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Genotypic variations in phenology, productivity and heat-use efficiency of rainfed maize (*Zea mays*) in acid soils of north eastern Himalayan region

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ABSTRACT

Northeastern Himalayan Region (NEHR) of India having frail landscape with unique climate, high rainfall with orography led wide spatio-temporal variation, often occurrence of droughts,terminal heat and high cloud covers causes antagonistic relationship with solar radiation. Growing of low yielding traditional genotypes susceptible to abiotic stresses including low radiation-use efficiency further decreased the productivity (<1.5 t/ha) of rainfed maize (*Zea mays* L.) in this region. The region needs improved genotypes to overcome these shortfalls. In present study, a field experiment was conducted during 2012 and 2013 to evaluate the performance of 15 improved genotypes and compared with popular traditional genotypes for physiological indices, radiation-use efficiency and finally, correlated with productivity. Results revealed that amongst the improved genotypes, hybrids Vivek QPM 9 followed by Prakash recorded significantly (P<0.05) higher physiological attributes and grain yield (4 860-5 055 kg/ha), which was two folds higher than the local genotype Chakhaochujak (hill) (2 081-2 113 kg/ha). Similarly, few other hybrids (HQPM 7, BIO 9681, PMH 1, PMH 4 and HM 4) also recorded significantly (*P<0.05)* higher (48 to 126%) grain yield over local genotypes. Estimated radiation-use efficiency indices (pheno- and helio-thermal, heat use efficiency) were significantly (P<0.05) higher in hybrids compared to local genotypes. Exploring improved genotypes suitable to rainfed hilly ecosystem, thus, promises improvement of maize productivity *vis-à-vis* food and livelihood security in the NEHR of India and other similar agro-ecological regions.

Key words: Eastern Himalayan Region, Heat-use efficiency, Physiology, Productivity, Rainfed Maize, Silking, Tasseling

Northeastern Himalayan region (NEHR) of India, by virtue of its strategic setting in the frail landscape of eastern Himalaya has unique climate, recipient of high rainfall with orography led wide spatio-temporal variation, often occurrence of meteorological droughts and terminal heat and high cloud cover lead antagonistic relationship with sunshine duration (Choudhury *et al*. 2012). This result in climate induced vulnerability to the productivity of second most important crop of the region, i.e. rainfed maize, by affecting crop phenology, growth and development, radiation and photosynthetic-use efficiencies. Growing of low yielding genotypes susceptible to abiotic stresses and low radiation-use efficiency even in high soil organic carbon containing soils (Choudhury *et al*. 2013) further reduces the productivity of rainfed maize in the region (<1.5 tonnes/ha) (Choudhary *et al*. 2013). With the increasing evidence of less seasonal rainfall, terminal heat, frequent occurrence of extreme weather events coupled with scanty water resources across the region, the maize crop in the region is also under great risk of partial to complete failure.

Dry matter accumulation between two successive phenological events is the result of crop growth rate and duration of the phenophase. This is the consequence of leaf expansion and leaf area being much more sensitive to water and nutrient deficits than photosynthetic rate (Khan *et al*. 2005). Growth parameters such as leaf area index, growth rate and leaf area duration are very important in assessing crop growth and may be an indication of potential productivity since, cultivars having balanced vegetative growth under stress leads to better economic returns (Khan *et al*. 2005). Physiological variation is an important trait in influencing light interception, crop growth and yield in cereals (Awal and Khan 2000). The final dry matter yield has been shown to be proportional to total amount of radiation intercepted by crop during growth (Valero *et al*. 2005) and is largely determined by leaf area (Tollenaar *et al*. 2005).

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High yielding varieties (HYVs) of maize widely adopted in other parts of country, but in the NEHR, most of the farmers are growing low yielding local varieties, less adaptive to changing climate, particularly to abrupt changes in rainfall and temperature. The information on interaction of phenology of these HYVs and ambient temperature on crop performance under rainfed, acidic soils of NEHR is very important. It is anticipated that HYVs of maize with better management practices have immense potential to increase the existing production level by 2-3 times in the hilly ecosystem of NEHR. However, the suitability and performance of these genotypes under the agro-ecological condition of NEHR of India has not been evaluated yet. Keeping these aspects in view, the present investigation was conducted with the hypothesis that the improved genotypes (HYVs) may give better grain yield and profitability without any penalty on grain quality over the local genotypes in the NEHR agro-ecologies of India.

