7.71	6.85	8.34	7.97	10.52	8.39
ZH15286	6.22	12.57	8.66	7.65	7.06	5.97	10.36	8.35
CAH1722	6.82	9.44	8.52	9.25	7.55	5.54	11.10	8.31
ZH1718	7.23	9.72	8.14	7.99	8.41	7.06	9.39	8.28
RML-86/RML-96	7.33	10.11	8.02	5.04	8.49	8.02	9.07	8.01
ZH138077	5.09	10.81	8.69	7.40	7.30	5.68	9.04	7.72
CAH1723	7.30	8.35	10.29	9.20	7.96	2.44	8.09	7.66
CAH1725	6.88	11.03	8.64	7.84	6.21	4.67	6.96	7.46
Rampur Hybrid-4/RML-17	5.29	9.62	9.35	7.73	7.27	3.27	9.35	7.41
Rampur Hybrid-6/RML-17	10.46	6.84	7.72	4.93	6.14	4.57	7.52	6.88
Minimum	4.55	6.84	7.71	4.93	6.14	2.44	6.96	6.88
Maximum	11.85	14.00	10.82	11.60	11.46	8.02	14.93	11.16
Mean	7.26	10.59	9.07	7.97	8.45	5.75	10.72	8.57
F-test								*
$LSD_{0.05}$								1.52
CV, %								17

MJ: Maharanijhoda, Jhapa; SS^1: Sagarnath, Sarlahi, location 1; SS^2: Sagarnath, Sarlahi, location 2; DB: Dumarwana, Bara; MC: Madi, Chitwan; RC: Rampur, Chitwan; NB: Nepalgunj, Banke

Prasanna in 2018 reported that 80% of the total maize area in South and South East Asia is rainfed which is prone to various climatic extremes such as drought, heat, waterlogging, acidity, or a combination of drought and heat. Abiotic stress-tolerant varieties are beneficial in the context of climate change in minimizing the production risks and improving farmers' livelihoods (Raghu et al., 2015). Grain yield may reduce by 101 kg ha^{-1} on a daily basis if a temperature of 35°C remains during pollination and grain filling stages (Naveed et al., 2016). All aspects of maize plants are affected by heat stress. It decreases plant height by 15% (Traore et al., 2000) producing short internodes (Weaich et al., 1996), reduces life cycle, retards growth and development (Chaubey et al., 2016), inhibits kernel growth rate, weight (Commuri and Jones, 2001) resulting in reduced grain yield.

HST hybrids can play a game-changer role to increase production and productivity in the context of climate change for sustainable food and feed security. High night-time temperatures affected maize yields in 2010 and 2012 across the U.S. Corn Belt (EPA, 2016). As climate change is a global phenomenon, Wang et al. (2011) predicted with >90% probability that a 15% maize yield reduction in the Jilin province of China may occur in 2070 due to the combined effect of temperature and precipitation changes. Due to more than a 5°C temperature increase in Iowa by the end of the 21st century, maize yield is estimated to decrease by 18% (Ummenhofer et al., 2015). Likewise, 15 to 50% maize yield reduction is predicted from the late 20th century to the middle and late 21st century in Iowa (Xu et al., 2016). In the case of Africa and Latin America, a 10% yield reduction has been predicted (Seed Map) to 2055 (Jones and Thornton, 2003). It is estimated that the average temperature in Nepal increased at an annual rate of 0.06°C from 1977 to 2000. The increment was 0.04°C in Terai and 0.08°C in the Himalayas (Synnott, 2012). Scientists in Zimbabwe also identified heat and drought stress-resilient maize hybrids and named them game-changer technology (ANGOP, 2016).

The tasseling, silking, pollination, and grain filling are extremely critical stages to have increased maize yields. Days to 50% anthesis and silking play a crucial role in identifying the maturity period and anthesis to the silking interval of the cultivar. Top yielding genotypes, such as P3396, Rampur Hybrid-10, CAH1715, ZH141592, CAH178, and CAH1719 have a lower ASI value. These hybrids have better synchrony between male and female flowers (Table 3 and 6) indicating better pollination even in the stress environment. This finding is in line with the findings of Noor et al. (2019). Edmeades et al. (2017) also showed a high positive correlation of grain yield with ASI in drought conditions. Similarly, Deutsch and his colleagues (2018) predicted 10–25% yield losses of major cereals – rice, maize, and wheat due to a per degree increase of global mean surface warming.

