Vol. 21, No. 2, pp. 404-415 (2021)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Phenological Events and Grain Yield of Maize as Influenced by Different Weather Parameters

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ABSTRACT

The phenological development (50% pollen shedding (PS), 50% silking (S) and 75% husk browning (HB)) and heat unit requirement of four maize cultivars at different growth stages were studied in randomized block design (RBD) with 3 replications at Regional Research Station, Ballowal Saunkhri during *kharif* 2013-17. The cultivars differed among themselves towards attainment of different phenophases and accumulation of heat units. The days acquired by PMH 1, PMH 2, PMH 4 and Prakash from sowing to physiological maturity were 75 to 85, 77 to 83, 80 to 85 and 71 to 81, respectively. The crop acquired lesser number of days accumulated growing degree days to mature during 2014 (35.2°C) and 2015 (36.3°C) due to higher than normal maximum temperature (seasonal mean) as compared to the other years. The grain yield remained higher in the years when higher maximum temperature was recorded. It means that higher maximum temperature was negatively correlated with the phenological events (-0.91 with PS; -0.50 with S and -0.55 with HB), but positively with the grain yield (0.81) during the study years. But minimum temperature (-0.98) and rainfall (-0.85) had negative correlation with grain yield. It means that lower grain yield years experienced more rainfall which is the reason for poor fertilization due to more pollen washout and hence lower grain yield and heat use efficiency. From the stepwise regression it has been clear that, grain yield depends significantly on both day and night temperature as well as rainfall during the crop season. The polynomial relationship of yield with temperature and rainfall depicts reduction in yield after certain limits of temperature and rainfall.

Key words: Maize, weather parameters, heat use efficiency, submontaneous region

Introduction

Maize (*Zea mays* L.) is the one of the most important cereal crop cultivated under varied agro-climatic regions. Maize is known as 'queen of cereals' due to highest genetic yield potential among the different cereals. Globally, maize is cultivated in about 160 countries under wider diversity of soil, climatic conditions and management practices (Kumar *et al*., 2017). The performance of maize is affected by management practices as well as environmental conditions that ultimately affect yield of crop (Porter 2005; Wahid *et al*., 2007). Weather variability is one of the major factors for the year to year variation in crop growth and yield. Physiological and morphological development in plant is influenced by various meteorological factors such as temperature is an important environmental factor influencing the growth, development and yield of crops. Early sowing of maize results in tasseling stage coinciding with high temperature; hot and dry conditions at tasseling reduce maize yield, therefore, it is important that this growth stage should coincide with the high cloud cover and adequate moisture (Meseka *et al*., 2018). Low yield in the late sown

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crop is mainly due to unfavorable environmental effects occurring during the reproductive phase of the crop as temperature controls many physiological processes. The knowledge of accumulated GDD can provide an estimated date as well as crop development stage (Theivasigamani *et al.*, 2013). The duration of each phenophase determines the accumulation and partioning of dry matter in different organs (Anbessa *et al*., 2007). A quantified value of heat or temperature units is required to reach a particular phenophase. Plants have a definite temperature requirement before they attain certain phenological stages. Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units system (Bishnoi *et al*., 1995). Air temperature based agromet indices *viz*., growing degree days (GDD), photothermal units (PTU), heliothermal units (HTU), phenothermal index (PTI) can be used to describe changes in phenological behaviour and growth parameters (Kumar *et al.,* 2010). The values of accumulated GDD, HTU and PTU for each phenophase, are relatively constant and independent of sowing date but vary in a crop from variety to variety (Phadnawis and Saini, 1992). In addition to temperature, rainfall and other weather parameters like relative humidity, day length etc. also play important role in crop growth and productivity. Evaluation of high yielding, stable genotypes having good quality are considered pre-requisite for increasing crop production in any region. So, there is a need to broader genetic base and selection or development of the genotypes having wider adaptability and resilience to climatic variability to replace old varieties with new and improved ones (Jat *et al.,* 2003). So, this experiment was conducted to study the effect of weather parameters on crop phenology, heat unit requirement and heat use efficiency and select the genotypes tolerant to weather aberrations in *Kandi* region of Punjab.

Material and Methods

Field experiment

A field experiment was conducted during *kharif,* 2013 to 2017 at Regional Research Station Ballowal Saunkhri (31°60′ N, 76°23′ E, 296m), Punjab to study the phenological development and Growing degree day (GDD) requirement of four maize cultivars (PMH 1, PMH 2, PMH 4 and Prakash). These cultivars were planted in a plot size of 9.6 m^2 with a spacing of 60 cm × 20 cm in a randomized block design (RBD) with 3 replications. The phenological stages were studied at every 2-3 days intervals.

Weather data

Daily maximum temperature, minimum temperature and rainfall data was collected from Agrometeorological Observatory of Regional Research Station, Ballowal Saunkhri.

