LR-4949
[1-7]

RESEARCH ARTICLE

Legume Research- An International Journal, Volume Issue : ()

Photothermal Quotient-An Effective Thermal Index for Evaluation of Lentil (*Lens culinaris* L.) Phenology and Yield in the Lower Gangetic Plains

S. Maji[1], P.K. Chakraborty[2], R. Nath[1], S. Mondal[1], S. Dey[1], P. Bandopadhyay[1], S. Banerjee[2]

10.18805/LR-4949

ABSTRACT

Background: Sowing time and variety-specific genetics influence the phenological development of lentil (*Lens culinaris* L.), affecting its heat and solar energy utilization for attaining satisfactory yield. The present study was conducted to assess how the different thermal indices behaved in explaining variation in phenology and yield components with corresponding effects on yield of lentil varieties grown under varying sowing dates.

Methods: The experiment comprised of four sowing dates in the main plots and five lentil varieties in the sub-plots, laid out in a split-plot design replicated thrice. The phenology, yield components and yield were recorded. The computed thermal indices and correlation and regression analyses were used to assess their effects on yield traits and yield.

Result: Sowing after 7th November reduced lentil yield by 13.6-22.5 kg ha^{-1} day^{-1} and 0.9-2.1% ha^{-1} day^{-1} on absolute and relative basis, respectively. The varieties WBL 77 and HUL 57 were less sensitive to temperature fluctuations resulting in stable yield performance under varying thermal regimes. Despite significant influence of temperature on yield traits, growing degree days explained 82.0-89.0%, while photothermal quotient (PTQ) explained 92.0-96.0% of the total variation in yield. PTQ emerged as a reliable yield predicting thermal index and might be used for breeding climate-smart lentil varieties.

Key words: Growing degree day, Lentil, Phenology, Photothermal quotient, Sowing dates.

INTRODUCTION

Any change in ambient temperature range during the crop growth period alters the phenological development, thus affecting the dry matter accumulation and productivity. Thermal indices such as growing degree days (GDD) and heat use efficiency (HUE) have been widely used to quantify the effects of temperature on phenology and yield performance in several crops (Pandey *et al*., 2010). On the contrary, photothermal quotient (PTQ) summarizes a larger volume of weather information by providing the dual effects of temperature and solar radiation on crop growth (Kumar *et al*., 2016). Since global solar radiation influences air temperature, inclusion of solar radiation in thermal indices is crucial for comprehensively evaluating the temperature effects on crop phenological developmental rate and productivity. The nature of heat and solar energy utilization also depend on the crop genetics and growing environment. A detailed understanding of the association between these weather parameters and yield of a particular crop helps in breeding climate-smart varieties.

Lentil (*Lens culinaris* L.) ranks second in India among food legumes, covering an area of 1.51 m ha with 1.56 m t and 1.03 t ha^{-1} of production and productivity, respectively (DES, 2020). It is grown as a rainfed winter crop in northern and eastern India. However, the shifting monsoons and erratic weather events have made winter agriculture prone to severe yield losses, especially in eastern India. Temperature abruptions associated with late sowing, especially during the reproductive stage, severely affect the floral and pod biologies, overall heat and solar energy utilization, yield components and productivity in winter food legumes (Maji *et al*., 2019). The genetic makeup of variety also influences the temperature sensitivity of vegetative and reproductive growth traits determining yield (Chaudhury *et al*., 2020). Therefore, the lentil genotypes with consistent yield performance across diverse weather conditions are likely to fit better in eastern India's short and erratic winters. Hence, this study was taken up with two objectives: (i) to identify the optimal sowing window and lentil varieties suitable for the lower Gangetic plains and (ii) to evaluate the effects of GDD and PTQ on lentil phenology and yield.

[1]Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741-252, West Bengal, India.
[2]Department of Agricultural Physics and Meteorology, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741-252, West Bengal, India.

Corresponding Author: S. Maji, Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur-741-252, West Bengal, India. Email: maji.srijani@bckv.edu.in

How to cite this article: Maji, S., Chakraborty, P.K., Nath, R., Mondal, S., Dey, S., Bandopadhyay, P. and Banerjee, S. (2022). Photothermal Quotient - An Effective Thermal Index for Evaluation of Lentil (*Lens culinaris* L.) Phenology and Yield in the Lower Gangetic Plains. Legume Research. DOI: 10.18805/LR-4949.