Plant and ear heights are considered important traits not only for higher grain yield but also for lodging resistance, disease reactions, fodder value, and tackling niche-specific farmers' problems. In demonstrations, the ear position of 50% and 83% of the hybrids in 2016/17 and 2017/18 was ≤0.50 and were tolerant of lodging.

In the experiment conducted during the spring of 2016/17, CAH1432, ZH15405, ZH141592, and CAH1715 heat-tolerant hybrids produced up to 14% higher grain yield than heat-tolerant registered Rampur Hybrid-8 (Table 2). CAH178, CAH1719, and CAH1432 produced grain yield statistically at par with P3533 and P3535 in the demonstration during the winter of 2016/17 (Table 4). Similarly, ZH141592 and Rampur Hybrid-10 were statistically at par with commercial check P3396 during the winter of 2017/18 (Table 6). The findings of these experiments agreed with the findings of Setimela (2017) who reported that climate-resilient hybrids had produced 20–25% higher grain yield compared to commercial varieties under low-input and stress environments in eastern and southern Africa. Likewise, other HTMA hybrids such as ZH191085 and ZH182082 tested by the Indian Institute of Maize Research (ICAR, 2020) yielded more than 8 t ha^{-1} under heat stress conditions. Generally, farmers harvest 6–7 t ha^{-1} grain yield from multi-national company hybrids. Therefore, the nationally developed and identified heat stress-resilient hybrids producing grain yield more than 7 t ha^{-1} in demonstrations are potential hybrids for the future.

CIMMYT first licensed the heat-stress resilient maize hybrids for deployment in Nepal in 2015 (CIMMYT, 2015). The HST hybrids identified better and licensed to Nepal are CAH1513, CAH1520, CAH158, CAH1511, and CAH1515 in 2015, CAH151, and CAH153 in 2016, and CAH1715 and CAH1721 in 2017. The first two HST hybrids, registered in Nepal were CAH151 and CAH153, as Rampur Hybrid-8 and Rampur Hybrid-10 for commercial cultivation in Terai and inner Terai regions up to 700 masl (Koirala, 2017a). For the first time in Nepal, the F1 seed of HST maize hybrids was produced on a larger scale in isolation by Lumbini Seed Company Pvt. Ltd., Rupandehi and Namuna Ekikrit Sahakari Kheti, Maharanijhoda, Jhapa in close collaboration with NMRP and had produced the seed yield of 2.5 and 2.2 t, respectively, in 2018/19 winter. As reported by hybrid growing farmers, the yield performance of Rampur Hybrid-10 is at par with better multi-national company hybrids, and its demand is in an increasing trend. In 2019/20 winter, Namuna Ekikrit Sahakari Kheti, Maharanijhoda, Jhapa; Madan Bhandari Memorial Academy, Morang; Lumbini Seed Company Pvt. Ltd., Rupandehi; Gorkha Seed Company Pvt. Ltd., Dang; Unique Seed Company Pvt. Ltd., Dhangadhi, Kailali, and Panchashakti Seed Company Pvt. Ltd., Dhangadhi, Kailali were engaged in producing 30.5 t F1 seed of Rampur Hybrid-10 as well as maintaining their parental lines in close collaboration with NMRP Rampur. Koirala et al. (2021) conducted various experiments on hybrid maize during winter from 2016/17 to 2018/19 in Terai and inner Terai ecological belt across Nepal and identified CAH1715, RML-86/RML-96 and, RML-95/RML-96 promising like in experiments and demonstrations as mentioned in this paper. Therefore, these hybrids are in the pipeline for release/registration, which will provide hybrids' selection options to both growers and seed producers. Neupane et al. (2020) reported that in addition to Rampur Hybrid-10, pipeline hybrids RML-86/RML-96 and RML-95/RML-96 are also heat stress-tolerant among the NMRP developed hybrids. Therefore, it is the right time to shift from OPVs to hybrids with remarkable emphasis on stress-resilient ones.