Growing degree days

Growing Degree Days (GDD) is used to estimate the growth and development of plants during the growing season. The growing degree days (GDD) were calculated as Gallagher *et al*. (1983):

$$\text{Growing degree day } (^{o}\text{C days}) = \frac{(T_{max} + T_{min})}{2} - T_b$$

Where,

T_{max} = Daily maximum temperature (^{o}C)

T_{min} = Daily minimum temperature (^{o}C)

T_b = Base temperature (10°C for maize) (Grigorieva *et al*., 2010)

The accumulated growing degree days (AGDD) were calculated by stagewise cumulation of the daily degree days.

Heat use efficiency

It was calculated as (Yousaf *et al*., 2019)

$$\text{Heat Use Efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{AGDD (°C day)}}$$

Statistical analysis

The data collected on yield and yield attributing characters, heat units and heat use efficiency (HUE) in respect of various cultivars were statistically analyzed by using factorial experiment in RBD design as directed by Cheema and Singh (1991) in statistical package CPCS-1. All the comparisons were made at 5% level of significance.

The correlations between different weather parameters and the phenology/grain yield of maize cultivars were developed. The stepwise regression between grain yield and different weather parameters was also carried out to check the dependency of grain yield. The regression analysis was also carried to develop relationship of different weather parameters with the grain yield of maize cultivars. The significance of the coefficient of determination was checked by using the F-test.

Results and Discussion

Weather during crop season

The weekly maximum temperature, minimum temperature and rainfall recorded during *Kharif* of 2013-2017 have been presented in Fig. 1a-c. The maximum temperature remained above normal in the years 2014 and 2015 in most of the standard meteorological weeks rather than 2013, 2016 and 2017. During the entire crop season, the mean weekly maximum temperature was 33.2, 35.2, 36.3, 33.6 and 33.5°C; minimum temperature was 24.2, 23.8, 23.8, 24.6 and 23.9°C; and rainfall was 717.2, 538.2, 592.2, 627.7 and 793.2 mm during 2013, 2014, 2015, 2016 and 2017, respectively (Fig. 2). The normal weekly maximum temperature, minimum temperature and rainfall for the cropping season are 33.4°C, 23.7°C and 798.1 mm, respectively. Out of five years, highest maximum temperature was observed during 2015 (36.3°C) followed by 2014 (35.2°C). This may be due to lower rainfall (538 mm and 592 mm during 2014 and 2015, respectively) during these years as compared to other. The number of rainy days, sunshine hours and evaporation during 2013, 2014, 2015, 2016 and 2017 were 27, 22, 26, 30 and 29; 6.29, 6.35, 6.74, 5.73 and 6.32; and 419.5, 470.3, 478.4, 481.4 and 469.6, respectively. The normal weekly rainy days, sunshine hours and evaporation for the cropping season are 32 days, 6.88 hours and 469.1mm, respectively.

Phenology

The phenological events of maize cultivars in different years have been given in Table 2. The cultivars selected for study were both long and short

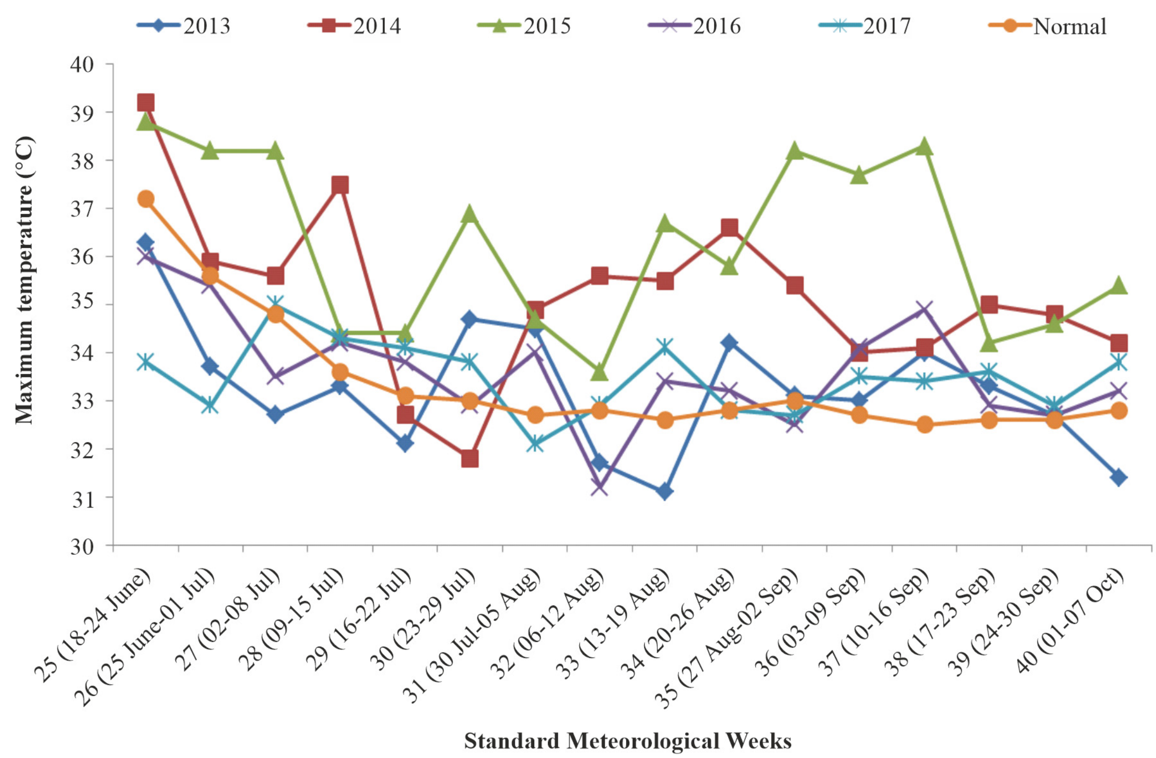

Fig. 1a. Standard Meteorological Week wise maximum temperature (°C) during *Kharif* 2013-2017