Submitted: 26-04-2022 **Accepted:** 01-10-2022 **Online:** 27-10-2022

MATERIALS AND METHODS

A three-year field experiment was conducted during the winter seasons of 2015-16, 2016-17 and 2017-18 at the District Seed Farm (AB block), Bidhan Chandra Krishi Viswavidyalaya (latitude-22°58′45″N, longitude-88°25′15″E and altitude-9.75 m above sea level). The experimental soil was sandy clay loam in texture (sand-47.7%, clay-24.3% and silt-27.9%) with a neutral pH (7.1) and had medium organic carbon (0.52%), available nitrogen (258.2 kg N ha^{-1}) and available potassium (153.5 kg K_2O ha^{-1}) but high available phosphorus (29.4 kg P_2O_5 ha^{-1}) status. The mean maximum temperatures during the experimental period were 29.2, 28.6 and 28.3°C, respectively in the three consecutive experimental years. The mean minimum temperatures in the same years were 16.7, 14.9 and 15.0°C, respectively. Total rainfall received during the crop growing period in 2015-16, 2016-17 and 2017-18 were 57.9, 22.8 and 52.5 mm, respectively. Year-wise weekly distribution of the mean atmospheric temperatures and the total rainfall during the experimental period are presented in Fig 1.

The experiment comprised four sowing dates in the main plots (D_1-31st October, D_2-7th November, D_3-14th November and D_4-21st November) and five varieties (V_1-HUL 57, V_2- WBL 77, V_3-KLS 218, V_4-WBL 58 and V_5-B 256) in the sub-plots, laid out in a split-plot design replicated thrice. Different varieties were sown after seed inoculation with recommended *Rhizobium* strain. A 25 cm (row-row) × 10 cm (plant-plant) spacing in a sub-plot area of 5 m × 4 m was