Increasing demand for maize, both for food and feed should come from increased yield in maize-based cropping system as an expansion of maize area forever is almost impossible. To develop self-reliance in maize; it is high time to adopt hybrid maize technology in Terai, inner Terai, foothill valleys, and potential pockets of the middle hills of Nepal, urgently and aggressively. If hybrids are the only potential options, it is always better to move with stress-resilient hybrids targeting climate change adaptation strategy (Cairns and Prasanna, 2018), and increased production and productivity as well, to translate the goal of maize self-sufficiency into reality. For this, 25% of the total maize area should be covered by native hybrids with an average yield of $\geq$6.00 t ha^{-1} in the farmers' fields that will boost the average national maize productivity of 4.00 t ha^{-1}. Efficient, profitable, and sustainable seed production should be done by private entrepreneurs in the public-private partnership model. To maintain this yield level, the contribution of hybrids and OPVs to total maize SRR should reach 25 and 8%, respectively. For this, there should be strong support from the government, and Nepal Agricultural Research Council (NARC) to "Hybrid maize factory" NMRP regarding well-equipped human, infrastructure, and financial resources to move hybrid research programs as per present and future demand of the country.

CONCLUSION

Developing and deploying heat stress-resilient (HSR) hybrids instead of OPVs could make the country self-sufficient for food, feed, and seed. The selected HSR hybrids are with ASI less than three, ear position at around the center point of the stalk, and produced grain yield more or at par with popular prevailing multi-national hybrids. The performances of hybrids such as CAH1432, ZH15405, ZH141592, CAH1715, CAH178, CAH1719, and CAH1432 need to be re-verified and released/registered for commercial cultivation. Then, these hybrids should be deployed in a public-private partnership model to generate employment opportunities and food/feed security for Nepal. Generally, heat and drought stresses appear together in rainfed agriculture in Nepal and therefore should be tackled together in the future in the case of maize.

ACKNOWLEDGMENTS

The authors are grateful for the technical and financial support of CIMMYT under the "Heat Tolerant Maize for Asia (HTMA)" project. Financial support from USAID is duly acknowledged. We are thankful to the staff at NMRP Rampur and farmers who were directly or indirectly involved and contributed while implementing project activities.

REFERENCES

Acharya, S.P. and Bhatta, G.R. (2013). Impact of climate change on agricultural growth in Nepal. *NRB Economic Review,* Nepal Rastra Bank, Research Department, 25(2): 1–16.

ADS. (2015). Agriculture Development Strategy (ADS) 2015–2035. Government of Nepal, Ministry of Agricultural Development, Singhdurbar, Kathmandu.

ANGOP. (2016). Zimbabwe: Scientists unveil maize seeds resistant to heat, drought. *ANGOP* (*Agencia Angola Press*) http://www.angop.ao/angola/en_us/noticias/africa/2016/9/43/Zimbabwe-Scientists-Unveil-Maize-Seeds-Resistant-Heat-Drought,b56c2554-4357-4357-815c-9bf6692823b7.html. Accessed on 26th July, 2020.

Cairns, J.E. and Prasanna, B.M. (2018). Developing and deploying climate-resilient maize varieties in the developing world. *Current Opinion in Plant Biology,* 45: 226–230.

Chaubey, I., Bosch, D.D., Munoz-Carpena, R., Harmel, R.D., Douglas-Mankin, K.R., Nejadhashemi, A.P., Srivastava, P. and Shirmohammadi, A. (2016). Climate change: a call for adaptation and mitigation strategies. *Transactions of the ASABE, 59*(6): 1709–1713.

CIF. (2018). Promoting climate resilient agriculture in Nepal. Building climate change resilient communities through private sector participation, Summary document. Case study, 2018. https://www.climateinvestmentfunds.org/sites/cif_enc/files/knowledge-documents/nepal_2_pages_dtp2doc.pdf. Accessed on 27th August, 2020.

CIMMYT. (1985). Managing trials and reporting data for CIMMYT's international maize testing program. CIMMYT Mexico. Pp. 20.

CIMMYT. (2015). The first heat-tolerant maize hybrids are licensed for deployment in Bangladesh, India, and Nepal. https://www.cimmyt.org/news/the-first-heat-tolerant-maize-hybrids-are-licensed-for-deployment-in-bangladesh-india-and-nepal/. Accessed on 17th September, 2017.

CIMMYT. (2016). Expanding for faster and wider deployment of heat-tolerant hybrids in South Asia. https://www.cimmyt.org/news/htma-expanding-for-faster-and-wider-deployment-of-heat-tolerant-hybrids-in-south-asia/. Accessed on 15th June, 2017.