MATERIALS AND METHODS

An experiment was conducted at Langol farm of ICAR Research Complex for NEH Region, Manipur Centre, Imphal, India during May to September of 2012 and 2013. Experimental site falls under humid sub-tropical climate ($24^0$49' N latitude, $93^0$55' E longitude and 780 m above MSL altitude). The daily minimum and maximum temperatures during the study period varied widely between 15.1 to 35.2 ^{0}C in 2012 and 14.3 to 36.4 ^{0}C in 2013, respectively. During the experimental years, the site received an average annual rainfall of 1 430 mm in 2012 and 818 mm in 2013, with high degree of monthly variations. The daily sunshine hour's varied from 0 to 11.8 hr in 2012 and 0 to 10.8 hr in 2013 and relative humidity (mean) ranged between 70 to 90%. The soil of experimental site was loamy in texture, acidic in reaction (pH 5.1), and high in organic carbon (1.56 %), medium in available nitrogen (alkaline permanganate N, 181.5 kg/ha), low in available phosphorus (9.1 kg/ha) and available potassium (60 kg/ha).

The experiment was laid out in randomized block design with 17 maize cultivars and replicated thrice. Two low productivity potential popular local maize cultivars namely Chakhaochujak (plain) and Chakhaochujak (hill) of the region were used as check for comparison of performance against 15 HYVs including composites (Pusa Composite-3 and Vijay Composite) and hybrids (HQPM 7, HQPM 5, BIO 9637, BIO 9681, PMH 1, HQPM 4, PMH 3, Vivek QPM 9, HM 8 and PMH 4). Maize was grown following recommended package and practices by sowing at about 5 cm depth during first week of May and harvested in late August to mid September. Several performance indices were estimated as follows:

Crop growth rate (CGR = $(W_2–W_1)/(T2–T1)$ g/day/m where, W_1 and W_2 are the dry weights recorded at time (in days) T_1 and T_2, respectively.

Leaf area duration (LAD) = $(LAI_1+LAI_2) \times (T_2–T_1)\times½$. where LAI_1 = Leaf area index at t_1, LAI_2 = Leaf area index at t_2, t_1 and t_2 = Time of first and second observations,

Growing degree days (GDD) = $\sum[(Tmax+Tmin)/2-Tbase]$

Helio-thermal unit (HTU) = GDD × Duration of sunshine hour

Heat-use efficiency (HUE) = Grain yield (kg/ha) ÷ GDD

Pheno-thermal index (PTI) = GDD ÷ Growth days

Two years data were presented separately. The data were subjected to analysis of variance (ANOVA) for 1-factor (17 genotypes) randomized block design (RBD) with least significant difference test (LSD) at 5% probability for comparison of treatment means. The Duncan's multiple range test was used to segregate the significance of difference at *P-value* $P<0.05$ by comparing the means of the corresponding treatment combinations. Statistical analysis was performed with SAS Version 9.2 (SAS Institute Inc. Cary, NC, USA).

RESULTS AND DISCUSSION

Genotypic variation on growth and physiological attributes

Genotypic variation had significant ($P<0.05$) effects on most of the physiological attributes. Among all the genotypes, hybrid Prakash took minimum days to reach 50% tasseling and 50% silking while Bio 9681, PMH 1 as well as traditional genotype Chakhaochujak (hill) took maximum days to reach 50% tasseling and silking. Anthesis to silking interval (ASI) was also longest in Chakhaochujak (hill) during both the years (Table 1). Genotypic variation was significant ($P<0.05$) in maize biomass production and leaf area across crop growth stages (30 DAS, 60 DAS and maturity). Biomass production and leaf area recorded the highest in hybrids cultivars during both the years. As a result, the crop growth rate (CGR) and leaf area duration (LAD) were also higher in hybrids (Vivek QPM 9, Prakash and PMH 4) than composite and local genotypes (Table 2). Our findings from the experiment depicts that the hybrid genotypes were better performing than composite and local genotypes. Low CGR and LAD in locals might be due to less genetic potential and decreased photosynthetic efficiency or lower rate of biomass production (Khan *et al*. 2005). Physiological attribute values were higher during vegetative phase than at flowering to maturity phase. Similar results of higher values for CGR and LAD during vegetative growth but a decline during the later stages were reported by Valero *et al*. (2005). This decline with age is attributed to general decline in photosynthetic efficiency as the leaf becomes old. Increase in LAD consequently increased the rate of dry matter accumulation which was proportional to rate of dry matter accumulation per unit area.

Genotypic variation on yield

Genotypic variation of maize had significant ($P<0.05$) effect on the grain yield and was reflected in wide variability of grain yield: 2 114 to 5 055 kg/ha in 2012 and in 2013, it varied from 2 049 to 4 989 kg/ha (Table 3). During both the years, Vivek QPM 9 followed by Prakash recorded the

Table 1 Effect of maize genotype on phenological stages in north eastern Himalayan regions of India