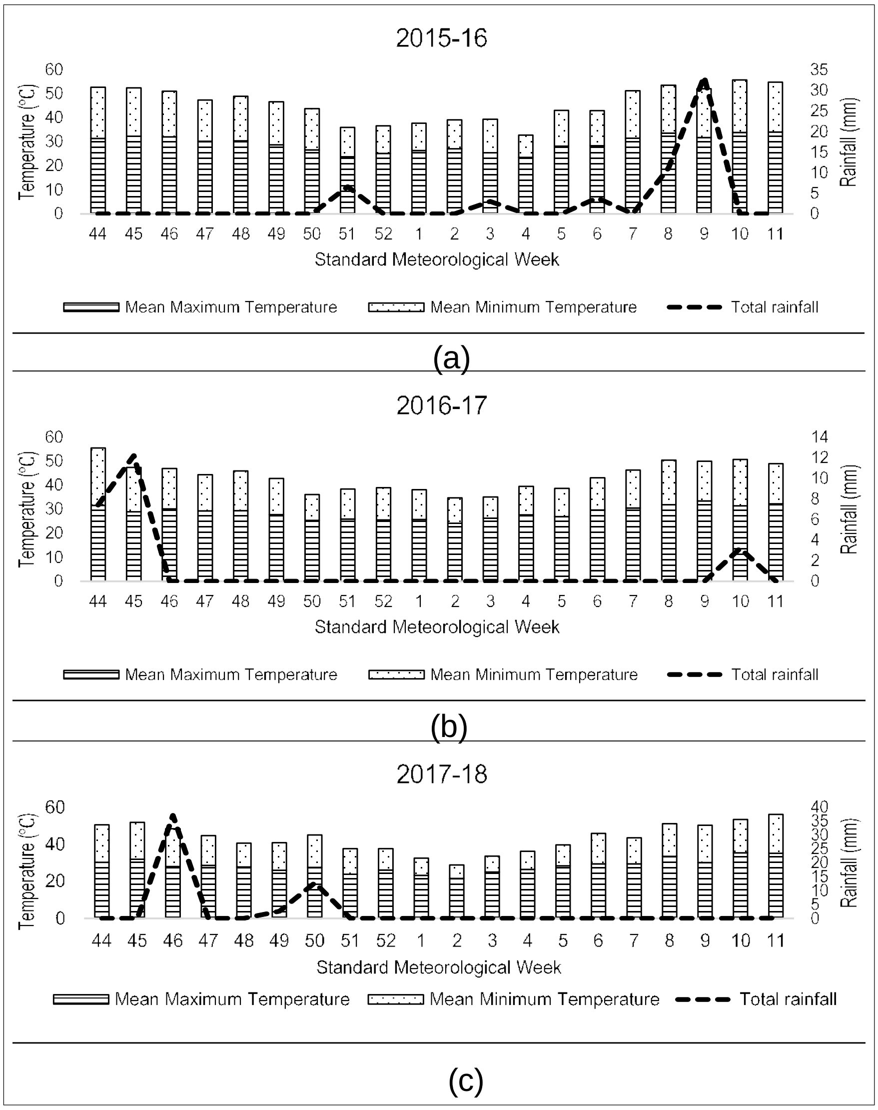

Fig 1: Weekly distribution of the mean maximum and minimum temperatures and the total rainfall during the experimental period (a) 2015-16, (b) 2016-17 and (c) 2017-18.

*Significant at p≤0.05.

maintained. A basal dose of 20 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} were applied. Single pre-sowing irrigation was given to ensure uniform germination and crop stand.

The dates of emergence (E), 50% flowering (50%F), 100% flowering (100% F) and Maturity (M) in each lentil variety under all the sowing dates were recorded. Pods per plant and hundred seed weight (HSW) were observed from randomly tagged ten plants from each treatment combination. Stover (STY) and seed yields (SY) were measured from a net area of 12.0 m^2 and expressed in t ha^{-1}. The harvest index (HI) is the ratio of SY and biological yield. The phenophase-wise growing degree days (GDD) considering a base temperature of 5.0°C and heat use efficiency (HUE- kg ha^{-1} °C day^{-1}) were calculated as per Kaur *et al*. (2019). Since the daily solar radiation (SR) of the experimental location was not available, it was computed from the Bristow and Campbell (1984) algorithm using maximum temperature (MAXT), minimum temperature (MINT), Julian days and latitude of the site. The photothermal quotient (PTQ) was calculated using the formula proposed by Ortiz-Monasterio *et al*. (1994), with the base temperature of 5.0°C in lentil.

$$\text{If AVGT}<5.0,\ \text{PTQ day}^{-1} = 0;$$

$$\text{If } 5.0<\text{AVGT}<10,\ \text{PTQ day}^{-1} = \text{SR} \times \{(\text{AVGT} - 5)/5.5\}/5.5;$$

$$\text{If AVGT}>10,\ \text{PTQ day}^{-1} = \text{SR}/(\text{AVGT} - 5);$$

Where;

AVGT = Daily average temperature (°C). {(MAXT + MINT)/2}.

SR= Daily solar radiation (MJ m $^{-2}$).

PTQ = Expressed as MJ m^{-2} day^{-1} °C^{-1}.

The yield losses due to deferred sowing dates were worked out using the regression equations proposed by Ortiz-Monasterio *et al.* (1994):

Equation (1)- Absolute loss: Yi= a + bSDi + u

Equation (2)- Relative loss: ln (Yi)= a + bSDi

Where,

Yi (kg ha^{-1}) = Yield of the sowing date.

SDi= Julian date for the sowing date.

Equations 1 and 2 provide an estimation of the yield losses on absolute (b= kg ha^{-1} day^{-1} yield loss) and relative (100 × b = percent day^{-1} yield loss) basis, respectively.

The data were subjected to analysis of variance (ANOVA) for split-plot design. Tukey's HSD (honest significant difference) was used to compare the treatment means using SAS version 9.1 for windows. The interaction effect between sowing dates and varieties was non-significant ($p>0.05$) (data not shown). Pearson's correlation coefficients was used to quantify the association among the thermal indices, yield and yield components. Regression analysis was employed to quantify the impacts of GDD, PTQ and yield components on yield.

RESULTS AND DISCUSSION

Yield and yield components

The 7th November sown crop recorded the highest SY (1.41 t ha^{-1}), STY (2.85 t ha^{-1}), pods per plant (155.5 plant^{-1}) and harvest index (0.33) (Table 1). Delayed sowing beyond first week of November adversely affected yield traits and yield in lentil. Singh *et al*. (2009) also reported that deferring sowing from 20th October to 10th November reduced lentil yield by approximately 10.4%, implying that early sowing ensures adequate sink partitioning by providing favourable growing conditions for optimal vegetative and reproductive growth.