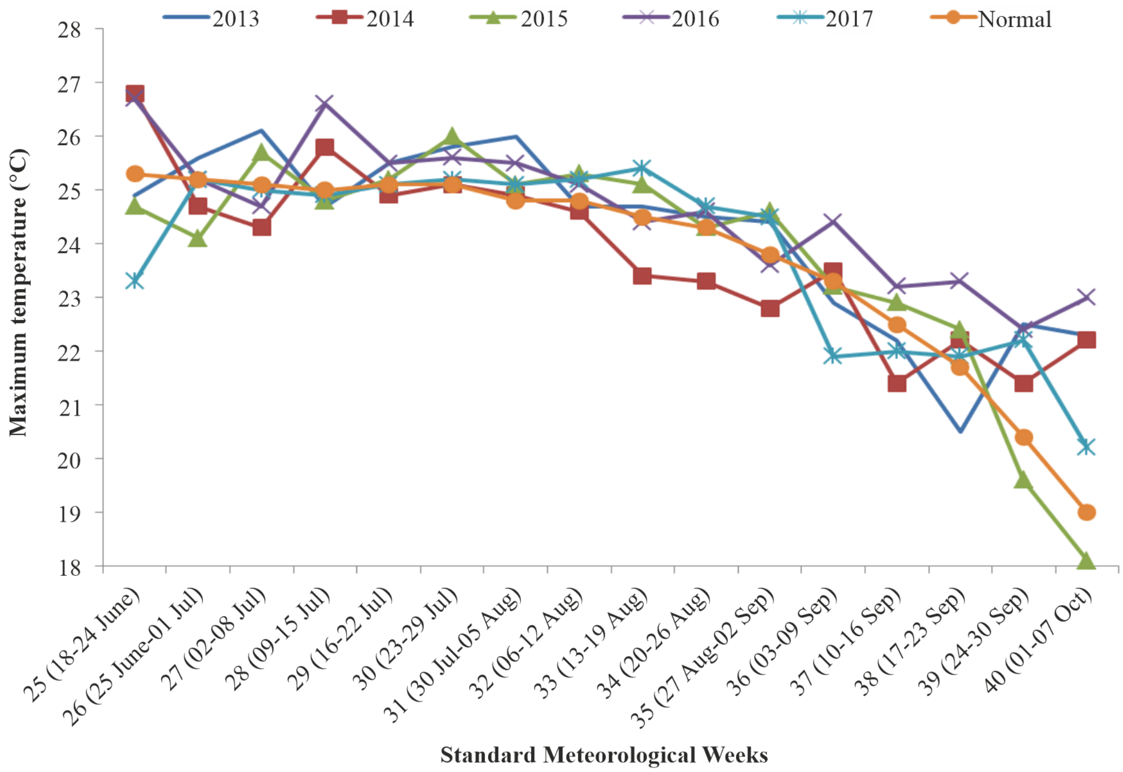

Fig. 1b. Standard Meteorological Week wise minimum temperature (°C) during *Kharif* 2013-2017