Commuri, P.D. and Jones, R.J. (2001). High temperatures during endosperm cell division in maize: A genotypic comparison under in vitro and field conditions. *Crop Science,* 41(4): 1122–1130.

Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B. and Naylor, R.L. (2018). Increase in crop losses to insect pests in a warming climate. *Science,* 361: 916–919.

Edmeades, G.O., Trevisan, W., Prasanna, B.M. and Campos, H. (2017). Tropical maize (*Zea mays* L.). In: Genetic improvement in tropical crops. Springer, Pp. 57–109.

EPA. (2016). Climate change impacts: Climate impacts on agriculture and food supply. https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-agriculture-and-food-supply_.html. Accessed on 10th February, 2017.

Gomez, K.A. and Gomez, A.A. (1984). Statistical procedures for agricultural research. 2nd edn. International Rice Research Institute, College, Laguna. Pp. 680.

Gong, F., Wu, X., Zhang, H., Chen, Y. and Wang, W. (2015). Making better maize plants for sustainable grain production in a changing climate. *Frontiers in Plant Science,* 6*(*835): 1–6.

ICAR. (2020). Heat tolerant maize for Asia (HTMA-II) https://iimr.icar.gov.in/heat-tolerant-maize-for-asia-htma-ii/. Accessed on 13th October, 2020.

Jones, G.P. and Thornton, P.K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change*, 13(1): 51–59.

Koirala, K.B. (2017a). Up-scaling of proven technology for maize improvement through participatory approach in Nepal. In: Pandey, Pradyumna Raj and Koirala, Keshab Babu (Editors). Best practices of maize production technologies in South Asia. SAARC Agriculture Centre, Dhaka, Bangladesh. Pp. 61–95.

Koirala, K.B., Giri, Y.P., Rijal, T.R., Zaidi, P.H., Sadananda, A.R. and Shrestha, J. (2017b). Evaluation of grain yield of heat stress-resilient maize hybrids in Nepal. *International Journal of Applied Sciences and Biotechnology,* 5(4): 511–522.

Koirala, K.B., Rijal, T.R., Pokhrel, K.P., Ghimire, B., and Panthi, G.P. (2017c). Identification of pro-vitamin A maize for Nepal. *Asian Journal of Science and Technology,* 12: 7170–7178.

Koirala, K.B., Rijal, T.R., KC, G., Khan, S., Mahato, D.N., Manandhar, S., Subedi, S. and Tripathi, M.P. (2020a). Evaluation of maize hybrids in Terai and inner Terai ecological belt of Nepal. *Journal of Agriculture and Forestry University*, 4: 109–116.

Koirala, K.B., Rijal, T.R., KC, G., Katuwal, R.B., Dhami, N.B., Acharya, R., Sharma, S.R., Adhikari, B.N. and Tripathi, M.P. (2020b). Performance evaluation of maize hybrids under rainfed environments across the middle hills of Nepal. *Tropical Agroecosystems,* 1(1): 43–49.

Koirala, K.B., Adhikari, J.B. and Tripathi, M.P. (2020c). On-farm evaluation of hybrid maize in different ecologies of Nepal. *Azarian Journal of Agriculture,* 7(3): 84–92.

Koirala, K.B., Adhikari, B.N. and Tripathi, M.P. (2021). Maize (*Zea mays* L.) hybrids for Terai ecological belt of Nepal. *Journal of Agricultural Research Advances,* 3(1): 21–28.

Lobell, D.B. and Burke, M.B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology,* 150(11): 1443–1452.

Malla, G. (2008). Climate change and its impact on Nepalese agriculture. *The Journal of Agriculture and Environment,* 9: 62–71.

Memoire, A. (2017). Nepal: Agriculture and food security project (TF13719). June 12–17. Pp. 9. Accessed on 18th July, 2019.

MoF. 2021. Economic Survey 2020/21. Government of Nepal. Ministry of Finance. Singh Durbar, Kathmandu, Nepal. Accessed on 10th June, 2021.

Monsanto. 2012. Heat and drought stress impacts on corn. *Technology development and agronomy*, Agronomic Alert, Pp. 3.

Naveed, M., Ahsan, M., Akram, H.M., Aslam, M. and Ahmed, N. (2016). Genetic effects conferring heat tolerance in a cross of tolerant × susceptible maize (*Zea mays* L.) genotypes. *Frontiers in Plant Science, 7*:729.