WBL 77 yielded the highest among the varieties with better yield attributing traits, closely followed by HUL 57. However, delaying sowing from 7th November to 21st November reduced the SY of HUL 57, WBL 77, KLS 218, WBL 58 and B 256 at the rates of 17.9, 13.6, 20.5, 22.5 and 22.1 kg ha^{-1} day^{-1} on absolute basis, respectively; the corresponding values for the same varieties were 1.4, 0.9, 1.7, 1.8, 2.1% ha^{-1} day^{-1} on relative basis.

Relationship between yield and yield components

Correlation analysis showed that pods plant^{-1}, 100 seed weight and stover yield significantly influenced lentil yield (Kumar *et al.,* 2020) (Table 2). Stepwise multiple regression analysis showed that R^2 values increased significantly with the addition of each yield component (according to the strength of degree of association) as predictor variable, indicating that yield is cumulative effect of the various yield components and no single trait emerged as a prime determinant (Table 3). The regression equation with 100

Table 1: Yield and yield components in lentil varieties sown under different dates (Mean of 3 years).

Date of sowing	Seed yield (t ha^{-1})	Stover yield (t ha^{-1})	Pods plant^{-1}	Hundred seed weight (g)	Harvest index
31-Oct	1.36a	2.78ab	147.32b	2.65a	0.327ab
07-Nov	1.41a	2.85a	155.50a	2.59ab	0.331a
14-Nov	1.24b	2.67bc	137.43c	2.50b	0.317cb
21-Nov	1.14c	2.57c	124.80d	2.39c	0.306c
Varieties					
HUL 57	1.34b	2.75a	141.67b	2.66ab	0.328ab
WBL 77	1.49a	2.89a	151.26a	2.73a	0.339a
KLS 218	1.26bc	2.72a	136.41b	2.55cb	0.315b
WBL 58	1.25c	2.73a	142.53ba	2.42dc	0.313b
B 256	1.10d	2.50b	134.45b	2.28d	0.305b

Within sowing dates and varieties, numbers followed by different letters are significantly different at $p\leq 0.05$.

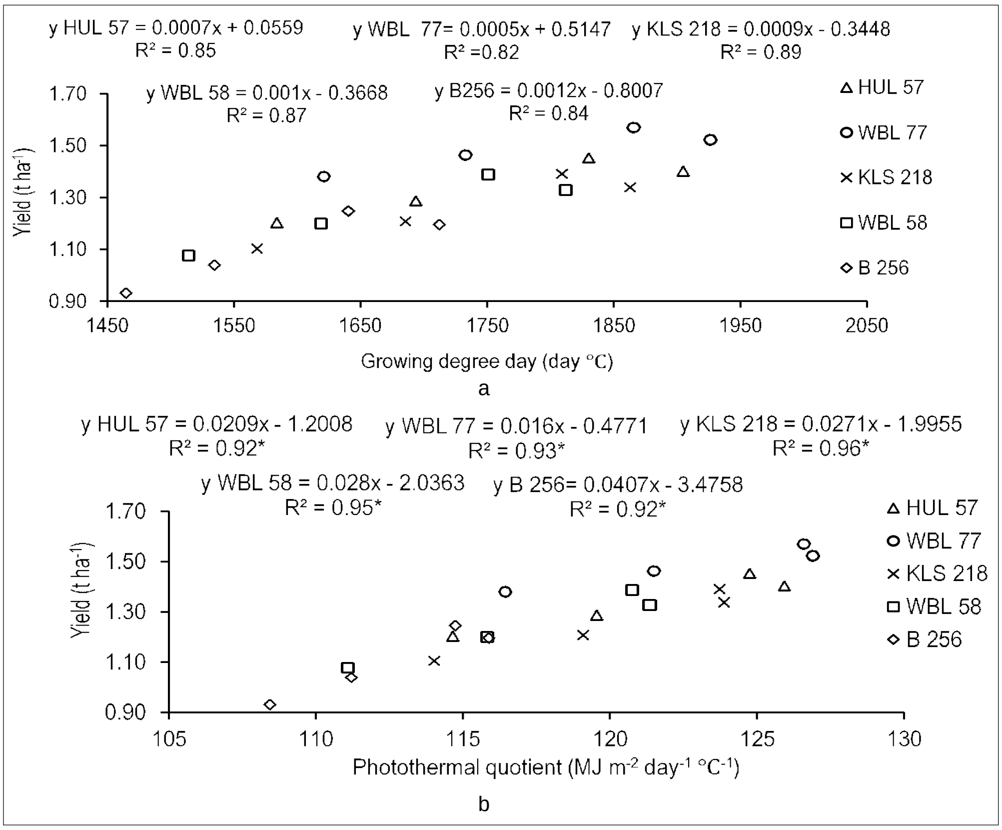

Fig 2: Effect of (a) growing degree day and (b) photothermal quotient on yield of lentil varieties. *Significant at p≤0.05.