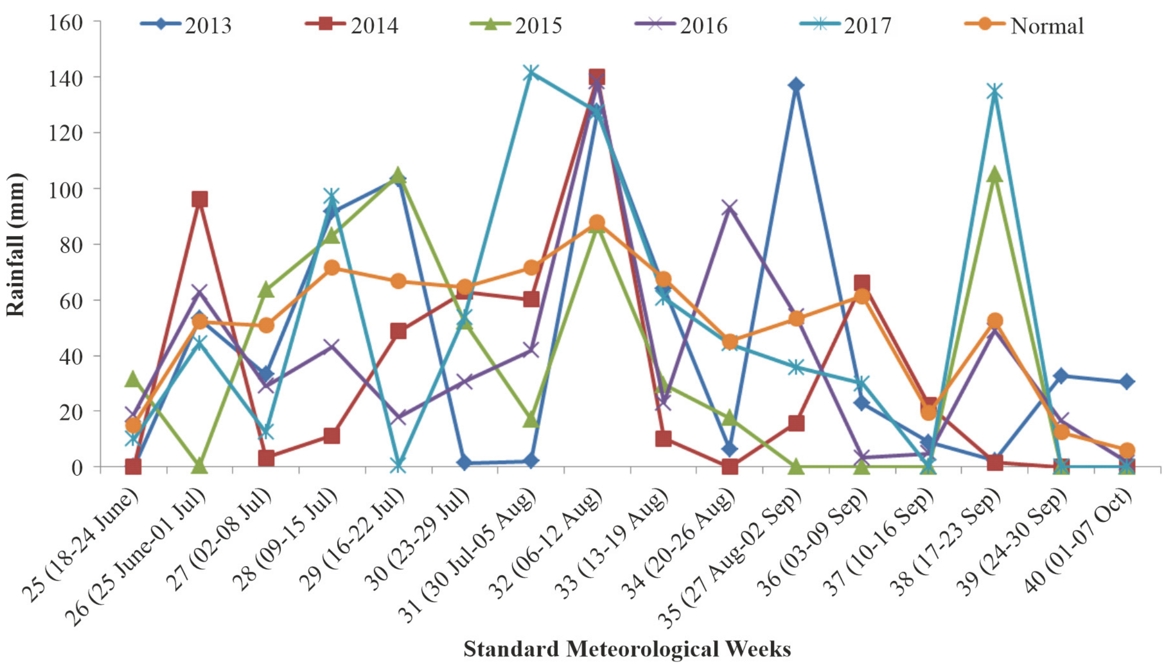

Fig. 1c. Standard Meteorological Week wise rainfall (mm) during *Kharif* 2013-2017

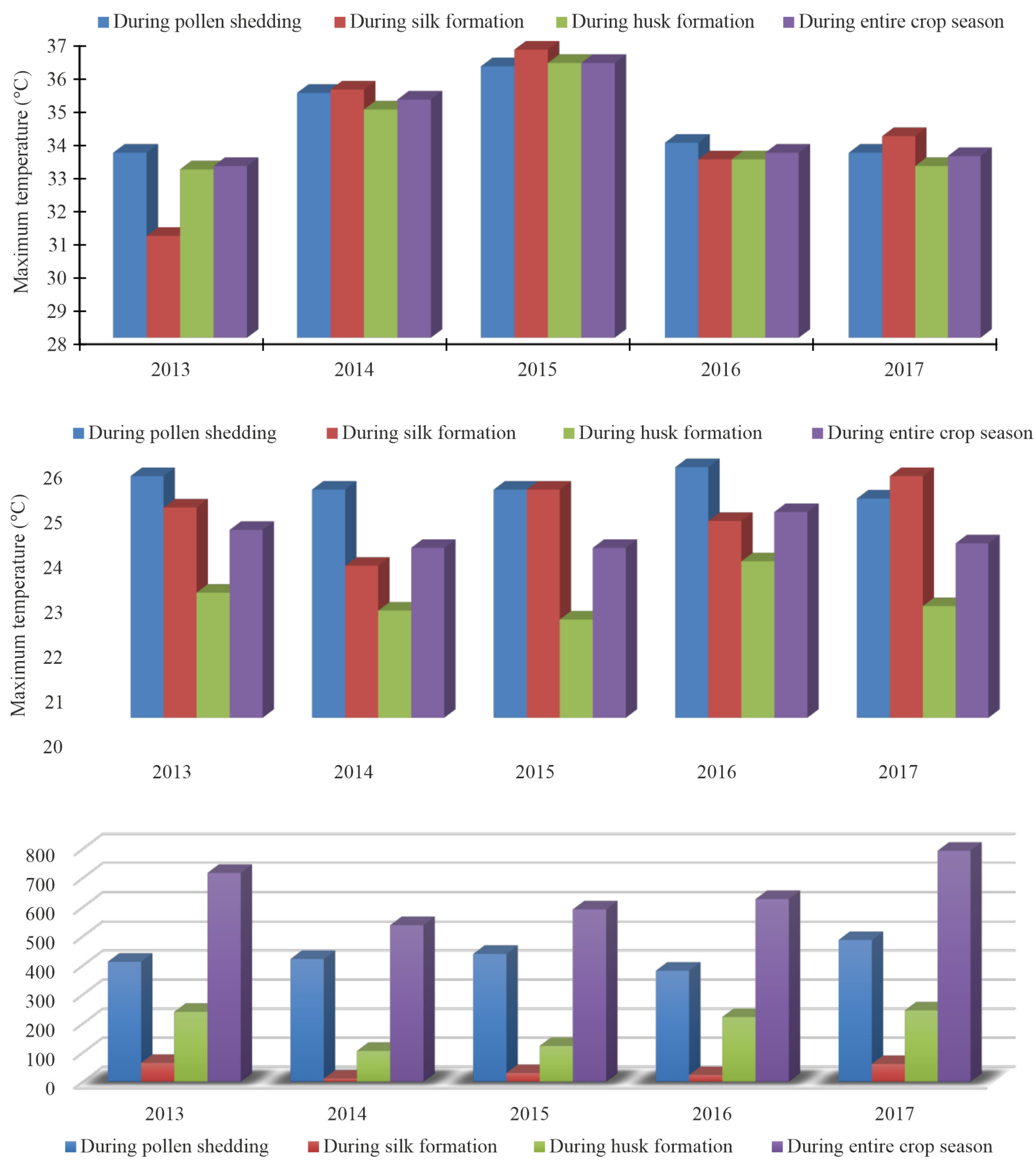

Fig. 2. Variation of maximum temperature, minimum temperature and rainfall during the pollen shedding, silking and husk browning stage from 2013-2017