Neupane, B., Poudel, A. and Wagle, P. (2020). Canopy temperature depression and normalized difference vegetation index as indicators of drought resistance and nitrogen recommendation in hybrid maize genotypes. *Azarian Journal of Agriculture,* 7(3): 69–75.

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 the reproductive stage. *Australian Journal of Crop Science,*13(4): 536–545.

Prasanna, B. (2018). Maize in Asia – Status, challenges and opportunities. In: Prasanna, B.M., Das, Aparna and Kaimenyi, Kelah K. (Editors). Book of Extended Summaries, 13th Asian Maize Conference, and Expert Consultation on Maize for Food, Feed, Nutrition, and Environmental Security. Ludhiana, India, October 8–11, 2018, CIMMYT, Mexico D.F. Pp. 1–8.

Raghu, P.T., Erenstein, O., Christian, B. and Krishna V.V. (2015). Adoption and outcomes of hybrid maize in the marginal areas of India. *Quarterly Journal of International Agriculture,* 54(2): 189–214.

Ranum, P., Pena-Rosas, J.P. and Garsia-Casal, M.N. (2014). Global maize production, utilization, and consumption. *Annals of the New York Academy of Sciences,* 1312: 105–112.

Rowhani, P., Lobell, D.B., Linderman, M. and Ramankutty, N. (2011). Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology,* 151(4): 449–460.

Setimela, P.S., Magorokosho, C., Lunduka, R., Gasura, E., Makumbi, D., Tarekegne, A., Cairns, J.E., Ndhele, T., Erenstein, O. and Mwangi, W. (2017). On-farm yield gains with stress-tolerant maize in Eastern and Southern Africa. *Agronomy Journal,* 109(2): 406–417.

Shrestha, A.B., Wake, C.P., Mayewski, P.A. and Dibb, J.E. (1999). Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971 to 94. *Journal of Climate,* 12: 2775–2786.

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. Pp. 87.

Synnott, P. (2012). Climate change, agriculture, and food security in Nepal. Developing adaptation strategies and cultivating resilience. Report prepared for mercy crops Nepal. Pp. 52.

Tesfaye, K., Zaidi, P.H., Gbegbelegbe, S., Boeber, C., Rahut, D.B., Getaneh, F., Seetharam, K., Erenstein, O. and Stirling, C. (2017). Climate change impacts and potential benefits of heat-tolerant maize in South Asia. *Theoretical Applied Climatology,*130(3–4): 959–970.

Traore, S.B., Carlson, R.E., Pilcher, C.D. and Rice, M.E. (2000). Bt and non-Bt maize growth and development as affected by temperature and drought stress. *Agronomy Journal*, *92*(5): 1027–1035.

Ummenhofer, C.C., Xu, H., Twine, T.E., Girvetz, E.H., McCarthy, H.R., Chhetri, N. and Nicholas, K.A. (2015). How climate change affects extremes in maize and wheat yield in two cropping regions. *Journal of Climate,* 28(12): 4653–4687.

Vinayan, M.T., Zaidi, P.H., Seetharam, K., Das, R.R., Viswanadh, S., Ahmed, S., Miah, M.A., Koirala, K.B., Tripathi, M.P., Arshad, M., Pandey, K., Chaurasia, R., Kuchanur, P.H., Patil, A. and Mandal, S.S. (2020). Genotype-by-environment interaction effects under heat stress in Tropical maize. *Agronomy,* 10: 1–18.

Wang, M., Li, Y., Ye, W., Bornman, J.F. and Yan, X. (2011). Effects of climate change on maize production, and potential adaptation measures: a case study in Jilin Province, China. *Climate Research,* 46(3): 223–246.

Weaich, K., Bristow, K.L. and Cass, A. (1996). Modeling preemergent maize shoot growth: II. High temperature stress conditions. *Agronomy Journal*, *88*(3): 398–403.

Xu, H., Twine, T.E. and Girvetz, E. (2016). Climate change and maize yield in Iowa. *PLoS ONE*, 11(5): e0156083.

Zaidi, P.H., Zaman-Allah, M., Trachsel, S., Seetharam, K., Cairns, J.E. and Vinayan, M.T. (2016). Phenotyping for abiotic stress tolerance in maize: Heat stress. A field manual. CIMMYT: Hyderabad, India. Pp. 32.