Table 2: Correlation coefficients between yield components and yield in lentil.

	Seed yield	Hundred seed weight	Stover yield	Pods plant^{-1}	Harvest index
Seed yield	1				
Hundred seed weight	0.92**	1			
Stover yield	0.92**	0.85**	1		
Pods plant^{-1}	0.88**	0.68**	0.81**	1	
Harvest index	0.81**	0.83**	0.71**	0.73	1

**Significant at p≤0.01.

Table 3: Yield prediction models based on yield components in lentil.

	R^2	R^2 change
SY=0.84 STY-0.99	0.85 p<0.01	-
SY=0.46 STY+0.42HSW-1.02	0.92 p<0.01	0.07 p<0.01
SY=0.14 STY+0.43HSW+0.01 POD-0.92	0.97 p<0.01	0.06 p<0.01

† SY-Seed yield, STY-Stover yield, HSW-Hundred seed weight, POD-Pods plant^{-1}.

seed weight, stover yield and pods plant^{-1} explained 97.0% of the total variation in lentil yield.

Crop phenology

The early sowings (31st October and 7th November) took 2-4 days less for emergence than the other two sowings (Table 4). The late sown winter crops usually require a longer time for seedling emergence due to low-temperature exposure decelerating the crop growth (Richards *et al*. 2020). Deferred sowing beyond 7th November reduced the overall crop duration by 7-13 days. Forced maturity due to high temperature-induced senescence shortened the life cycle of late sown fababean (Prakash *et al*., 2018). The results also reveal that the 31st October and 7th November sowings with more days to flowering culminated in significantly higher yield, evidencing the paramount importance of adequate vegetative window. A shorter vegetative phase limits biomass accumulation resulting in yield losses because seed filling depends on current assimilation and redistribution from pre-stored vegetative pools (Sehgal *et al*., 2018).

The varieties HUL 57, WBL 77 and KLS 218 recorded significantly longer duration to achieve various phenological stages. Pooled analysis revealed that the crop

Table 4: Phenology, growing degree days, heat use efficiency, photothermal quotient in lentil varieties sown under different dates (Mean of 3 years).

Sowing dates	Phenology (Calendar days)				Growing degree day (day°C)				Photothermal quotient (MJ m^{-2} day^{-1}°C^{-1})				HUE (kg ha^{-1} day^{-1}°C)
	S-E	S-50% F	S-100% F	S-M	S-E	S-50% F	S-100% F	S-M	S-E	S-50% F	S-100% F	S-M	
31-Oct	9b	75a	82a	119a	182.01c	1184.55a	1280.07a	1843.52a	6.1b	69.8a	78.9a	122.8a	0.738b
07-Nov	11ab	73a	81a	116b	209.16b	1110.84b	1204.21b	1779.13b	8.7ab	71.8a	81.4a	122.1a	0.793a
14-Nov	13a	70b	77b	109c	232.97a	1024.20c	1111.38c	1652.96c	10.9a	71.7a	80.3a	117.4b	0.749b
21-Nov	13a	68c	73c	103d	219.04ab	951.72d	1032.37d	1550.25d	11.4a	71.6a	78.7a	112.9c	0.736b
Varieties													
HUL 57	12a	75a	82a	114a	225.67a	1108.07a	1202.01a	1753.04a	1672.3a	75.3a	84.1a	121.2a	0.764b
WBL 77	12ab	73ab	80ab	116a	212.70ab	1086.62ab	1181.78ab	1786.37a	1590.8ab	73.1ab	82.4ab	122.9a	0.836a
KLS 218	11b	74ab	81ab	113ab	201.25b	1091.68ab	1185.08ab	1731.33ab	1493.1b	73.5ab	82.6ab	120.2ab	0.729bc
WBL 58	12ab	72b	78b	110b	215.59ab	1068.76b	1157.27b	1673.84b	1596.4ab	71.4b	80.0b	117.3b	0.744b
B 256	11b	65c	71c	106c	198.77b	984.02c	1058.90c	1587.73c	1472.4b	63.0c	70.1c	112.6c	0.696c

Within sowing dates and varieties, numbers followed by different letters are significantly different at $p \leq 0.05$. S-sowing, E-Emergence, 50% F-50% flowering, 100% F-100% flowering, M-Maturity, HUE-Heat use efficiency (kg ha^{-1} °C day^{-1}).

duration of HUL 57, WBL 77 and KLS 218 ranged from 113 to 116 days.