Maize genotypes	At 50% tasseling		At 50% silking		ASI*	
	2012	2013	2012	2013	2012	2013
HQPM 7	59.00^{bc}	59.17^{abcde}	63.42^{cd}	64.50^{bcd}	4.42^{b}	5.33
HQPM 5	60.70^{ab}	58.87^{abcde}	64.98b^{c}	64.50^{bcd}	4.28^{b}	5.63
BIO 9637	58.80^{bcd}	58.90^{abcde}	63.25^{d}	64.50^{bcd}	4.45^{b}	5.60
BIO 9681	62.77^{a}	60.77^{abc}	67.42^{a}	66.50^{ab}	4.65^{b}	5.73
PMH 1	61.53^{a}	60.03^{abcd}	66.25^{ab}	65.83^{abc}	4.72^{b}	5.80
HQPM 4	56.42d^{efg}	58.42^{bcde}	62.43^{def}	64.23^{bcd}	6.02^{ab}	5.82
PMH 3	55.33^{fgh}	57.50^{def}	61.40^{efg}	63.67^{cde}	6.07^{ab}	6.17
$^{+}$V QPM 9	58.16^{cde}	58.00^{cdef}	62.68^{de}	63.60^{cde}	4.52^{b}	5.60
HM 8	57.50^{cdef}	56.17^{efg}	62.43^{def}	61.83^{de}	4.93^{b}	5.67
PMH 4	54.33^{ghi}	53.67^{hi}	60.13^{gh}	59.00^{fg}	5.80^{ab}	5.33
HM 4	54.25^{ghi}	55.17^{ghi}	59.47^{h}	61.10^{ef}	5.22^{ab}	5.93
Prakash	52.20^{i}	52.70^{i}	56.97^{i}	58.50^{g}	4.77^{b}	5.80
DHM 117	56.43^{defg}	52.33^{i}	61.23^{efg}	57.33^{g}	4.80^{b}	5.00
$^{++}$VC	62.00^{a}	61.53^{ab}	65.93^{ab}	66.93^{ab}	3.93^{b}	5.40
$^{\$}$PC 3	58.50^{bcd}	60.67^{abc}	62.87^{de}	66.27^{abc}	4.37^{b}	5.60
$^{\%}$CC (plain)	55.83^{efgh}	61.33^{ab}	61.73d^{efg}	66.60^{ab}	5.90^{ab}	5.27
$^{\%\%}$CC (hill)	53.67^{hi}	61.67^{a}	60.78^{fgh}	67.60^{a}	7.12^{a}	5.93
LSD (P=0.05)	2.16	2.70	1.59	2.4	1.79	NS

$^{\#}$ Means in the column followed by common letter (a-i) are statistically not significant at 5% level of significance. $^{+}$V QPM 9= Vivek QPM 9; $^{++}$VC= Vijay composite; $^{\$}$PC 3= Pusa Composite-3; $^{\%}$CC (plain)= Chakhaochujak (plain), $^{\%\%}$CC (hill)= Chakhaochujak (hill).

Table 2 Effect of maize genotype on crop growth attributes in north eastern Himalayan regions of India

Maize genotype	CGR (g/m^2/day)				LAD (days)			
	2012		2013		2012		2013	
	30-60 DAS	60 DAS-Mat	30-60 DAS	60-DAS-Mat	30-60 DAS	60-DAS-Mat	30-60 DAS	60-DAS-Mat
HQPM 7	16.80^{ab}	12.75^{bc}	14.28^{bcdef}	13.82^{ab}	77.50^{cd}	158.44^{bc}	75.65^{de}	154.88^{bcd}
HQPM 5	13.58^{cde}	13.24^{ab}	14.14^{cdef}	13.78^{ab}	65.90^{ef}	138.76^{def}	64.75^{fg}	137.07^{efg}
BIO 9637	14.31^{bcde}	13.87^{ab}	14.09^{cdef}	13.92^{ab}	67.40^{ef}	134.16^{ef}	66.95^{fg}	132.29^{fgh}
BIO 9681	16.47^{ab}	13.71^{ab}	15.90^{abcd}	13.02^{abc}	79.70^{bc}	156.31^{c}	77.95^{cde}	152.59^{cde}
PMH 1	16.99^{a}	13.65^{ab}	15.98^{abc}	13.79^{ab}	86.15^{b}	174.31^{ab}	85.00b^{c}	171.43^{ab}
HQPM 4	15.30^{abcde}	12.75^{bc}	15.27^{abcde}	13.29^{abc}	71.20^{de}	153.81^{cd}	70.60^{ef}	151.89^{cde}
PMH 3	15.62^{abcd}	14.12^{ab}	14.08^{cdef}	14.59^{a}	65.05^{efg}	132.16^{f}	64.70^{fg}	130.19^{fgh}
$^{+}$V QPM 9	17.52^{a}	14.58^{a}	17.50^{a}	14.01^{ab}	93.70^{a}	181.99^{a}	93.25^{a}	178.82^{a}
HM 8	15.94^{abc}	13.50^{ab}	15.62^{abcde}	13.55^{ab}	76.40^{cd}	149.02^{cde}	74.65^{de}	147.26^{def}
PMH 4	17.19^{a}	13.79^{ab}	16.17^{abc}	14.08^{ab}	86.40^{b}	179.10^{a}	83.95^{c}	174.19^{a}
HM 4	17.20^{a}	14.74^{a}	16.55^{ab}	13.52^{ab}	82.40^{bc}	158.37^{bc}	80.00^{cd}	154.94^{bcd}
Prakash	17.35^{a}	14.16^{ab}	16.81^{a}	13.96^{ab}	94.35^{a}	175.40^{a}	92.45^{ab}	168.90^{ab}
DHM 117	13.65^{cde}	13.62^{ab}	13.63^{def}	15.45^{a}	63.05^{fg}	132.61^{f}	62.40^{gh}	131.59^{fgh}
$^{++}$VC	13.47^{cde}	13.27^{ab}	13.40^{ef}	11.83^{bcd}	57.95^{gh}	123.13^{f}	59.55^{gh}	119.80^{gh}
$^{\$}$PC 3	13.31^{de}	13.36^{ab}	13.63^{def}	10.40^{d}	61.70^{fgh}	126.33^{f}	60.20^{gh}	120.98^{gh}
$^{\%}$CC (plain)	13.12^{de}	11.39^{c}	12.25^{f}	10.19^{d}	58.10^{gh}	137.67^{def}	56.40^{h}	138.28^{def}
$^{\%\%}$CC (hill)	12.90^{e}	11.21^{c}	12.12^{f}	10.76^{cd}	54.80^{h}	138.39^{def}	77.95^{cde}	184.51^{a}
LSD (P=0.05)	2.58	1.63	2.34	2.56	7.23	16.37	7.59	17.19