duration type. Among different maize cultivars, number of days to 50 % pollen shedding was significantly higher in the PMH 1 followed by PMH 4, PMH 2 and Prakash. The PMH 2 and Prakash cultivars were statistically at par with each other in terms of pollen shedding during the years 2014, 2015 and 2016. The cultivars took a greater number of days to complete the 50% pollen shedding during 2016 followed by the year 2017, 2013, 2014 and 2015. The length of pollen shedding stage varied from 44 to 58 days, 43 to 52 days, 44 to 49 days, 47 to 60 days and 51 to 57 days, respectively during years 2013, 2014, 2015, 2016 and 2017 (Table 1). The more number of days for the pollen shedding during 2016 and 2017 followed by 2013 may be due to the lower maximum temperature and more rainfall at this stage during these years as compared to the 2014 and 2015.

The number of days to 50% silking varied significantly among the maize cultivars during 2013, 2014 and 2015, whereas these were non-significant in the years 2016 and 2017. PMH 2 and PMH 4 were statistically at par with each other during years 2013 and 2014. The length of 50% silking varied from 47 to 60 days, 48 to 54 days, 45 to 50 days, 50 to 61 days and 57 to 59 days, respectively during years 2013, 2014, 2015, 2016 and 2017 (Table 2). The days to silking acquired by the maize crop during different years coincide also with the maximum temperature very well. The temperature 34°C reduced the number of days taken by the maize cultivars for silking during the years 2014 and 2015 (Table 2).

The time taken by maize cultivars to attain the 75% husk browning varied significantly during 2013, 2014 and 2015, but it was statistically at par during 2016 and 2017. Maximum number of days to husk browning was taken by maize cultivar PMH 1, followed by PMH 4, PMH 2 and Prakash (Table 3). The crop took maximum number of days during year 2017. The length of husk browning stage varied from 73 to 84 days, 77 to 81 days, 71 to 83 days, 78 to 82 days and 83 to 85 days during years 2013, 2014, 2015, 2016 and 2017, respectively. The overall temperature during the season was less during 2013, 2016 and 2017 which might have led to the lengthening in growth period of the cultivars (Fig. 1a). Harrison *et al.* (2011) also report that increase in temperature results in the shortening of the crop growth stages. Asif *et al.* (2007) and Gozubenli *et al*. (2001) also reported similar results on maize crop.

Growing degree days

The growing degree days acquired by the maize cultivars have been presented in Table 2. The accumulated growing degree days by different maize cultivars for the 50% pollen shedding stage varied from 848 to 1096, 841 to 1014, 894 to 1008, 926 to 1156 and 974 to 1084 °C day for 2013, 2014, 2015, 2016 and 2017, respectively. The accumulated growing degree days by different maize cultivars for the 50% silking stage varied from 900 to 1138, 653 to 1046, 915 to 1036, 951 to 1176 and 1190 to 1120°C day, respectively for the years 2013, 2014, 2015, 2016 and 2017. The accumulated growing degree days by different maize cultivars for the 75% husk browning stage varied from 1370 to 1560, 1469 to 1547, 1451 to 1655, 1498 to 1573 and 1538 to 1566°C day, respectively for 2013, 2014, 2015, 2016 and 2017. It has been observed that the lesser the days taken by maize cultivars to complete its phenological stages, lesser the accumulation of growing degree days by the crop. Pettigrew (2008) in maize and Sandhu and Singh (2020) in moongbean reported similar results in relation to growing degree days.

Grain yield

The grain yield of the maize cultivars during *Kharif* 2013-2017 has been given in Table 3. The data showed that the PMH 1 cultivar had significantly higher grain yield as compared to other cultivars during 2013 and 2014, while PMH 4 gave higher yield during 2015 to 2017. Higher rainfall during the pollen shedding stage may have resulted in reduced grain yield during 2016 and 2017 resulting in poor fertilization. Li *et al.* (2019) also reported that rainfall at reproductive stage adversely impacts the grain yield in maize.

Heat use efficiency

The heat use efficiency indicates the efficiency of crop to utilize the available heat energy and its quantification is useful for the assessment of yield potential of a crop in different environment. The heat use efficiency increases from vegetative stage to physiological maturity of the crop (Mehta and Dhaliwal, 2020).

The heat use efficiency of the maize cultivars during *kharif* 2013-2017 has been given in Table 3. The data showed that the PMH 1 cultivar utilized heat efficiently as compared to other cultivars during 2013 and 2014, while PMH 4 was efficient utilizer of heat during 2015 to 2017.