Growing degree days and heat use efficiency

The 14th and 21st November sowings recorded significantly higher thermal time requirement for seedling emergence (Table 4). Relatively lower mean temperatures delayed the emergence of late sown lentils in the current study, increasing the heat unit consumption as reported by Richards *et al.* (2020). The trend of heat unit accumulation followed the pattern of variation in phenological development during the crop growth period. Sowing after 7th November reduced the crop duration and heat unit consumption from sowing to maturity by 7-13 days and 7.0-12.8%, respectively compared to early sowings. Late sowing lowers heat unit consumption due to supra-optimal thermal regime during the reproductive phase, which accelerates senescence.

The varieties HUL 57, WBL 77 and KLS 218 recorded significantly higher heat unit consumption to attain various phenological stages and no significant difference was observed between them (Table 4). The variation emerging from the characteristic genetic makeup of crop varieties had a marked influence on phenology and heat unit consumption, eventually affecting yield (Pandey *et al*., 2010). Regression analysis revealed that GDD caused 82.0-89.0% of the total variation in the yield of lentil varieties (Fig 2a).

The 7th November sowing had the highest HUE (0.793 kg ha^{-1} °C day^{-1}), which was possibly due to a proportional increase in dry matter per heat unit absorbed (Table 4). High-temperature exposure during the late vegetative and reproductive stages might have adversely affected dry matter accumulation, reducing the HUE in the late sowing. Among the varieties, WBL 77 recorded the highest HUE, indicating its wider adaptability under varying thermal environments.

Photo-thermal quotient

The crop sown within the first week of November recorded significantly higher total PTQ during the crop growing period (Table 4). The varieties HUL 57, WBL 77 and KLS 218 recorded significantly higher PTQ, resulting in a higher yield. Per unit increase in PTQ increased the yield by 20.9, 16.0, 27.1, 28.0, 40.7 kg ha^{-1} in HUL 57, WBL 77, KLS 218, WBL 58 and B 256, respectively. Yield increases with increasing PTQ since low PTQs indicated elevated mean temperatures and radiation intensity (Ortiz-Monasterio *et al*. 1994). Heat stress reduces lentil seed filling duration and yields by 5.5-8.1 days and 38.0-58.0%, respectively (Sita *et al*., 2018). The regression analysis showed that the PTQ caused 92.0-96.0% of the total variation in the yield (Fig 2b). Thus, PTQ was a better yield predictor than GDD since the former quantifies the combined effects of both radiation and temperature (Kumar *et al*., 2016).

Effect of temperature and PTQ (phenophase-wise) on yield components and yield

The temperature during E-50% F exhibited no significant effect on the stover yield of WBL 77 and HUL 257, implying lower sensitivity of these two varieties to temperature

Table 5: Correlation coefficients among yield, yield components and phenological stage-wise MAXT, MINT and PTQ.