$^{\#}$ Means in the column followed by common letter (a-i) are statistically not significant at 5% level of significance. $^{+}$V QPM 9= Vivek QPM 9; $^{++}$VC= Vijay Composite; $^{\$}$PC 3= Pusa Composite-3; $^{\%}$CC (plain)= Chakhaochujak (plain), $^{\%\%}$CC (hill)= Chakhaochujak (hill).

highest grain yield while Chakhaochujak (hill) recorded the lowest grain yield. Similar to grain yield, oil and starch yields were also maximum in Vivek QPM 9 followed by Prakash while protein yield was maximum in HM 4 and Prakash followed by Vivek QPM 9 (Table 3). The minimum grain yield, oil, protein and starch yields were found in Chakhaochujak (hill), Chakhaochujak (plain) and Vijay composite.

Table 3 Effects of genotypes on maize yields in north eastern Himalayan regions of India

Cultivar	Grain yield (kg/ha)		Stover yield (kg/ha)		Oil yield (kg/ha)		Protein yield (kg/ha)		Starch yield (kg/ha)	
	2012	2013			2012	2013	2012	2013	2012	2013
HQPM 7	#4020.4^{d}	4004.47^{ef}	7882.9	7732.7	190.1^{de}	184.27^{cd}	305.5^{e}	304.53^{ef}	2902.3^{de}	2860.47^{de}
HQPM 5	3296.0^{g}	3269.13^{hi}	7391.7	7690.3	125.1^{h}	121.60^{h}	250.4^{h}	243.60^{i}	2420.6^{g}	2405.07^{g}
BIO 9637	3486.6^{f}	3425.50^{gh}	7561.3	7741.5	146.6^{g}	141.40^{g}	307.1^{e}	299.50^{fg}	2516.3^{fg}	2474.60^{g}
BIO 9681	4091.6^{d}	4023.60^{e}	7965.9	7875.8	173.1^{f}	167.80^{ef}	312.6^{e}	306.57^{ef}	2969.6^{d}	2898.77^{d}
PMH 1	4706.0^{b}	4544.93^{c}	8243.3	8149.6	218.5^{b}	205.87^{b}	336.0^{d}	331.97^{de}	3407.9^{b}	3291.10^{b}
HQPM 4	3640.7^{f}	3605.17^{g}	7748.6	7941.2	169.0^{f}	160.50^{ef}	346.4^{d}	345.93^{cd}	2595.6^{f}	2600.53^{f}
PMH 3	3155.7^{gh}	3130.37^{ij}	7884.6	7973.0	122.7^{h}	118.20^{h}	284.4^{fg}	268.67^{hi}	2274.6^{h}	2258.27^{h}
+V QPM 9	5055.3^{a}	4989.17^{a}	8598.4	8487.1	241.9^{a}	233.57^{a}	412.5^{b}	414.67^{b}	3593.7^{a}	3523.63^{a}
HM 8	3845.6^{e}	3829.17^{f}	7808.7	7805.1	147.4^{g}	145.03^{g}	278.7^{fg}	280.97^{fgh}	2795.4^{e}	2741.00^{e}
PMH 4	4838.3^{b}	4737.33^{b}	8379.3	8209.7	203.0^{cd}	195.83b^{c}	373.7^{c}	372.53^{c}	3510.7^{ab}	3398.87^{ab}
HM 4	4352.6^{c}	4287.20^{d}	8472.9	8059.5	180.2^{ef}	170.57^{de}	432.9^{a}	417.87^{b}	3115.6^{c}	3088.37^{c}
Prakash	4872.0^{b}	4860.50^{ab}	8285.7	8313.9	209.8^{bc}	206.47^{b}	430.5^{ab}	455.07^{a}	3481.9^{ab}	3477.53^{a}
DHM 117	3013.3^{hi}	2957.17^{jk}	7379.4	7464.2	124.2^{h}	120.40^{h}	267.5^{gh}	266.17^{hi}	2175.5^{hi}	2136.43^{h}
++VC	2805.7^{j}	2702.03^{l}	7245.1	7204.5	102.0^{i}	97.33^{i}	201.4^{j}	191.03^{j}	2066.8^{i}	1976.20^{i}
$PC 3	2921.0^{ij}	2774.83^{kl}	7188.6	6755.7	128.7^{h}	121.43^{h}	297.0^{ef}	273.00^{ghi}	2080.9^{i}	1975.00^{i}
%CC (plain)	2441.0^{k}	2255.50^{m}	7116.1	6617.9	166.9^{f}	153.87^{fg}	221.9^{i}	207.43^{j}	1738.3^{j}	1593.67^{j}
%%CC (hill)	2113.7^{l}	2048.83^{n}	7040.2	6769.9	97.2^{i}	93.33^{i}	203.1^{j}	199.90^{j}	1574.5^{k}	1510.57^{j}
LSD (P=0.05)	168.2	183.3	705.5	834.01	13.23	14.78	18.47	27.32	127.96	122.87