Table 1. Time taken by maize cultivars to complete different phenological events during *kharif* 2013-17

Cultivars	50 % Pollen shedding						50% Silking						75% husk browning					
	2013	2014	2015	2016	2017	Pooled Analysis	2013	2014	2015	2016	2017	Pooled Analysis	2013	2014	2015	2016	2017	Pooled Analysis
PMH 1	57.7	52.3	49.3	60.0	57.3	55.3	60.0	54.0	50.7	61.0	59.3	57.0	84.3	81.7	75.3	79.3	85.0	81.1
PMH 2	49.3	43.0	44.7	47.7	51.0	47.1	51.7	51.7	46.3	49.0	58.7	51.5	78.3	77.3	83.7	78.3	83.3	80.2
PMH 4	52.0	48.0	46.0	52.3	56.3	50.9	54.0	51.0	49.7	52.7	58.0	53.1	80.0	80.3	80.3	82.0	85.0	81.5
Parkash	44.3	43.7	44.0	49.7	55.0	47.3	47.0	48.7	45.0	50.7	57.7	49.8	73.3	78.7	71.7	78.0	85.0	77.3
CD	3.4	3.4	1.8	8.4	2.0	1.7	3.3	1.9	1.5	NS	NS	1.8	5.9	2.7	2.7	NS	NS	2.1

Table 2. Accumulated growing degree days by maize cultivars to complete different phenological events during *kharif* 2013-17

Cultivars	50 % Pollen					50% Silking					75% husk browning				
	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
PMH 1	1096.8	1014.9	1008.1	1156.8	1084.4	1138.2	1046.8	1036.3	1176.3	1120.7	1560.7	1547.3	1515.5	1519.6	1561.3
PMH 2	945.0	841.9	908.5	926.0	974.3	988.1	1002.4	943.8	951.4	1108.3	1458.9	1469.1	1655.3	1504.5	1538.9
PMH 4	994.9	922.0	937.0	1014.5	1066.9	1031.8	989.3	1015.2	1020.7	1096.8	1487.8	1523.2	1599.9	1573.3	1566.9
Parkash	848.6	853.7	894.0	964.2	1043.9	900.5	953.9	915.4	982.9	1090.1	1370.7	1493.5	1451.7	1498.5	1566.9
CD	63.8	71.8	38.7	155.3	35.2	60.8	NS	31.9	NS	NS	102.9	47.1	45.8	NS	NS

Table 3. Grain yield and heat use efficiency of maize cultivars during *kharif*, 2013-2017

Cultivars	Yield						Heat use efficiency (kg/ha/°C day)				
	2013	2014	2015	2016	2017	Pooled Analysis	2013	2014	2015	2016	2017
PMH 1	7194.7	6736.0	5441.0	5434.3	4899.0	5941.0	4.62	4.36	3.59	3.62	3.14
PMH 2	5739.3	6055.7	7215.7	5118.0	5083.7	5842.5	3.94	4.12	4.36	3.42	3.30
PMH 4	5649.7	6201.7	7333.3	6076.3	5159.7	6084.1	3.80	4.07	4.58	3.87	3.29
Parkash	4778.0	6010.3	5181.0	5548.3	4834.7	5270.5	3.50	4.02	3.57	3.70	3.09
CD	693.2	NS	1509.0	NS	NS	381.1	0.57	NS	NS	NS	NS

Table 4. Stepwise regression models between weather parameters and agro-climatic indices and grain yield of maize

Parameters	Equation	R^2
Tmax	Y= -5026.4+316.6 Tmax	0.18*
Tmin	Y= 16552.0-450.4 Tmin	0.13*
Rain	Y= 7960.9-4.3 Rain	0.24*
Tmax&Tmin	Y= 10.1+0.22 Tmax-4.6 Tmin	0.73*
Tmax& Rain	Y= 5588.3+60.6 Tmax-3.7 Rain	0.25*
Tmin& Rain	Y= 19065.7- 463.2 Tmin-4.4Rain	0.38*
Tmax, Tmin& RF	Y= 22217.7- 69.6 Tmax – 480.9 Tmin – 5.1 RF	0.38*
GDD pollen shedding	Y= 6475.5 – 0.7 GDD Pollen shedding	-0.006
GDD silking	Y= 6258.3 – 0.5 GDD Silking	0.13
GDD husk browning	Y= -4586.0 + 6.8 GDD Husk browning	0.24*
GDD pollen shedding, silking and husk browning	Y= - 4467.9 – 3.2 GDD Pollen shedding – 0.2 GDD Pollen shedding + 8.9 GDD Husk browning	0.38*
Tmax, Tmin, RF & GDD pollen shedding, silking and husk browning	Y= 20784.8 – 410.4 Tmax – 363.2 Tmin – 8.7 RF – 1.5 GDD Pollen shedding – 1.3 GDD Pollen shedding + 8.1 GDD Husk browning	0.67*
GDD pollen shedding to silking	Y= 5788.6 – 0.11 GDD Pollen shedding to silking	9.1E-05
GDD silking to husk browning	Y= 4366.9 + 2.8 GDD Silking to husk browning	0.13*
GDD pollen shedding to husk browning	Y= 243.3 – 0.6 GDD Pollen shedding to husk browning	0.61*
Tmax, Tmin, RF, GDD pollen shedding to silking, GDD silking to husk browning, GDD pollen shedding to husk browning	Y= 22259.8 – 140.2Tmax – 428.6Tmin – 5.0 RF+ 2.69 GDD pollen shedding to silking+ 1.88 GDD silking to husk browning + 0.0 GDD pollen shedding to husk browning	0.40*