Parameters	MAXT S-E	MAXT E-50% F	MAXT E-100% F	MAXT 100% F-M	MINT S-E	MINT E-50% F	MINT E-100% F	MINT 100% F-M	PTQ S-E	PTQ E-50% F	PTQ E-100 %F	PTQ 100% F-M
						HUL 57						
SY	0.92	0.84	-0.86	-0.75	0.82	0.86	-0.70	-0.76	-0.81	0.95*	-0.35	0.90
STY	0.40	0.53	-0.10	-0.41	0.50	0.58	0.20	-0.42	-0.70	0.51	0.27	0.37
POD	0.95*	0.89	-0.88	-0.81	0.88	0.91	-0.61	-0.82	-0.87	0.94	-0.24	0.94
HSW	0.99**	0.95	-0.98*	-0.93	0.95	0.94	-0.45	-0.93	-0.87	0.79	-0.02	0.99**
						WBL 77						
SY	0.91	0.76	-0.92	-0.72	0.79	0.78	-0.61	-0.76	-0.72	0.06	0.86	0.88
STY	0.53	0.30	-0.70	-0.27	0.33	0.33	-0.89	-0.33	-0.20	-0.47	0.97*	0.47
POD	0.91	0.76	-0.92	-0.72	0.79	0.78	-0.61	-0.76	-0.73	0.08	0.85	0.88
HSW	0.95	0.96*	-0.95*	-0.96*	0.96*	0.96*	-0.08	-0.98*	-0.91	-0.13	0.68	0.96*
						KLS 218						
SY	0.94	0.87	-0.92	-0.77	0.84	0.83	-0.33	-0.79	-0.75	0.84	0.96*	0.91
STY	0.88	0.75	-0.86	-0.65	0.71	0.71	-0.54	-0.67	-0.59	0.69	0.99*	0.85
POD	0.88	0.76	-0.86	-0.65	0.72	0.72	-0.51	-0.68	-0.61	0.72	0.99**	0.85
HSW	0.99**	0.97*	-0.99**	-0.93	0.95	0.95*	-0.12	-0.94	-0.88	0.90	0.82	0.99**
						WBL 58						
SY	0.93	0.83	-0.88	-0.65	0.84	0.80	-0.18	-0.65	-0.75	0.95*	0.96*	0.75
STY	0.93	0.83	-0.88	-0.65	0.84	0.80	-0.18	-0.65	-0.75	0.95*	0.96*	0.75
POD	0.91	0.79	-0.85	-0.61	0.81	0.76	-0.24	-0.61	-0.71	0.94	0.98*	0.71
HSW	0.99*	0.97*	-0.87	-0.92	0.97*	0.97*	0.29	-0.92	-0.92	0.98*	0.73	0.93
						B 256						
SY	0.94	0.88	-0.93	-0.88	0.87	0.79	0.76	-0.89	-0.79	0.72	0.95*	0.79
STY	0.94	0.90	-0.93	-0.88	0.89	0.82	0.72	-0.88	-0.81	0.75	0.94	0.83
POD	0.84	0.72	-0.84	-0.80	0.70	0.57	0.85	-0.83	-0.61	0.51	0.95*	0.58
HSW	0.99**	0.97*	-0.98*	-0.95*	0.96*	0.90	0.72	-0.94	-0.91	0.86	0.94	0.89

*Significant at p≤0.05, **Significant at p≤0.01. †SY-seed yield, STY-Stover yield, HSW-Hundred seed weight, POD-Pods plant-1, MAXT-Maximum temperature, MINT-Minimum temperature, PTQ-Photothermal quotient, S-Sowing, E-Emergence, 50% F-50% flowering, 100% F-100% flowering, M-Maturity.

fluctuations during the vegetative stage (Table 5). Among the yield components, 100 seed weight and pods plant^{-1} were more sensitive to maximum than minimum temperature during E-100%F. However, both maximum and minimum temperatures during 100%F-M showed strong negative correlations with these traits, irrespective of varieties. The maximum and minimum temperatures during the 100% F-M also had a comparable negative impact on the final yield. Since heat stress affects reproductive biology, biomass accumulation and leaf function-associated traits in lentils (Bhandari *et al*. 2020), late sowing-associated elevated temperatures are likely to reduce lentil productivity as observed herein.

The PTQs during E-100%F and 100% F-M had a stronger influence on yield and yield components than either maximum or minimum temperature (Table 5). These findings align with Ortiz-Monasterio *et al*. (1994), who reported that increased PTQ during 20 and 10 days before and after heading improved grains m^{-2} in wheat.

CONCLUSION

The optimal sowing window in the Lower Gangetic Plains was the first week of November for intensifying lentil productivity through improved phenology and thermal energy use. The two promising varieties *viz*. HUL 57 and WBL 77 exhibited lower sensitivity towards temperature fluctuations during the vegetative stage with consistent performance across varying thermal regimes. Temperature significantly influenced yield components, with pods plant^{-1} and 100 seed weight being more sensitive to maximum temperature during vegetative and early reproductive stages and both maximum and minimum temperatures during the late reproductive phase. However, the stronger correlation between photo-thermal quotient and yield components made it a more reliable yield predictor. Hence, photo-thermal quotient might serve as a more effective thermal index in identifying temperature-sensitive traits than the widely-used growing degree day for breeding climate-smart lentil varieties with wider adaptability.

Conflict of interest: None.