Means in the column followed by common letter (a-i) are statistically not significant at 5% level of significance. +V QPM 9= Vivek QPM 9; ++VC= Vijay Composite; $PC -3= Pusa Composite-3; %CC (plain)= Chakhaochujak (plain), %%CC (hill)= Chakhaochujak (hill).

Superiority of hybrid genotypes (Vivek QPM 9, Prakash and PMH 4) in physiological indices and crop growth rate might have led to higher productivity compared to other improved as well as traditional genotypes (Canavar and Kaynak 2010). This might be due to genetically better suitability of these maize genotypes in this sub-tropical climate with acidic soils of eastern Himalayan Region (Patel *et al*. 2005). As a result, the lowest maize grain yield was recorded in traditional genotypes (Chakhaochujak hill and plain). These findings are in line with those of Canavar and Kaynak (2010).

Genotypic variation on heat units

Genotypic variation on heat requirements were estimated in terms of growing degree days (GDD), helio-thermal unit (HTU), pheno-thermal index (PTI) and heat-use efficiency (HUE) (Table 4). With the advancement in phenological growth stages (50% tasseling, 50% silking and maturity), GDD and HTU also increased consistently across all the genotypes. Among the genotypes, significant ($P<0.05$) differences were observed in GDD and HTU during all the growth stages in 2013. However, in 2012, the differences in GDD among the genotypes were non-significant at tasseling and maturity stages but at silking stage, it was significant ($P<0.05$) higher in hybrid genotype HQPM 5 and was comparable to traditional genotypes Chakhaochujak-hill and plain (Table 4). The lowest HTU was observed in 2013 in Pusa Composite 3 at tasseling, in PMH 1 and PMH 3 at 50% silking stage and in Chakhaochujak (plain) and Chakhaochujak (hill) at maturity stage (Table 4). The highest and significant ($P<0.05$) HUE was recorded in Prakash followed by Vivek QPM 9 in 2012, while in 2013, the maximum HUE was found in Vivek QPM 9 followed by Prakash. The lowest HUE was found in Chakhaochujak (hill) in both the consecutive years (Fig 1). In the present study, we found that during 2013, accumulated temperature of >10 ^{0}C and the required GDD varied across maize genotypes at different growth periods (emergence to 50% tasseling, 50% tasseling to 50% silking and 50% silking to maturity), in contrast to previously reported works (Sacks and Kucharik 2011). The variation in accumulated temperature, HTU and GDD observed during various growth stages might be due to changes in photoperiods (Tollenaar and Lee 2011) as well as in air temperature and sunshine durations across crop growth periods (Li and Wang 2010) in the study area. Canavar and Kaynak (2010) reported that rapid attainment of phenological stages was associated with

Fig 1 Genotypic variation of maize for heat use efficiency in north eastern Himalayan regions of India

Table 4 Effect of maize genotype on heat unit's requirement in north eastern Himalayan regions of India