Stepwise regression of grain yield with different weather parameters

The stepwise regression analysis attempted between grain yield, growing degree days and different weather parameters (Table 4). It showed that the effect of maximum temperature, minimum temperature and rainfall was significant (R^2 = 0.18 to 0.24). It is clear from the analysis that grain yield varied positively with maximum temperature but negatively with the minimum temperature and rainfall. The effect of both maximum and minimum temperature was highly significant as compared to their effect with rainfall. The coefficient of determination (R^2= 0.69) increased with the addition of growing degree days upto flowering along with other weather parameters. The growing degree days from silking to husk browning affected grain yield more as shown by coefficient of determination (R^2 = 0.13 and 0.61). The growing degree days from sowing to maturity had little effect on the grain yield of taramira cultivars during different crop years as shown by the coefficient of determination (R^2 = 0.24). The combined effect of the growing degree days along with weather parameters shows more significant effects on the grain yield (R^2= 0.40 and 0.67).

Regression relationship of maximum temperature, minimum temperature and rainfall up to pollen shedding with grain yield of four maize cultivars

The regression analysis of different weather parameters with grain yield has been shown in Fig. 3. Regression analysis of maximum temperature at pollen shedding with yield revealed that with increase in maximum temperature beyond 35°C there was reduction the grain yield of variety PMH 1 and Prakash. This may be due to the sensitivity of the pollens of these varieties to higher temperature which might have affected the pollen viability, whereas the grain yield of varieties PMH 2 and PMH 4 increased with increase in temperature indicating that the temperature has no effect on the pollen viability of these cultivars. Different crops have different optimum and critical temperature thresholds in different development and growth phases; when these thresholds are exceeded, a series of physiological processes associated with yield formation are affected, leading to dramatic yield losses (Prasad *et al.*, 2017).

Regression analysis of grain yield with minimum temperature at pollen shedding also indicated the sensitivity of PMH 1 to increase in minimum temperature *i.e.* reduction in yield was observed with increase in minimum temperature, whereas the other varieties showed no sensitivity to fluctuations in minimum temperature.

Rainfall is the most significant climatic factor that affects the crop growth and production in the rainfed areas of the country. The regression analysis of cultivars with rainfall indicates that the yield of crop reduced with increase in rainfall. These results are in line with that of Li *et al.* (2019) who also reported the adverse effect of rainfall at reproductive stage on grain yield of maize.

Correlation of different growth stages and grain yield with weather parameters

The correlations of different weather parameters, phenology and grain yield of maize cultivars have been presented in Table 6. The correlation analysis results revealed that days taken for the pollen shedding (-0.91), silking (-0.50) and husk browning (-0.55) have been negatively correlated with the average maximum temperature (Table 5). It means that higher maximum temperature shortens the growing period of the crop. The positive correlation with rainfall shows that with increase in rainfall the number of days taken by the crop to complete pollen shedding, silking and husk browning also increases this may be due to the fall in temperature due to the prolonged spell of rains (Li *et al.,* 2019).

Table 5. Correlation analysis between days taken to complete different phenological stages and their respective weather parameters, phenological stages and grain yield

	Days taken to pollen shedding	Days taken to silking	Days taken to husking
Maximum temperature	-0.91*	-0.50	-0.55
Minimum temperature	0.09	0.32	-0.04
Rainfall	0.23	0.58	0.53

Table 6. Correlation analysis between grain yield and maximum temperature upto different different phenological stages

	Maximum temperature upto pollen shedding	Maximum temperature upto silking	Maximum temperature upto husking	Maximum temperature for entire season
Grain yield	0.81**	0.43	0.77	0.76

The positive correlation of maximum temperature with grain yield at different growth stages has been observed (Table 6). It means more yield in the years with high maximum temperature in spite of shortened growth period of the crop as signified in Table 9. The grain yield showed negative and significant correlation minimum temperature (-0.98) and rainfall (-0.85). This may be due to negative effect of minimum temperature and rainfall during those years (Table 7 and 8) as pollens get wash away due to more rainfall resulting in poor fertilization and grain yield. Also higher the