REFERENCES

Bhandari, K., Sita, K., Sehgal, A., Bhardwaj, A., Gaur, P., Kumar, S., Singh, S., Siddique, K.H., Prasad, P.V., Jha, U. and Nayyar, H. (2020). Differential heat sensitivity of two cool season legumes, chickpea and lentil, at the reproductive stage, is associated with responses in pollen function, photosynthetic ability and oxidative damage. Journal Agronomy and Crop Science. 206: 734-758.

Bristow, K.L. and Campbell, G.S. (1984). On the relationship between incoming solar radiation and daily maximum and minimum temperature. Agricultural and Forest Meteorology. 31: 159-166.

Chaudhary, S., Devi, P., Bhardwaj, A., Jha, U.C., Sharma, K.D., Prasad, P.V.V., Siddique, K.H.M., Bindumadhava, H., Kumar, S. and Nayyar, H. (2020). Identification and characterization of contrasting genotypes/cultivars for developing heat tolerance in agricultural crops. Current status and prospects. Frontiers in Plant Science. 11: 587264. doi: 10.3389/fpls.2020.587264.

DES, Directorate of Economics and Statistics, Department of Agriculture Cooperation and Farmers' Welfare. (2020). Ministry of Agriculture and Farmers' Welfare, Government of India, New Delhi (http://eands.dacnet.nic.in).

Kaur, H., Kingra, P.K. and Singh, S.P. (2019). Effect of sowing date, irrigation and mulch on thermal time requirement and heat use efficiency of maize (*Zea mays* L.). Journal of Agrometeorology. 20: 46-50.

Kumar, A., Gill, R.K. and Singh, M. (2020). Genetic variability and association analysis for various agro morphological traits in lentil (*Lens culinaris* M.). Legume Research. 43: 776-779.

Kumar, P.V., Rao, V.U.M., Bhavani, O., Dubey, A.P. and Singh, C.B. (2016). Effect of temperature and photothermal quotient on the yield components of wheat (*Triticum aestivum* L.) in Indo-Gangetic plains of India. Experimental Agriculture. 52: 14-35.

Maji, S., Das, A., Nath, R., Bandopadhyay, P., Das, R. and Gupta, S. (2019). Cool Season Food Legumes in Rice Fallows: An Indian perspective. In: Agronomic Crops. [(Ed.) Hasanuzzaman, M.)]. Springer, Singapore. pp. 561-605.

Ortiz-Monasterio, J.I., Dhillon, S.S. and Fischer, R.A. (1994). Date of sowing effects on grain yield and yield components of irrigated spring wheat cultivars and relationships with radiation and temperature in Ludhiana, India. Field Crops Research. 37: 169-184.

Pandey, I.B., Pandey, R.K., Dwivedi, D.K. and Singh, R.S. (2010). Phenology, heat unit requirement and yield of wheat (*Triticum aestivum*) varieties under different crop-growing environment. Indian Journal of Agricultural Sciences. 80: 136-140.

Prakash, V., Singh, A.K., Kumar, R., Mishra, J.S., Kumar, S., Dwivedi, S.K., Rao, K.K., Samal, S.K. and Bhatt, B.P. (2018). Thermal regimes: The key to phenological dynamics and productivity of fababean (*Vicia faba* L.). Journal of Agrometeorology. 20: 36-39.

Richards, M.F., Preston, A.L., Napier, T., Jenkins, L. and Maphosa, L. (2020). Sowing date affects the timing and duration of key chickpea (*Cicer arietinum* L.) growth phases. Plants. 9: 1257.

Sehgal, A., Sita, K., Siddique, K.H., Kumar, R., Bhogireddy, S., Varshney, R.K., HanumanthaRao, B., Nair, R.M., Prasad, P.V. and Nayyar, H. (2018). Drought or/and heat-stress effects on seed filling in food crops: Impacts on functional biochemistry, seed yields and nutritional quality. Frontiers in Plant Science. 9: 1705.

Singh, H., Elamathi, S. and Anandhi, P. (2009). Effect of row spacing and dates of sowing on growth and yield of lentil (*Lens culinaris*) under north eastern region of UP. Legume Research. 32: 307-308.

Sita, K., Sehgal, A., Bhandari, K., Kumar, J., Kumar, S., Singh, S., Siddique, K.H. and Nayyar, H. (2018). Impact of heat stress during seed filling on seed quality and seed yield in lentil (*Lens culinaris* Medikus) genotypes. Journal of the Science of Food and Agriculture. 98: 5134-5141.