Maize genotype	Growing degree days						Helio-thermal unit					
	At 90% tasseling		At 90% silking		At maturity		At 90% tasseling		At 90% silking		At maturity	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
HQPM 7	796.5^{a}	988.1^{abc}	985.2^{bcdef}	1976.5^{ab}	1011.1^{ab}	1792.3^{d}	4052.5^{b}	4867.2^{ab}	4993.4^{bcde}	8375.7^{ab}	5005.1^{ab}	8516.1^{d}
HQPM 5	910.5^{ab}	1002.2^{abc}	980.2^{bcdef}	1976.5^{ab}	1164.2^{a}	1792.3^{d}	4593.6^{ab}	4944.9^{ab}	5007.0^{bcde}	8377.2^{ab}	5729.2^{a}	8516.1^{d}
BIO 9637	832.7^{ab}	1014.6^{abc}	916.0^{ef}	1838.9^{ab}	1090.5^{ab}	1792.3^{d}	4269.0^{ab}	5011.3^{ab}	4694.1^{de}	7828.8^{b}	5422.8^{ab}	8495.9^{d}
BIO 9681	914.6^{ab}	1054.0^{ab}	923.4^{ef}	1881.0^{ab}	1088.8^{ab}	1862.4^{cd}	4556.5^{ab}	5119.7^{ab}	4664.1^{e}	8088.6^{ab}	5241.6^{ab}	8865.4^{cd}
PMH 1	882.1^{ab}	1091.4^{a}	999.6^{abcde}	1976.5^{ab}	1079.9^{ab}	1792.3^{d}	4438.7^{ab}	5322.2^{a}	5070.5^{abcde}	8381.9^{ab}	5256.0^{ab}	8495.9^{d}
HQPM 4	924.4^{ab}	1026.6^{abc}	908.7^{ef}	2019.6^{a}	960.6^{b}	2110.0^{b}	4748.4^{ab}	5086.9^{ab}	4660.2^{e}	8556.4^{ab}	4808.5^{ab}	10008.7^{b}
PMH 3	937.4^{ab}	1075.1^{ab}	957.4^{cdef}	1852.3^{ab}	982.0^{ab}	1792.3^{d}	4818.7^{a}	5332.2^{a}	4895.4^{cde}	7905.7^{b}	4958.2^{ab}	8516.1^{d}
+V QPM 9	897.1^{ab}	1035.0^{abc}	960.9^{cdef}	1941.0^{ab}	984.9^{ab}	1804.2^{d}	4590.3^{ab}	5134.5^{ab}	4941.9^{bcde}	8285.3^{ab}	4913.0^{ab}	8582.6^{d}
HM 8	795.1^{b}	929.7^{c}	944.4^{def}	1894.3^{ab}	960.6^{b}	1854.1^{cd}	4081.3^{b}	4668.9^{b}	4851.1^{cde}	8121.0^{ab}	4808.2^{ab}	8792.5^{cd}
PMH 4	865.4^{ab}	982.4^{bc}	929.4^{def}	1965.4^{ab}	994.9^{ab}	1971.7^{bc}	4465.5^{ab}	4944.1^{ab}	4819.4^{de}	8300.3^{ab}	5051.8^{ab}	9393.8^{bc}
HM 4	962.9^{a}	995.6^{abc}	983.2^{bcdef}	1900.0^{ab}	915.9^{b}	1863.6^{cd}	4962.3^{a}	4979.8^{ab}	5060.4^{abcde}	8118.4^{ab}	4646.8^{b}	8872.0^{cd}
Prakash	919.8^{ab}	1007.0^{abc}	916.8^{ef}	1846.3^{ab}	930.6^{b}	1863.6^{cd}	4721.4^{ab}	5114.4^{ab}	4674.9^{e}	7895.9^{b}	4776.5^{ab}	8872.0^{cd}
DHM 117	880.6^{ab}	981.4^{bc}	884.5^{f}	1826.2^{b}	1006.4^{ab}	1769.6^{d}	4505.5^{ab}	5041.0^{ab}	4592.9^{e}	7775.1^{b}	5094.3^{ab}	8286.9^{d}
++VC	969.7^{a}	1020.7^{abc}	1078.7^{ab}	1946.6^{ab}	1057.8^{ab}	2063.6^{b}	4850.9^{a}	4957.9^{ab}	5414.7^{ab}	8284.0^{ab}	5177.0^{ab}	9763.8^{b}
$PC 3	839.1^{ab}	1013.5^{abc}	1095.9^{a}	1894.3^{ab}	1101.3^{ab}	2051.0^{b}	4291.0^{ab}	4938.6^{ab}	5536.5^{a}	8084.3^{ab}	5490.2^{ab}	9663.8^{b}
%CC (plain)	914.4^{ab}	1059.6^{ab}	1059.0^{abc}	1940.7^{ab}	905.2^{b}	2292.7^{a}	4680.2^{a}	5144.7^{ab}	5315.0^{abc}	8334.5^{ab}	4548.3^{b}	10810.4^{a}
%%CC (hill)	952.5^{a}	1080.9^{ab}	1032.9^{abcd}	2020.8^{a}	1014.8^{ab}	2280.0^{a}	4898.6^{ab}	5199.7^{a}	5168.6^{abcd}	8721.3^{a}	5120.8^{ab}	10780.0^{a}
LSD (P=0.05)	151.7	107.6	103.6	191.4	198.1	160.4	736.5	525.4	493.0	794.5	960.9	744.7

Means in the column followed by common letter (a-i) are statistically not significant at 5% level of significance. +V QPM 9= Vivek QPM 9; ++VC= Vijay Composite; $PC -3= Pusa Composite-3; %CC (plain)= Chakhaochujak (plain), %%CC (hill)= Chakhaochujak (hill).

a significant (P<0.05) decrease in heat unit requirement from sowing to maturity. Significantly, (P<0.05) higher HUE was found in Vivek QPM 9 and Prakash hybrids. As the heat-use efficiency is ratio of grain yield to GDD and thus, increase in HUE enhanced the maximum utilization of solar radiation across maize genotypes (Canavar and Kaynak 2010).