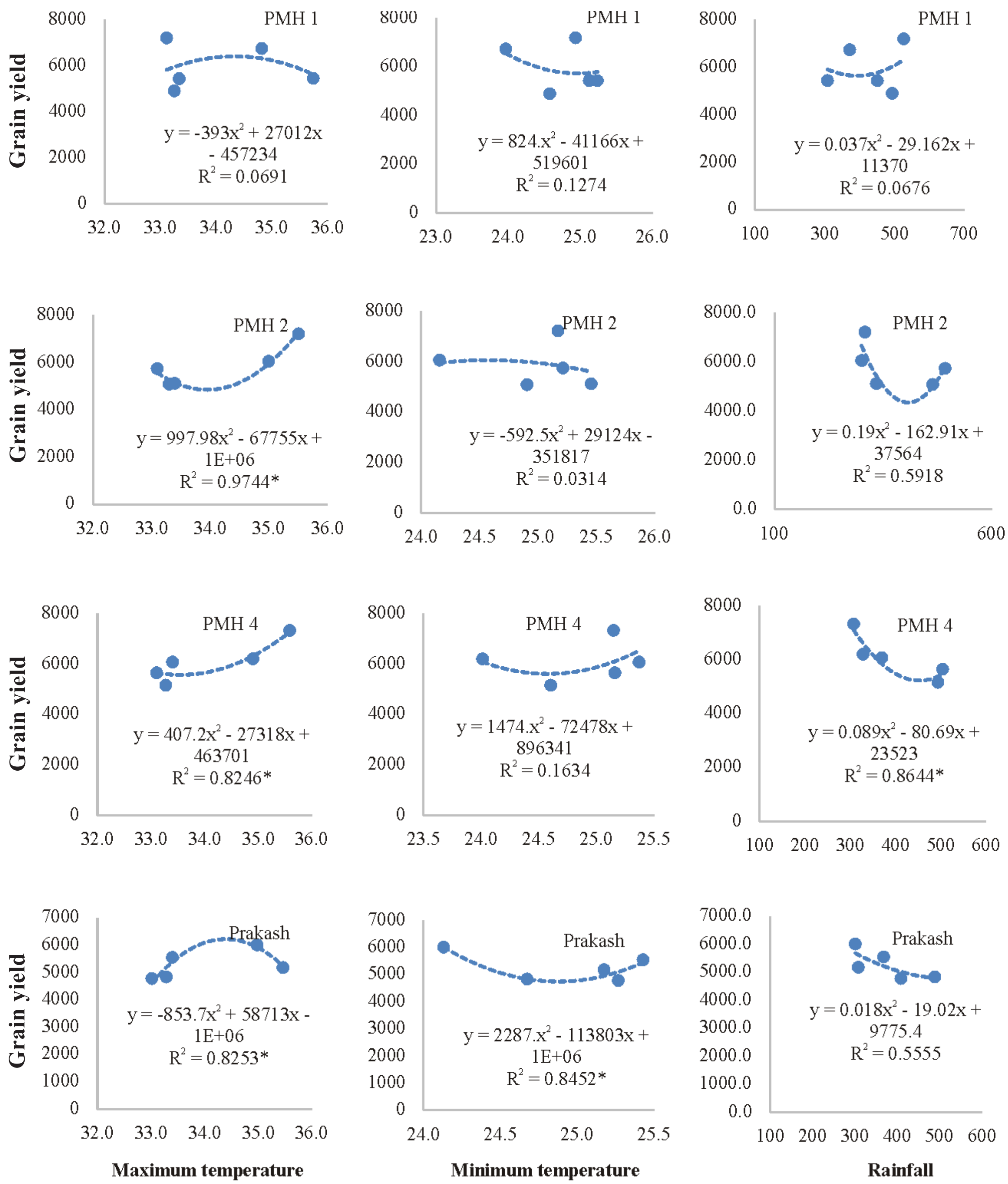

Fig. 3. Regression relation of maximum temperature, minimum temperature and rainfall up to pollen shedding with grain yield of maize cultivar

Table 7. Correlation analysis between grain yield and average minimum temperature upto different phenological stages

	Minimum temperature upto pollen shedding	Minimum temperature upto silking	Minimum temperature upto husking	Minimum temperature for entire season
Grain yield	0.09	-0.53	-0.34	-0.98*

Table 8. Correlation analysis between grain yield and rainfall upto different phenological stages

	Rainfall upto pollen shedding	Rainfall upto silking	Rainfall upto husking	Rainfall for entire season
Grain yield	-0.40	-0.59	-0.84**	-0.85**

Table 9. Correlation of different phenological events with the grain yield

	Days taken to pollen shedding	Days taken to silking	Days taken to husking
Grain yield	-0.98*	-0.94*	-0.87**

minimum temperature will result in more respiration losses and hence grain yield will reduce. Wang *et al.* (2016) also found correlations of maize cultivars with different weather parameters.

Conclusion

Correlating different weather parameters to find out the parameters affecting yields has been the aim of research study. The maize crop yield is a function of weather and crop management practices. The negative relation between the temperature and grain yield of maize indicates decrease in yield which clearly highlights that weather parameters such as temperature, rainfall affect the productivity in any region. Relationship between two or more weather parameters and grain yield of crops can be used for yield prediction well before the actual harvesting of the crops. The unusual weather during vegetative and reproductive period of a crop adversely affects the crop yield. The results clearly indicated the higher maximum temperature affect the phenological events in maize crop negatively, whereas minimum temperature and rainfall affected grain yield of the crop. Proper irrigation scheduling, alteration in sowing date to match various growth stages with the monsoon, microclimate modification etc. management practices can be followed to cope with the weather aberrations.

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Received: September 25, 2021; Accepted: December 30, 2021