Genotypic variation on physiological attributes vs grain yield

Performance of genotypes in terms of grain yields were strongly influenced by physiological attributes (CGR and LAD) and heat-use efficiency (HUE) across all the stages of crop growth (Fig 2-4). In the initial stages of growth (30-60 DAS), CGR significantly (*P<0.05*) influenced the grain yield in a positive direction and was reflected by a very strong correlation (R^2=0.79-0.82). In later stage (60 DAS-maturity) also, CGR had positive influence on grain yield (R^2=0.32-0.67) (Fig 2). Similarly, from the relationship between LAD and grain yield, it was observed that LAD also significantly (*P<0.05*) influenced the grain yield performance of cultivars and was more strongly correlated in the initial stage (30– 60 DAS) (R^2=0.68-0.96) than 60 DAS- maturity stages of growth (R^2 = 0.29-0.81) (Fig 3). Higher LAD resulted in higher HUE during both initial (30-60 DAS) (R^2=0.62-0.95) and later (60 DAS- maturity) stages of growth (R^2=0.22-0.74) (Fig 4).

Present investigation showed that HYVs including selected hybrids (Vivek QPM 9, Prakash, PMH 4 and HQPM 7) adaptable to the agro-ecological conditions of NEHR in India could be promising options in replacing local low yielding genotypes (Chakhaochujak- plain and hill) for improving maize grain productivity by more than 2 folds over the existing productivity (<1.5 t/ha) in the region. Thus, adoption of promising hybrids can increase the productivity of maize *vis-à-vis* food and livelihood security

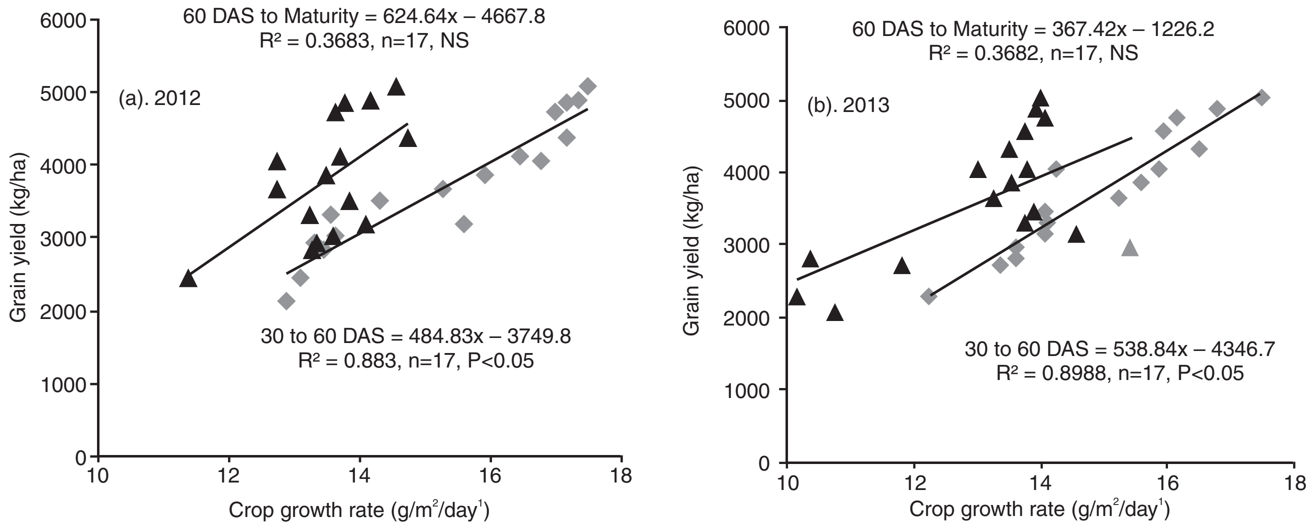

Fig 2 Correlation between crop growth rate and grain yield in maize

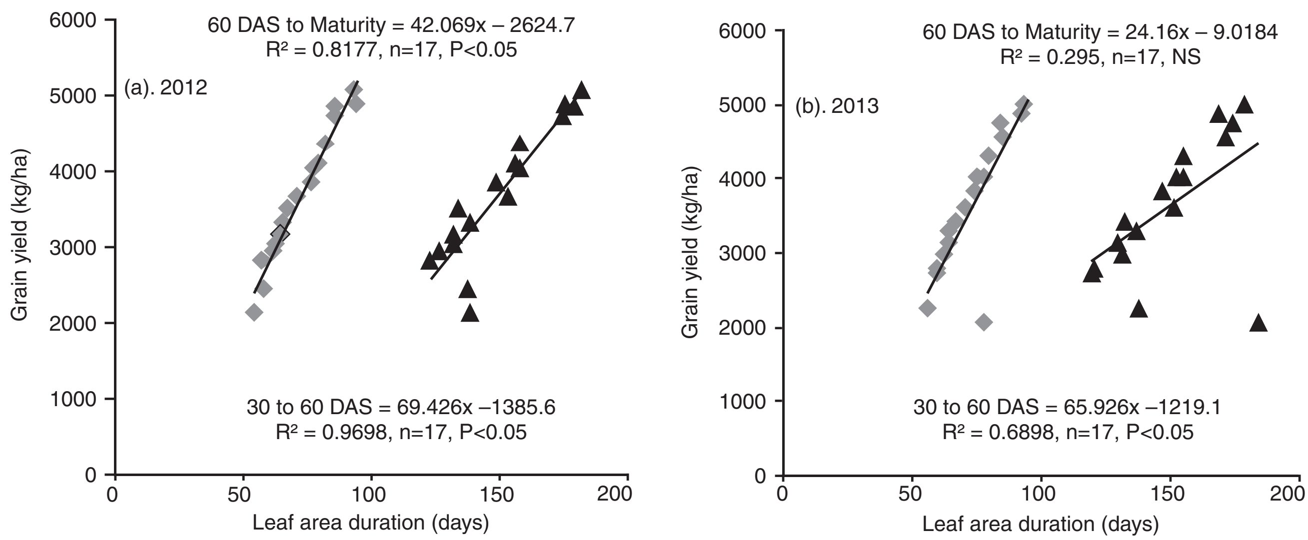

Fig 3 Correlation between leaf area duration and grain yield in maize

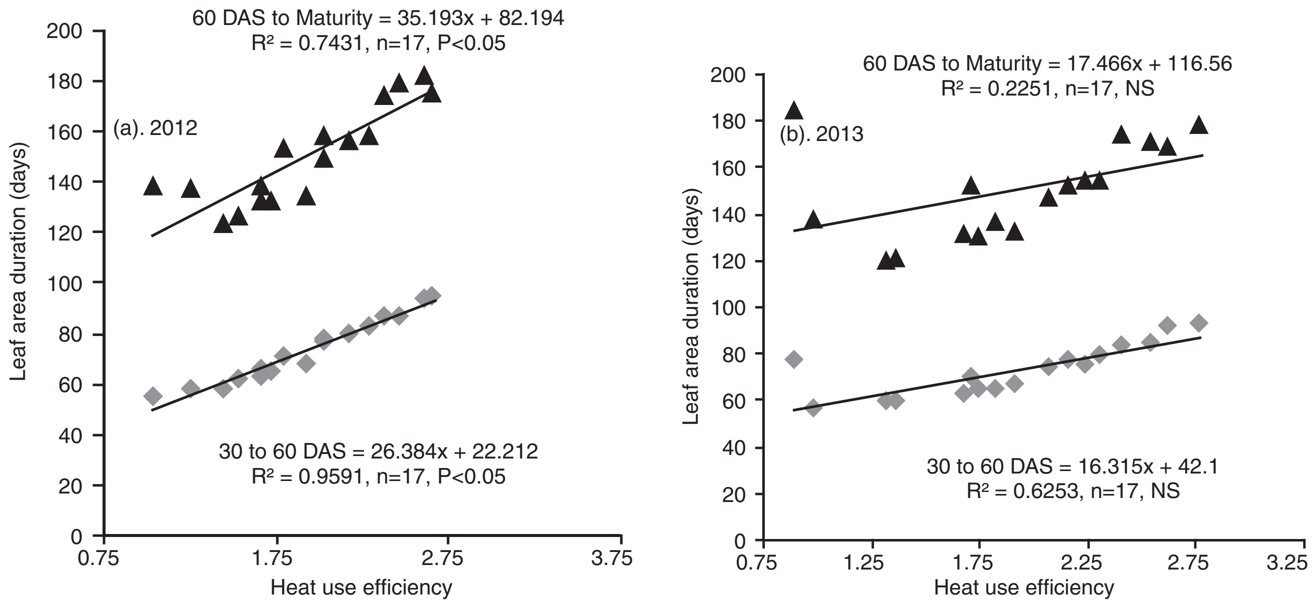

Fig 4 Correlation between heat use efficiency and leaf area duration in maize

of burgeoning population in the rainfed hilly ecosystem of NEHR of India and other similar rainfed agro-ecological regions of the world.

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