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EVALUATION OF AGROCLIMATIC INDICES AND YIELD OF INDIAN MUSTARD (*BRASSICA JUNCEA* L.) UNDER DIFFERENT THERMAL REGIMES

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ABSTRACT

Climate change has had a profound impact on agriculture. Given the current trend of rising temperatures, an investigation was conducted to assess the influence of weather variability on mustard crop. Two different varieties, Pusa Bold and Varuna, were evaluated across varying dates of sowing: October 15th, November 10th, and December 5th. Agroclimatic indicators such as Growing Degree Day (GDD), Helio-thermal units (HTU), Photo-thermal units (PTU), and Photo-thermal Index (PTI) were employed to examine their correlation with yield under different sowing conditions. The findings revealed that the duration between various phenological stages, from emergence to physical maturity, was longest in the October 15th sowing (154 days), followed by November 10th (132 days), and December 5th (113 days). This reduction in duration for later-sown mustard crops may be attributed to higher temperatures (30-35°C) during the reproductive phase, which led to forced maturity. Across all three sowing dates, the Varuna variety took longer to reach maturity (135 days) compared to Pusa Bold (131 days). Mustard crops sown on October 15th required more thermal and heat units compared to those sown on November 10th and December 5th, owing to their longer maturation period. Yield attributing characters such as the number of siliqua per plant, number of seeds per siliqua, 1000-seed weight, biological yield, and seed yield were significantly higher in early-sown crops, followed by those sown in the normal and late periods.

Keywords: Growing degree days, Helio-thermal unit, Phenological stages, Photo-thermal index, Photo-thermal unit

Various phonological stages of crop, spanning from planting to harvesting, are influenced by weather conditions. Temperature and radiation stand out as significant weather elements impacting crop yield. The growth and development of crops are intricately linked to the amount of solar energy received and the thermal fluctuations experienced during the growth period (Neog and Chakravarty, 2005).

Mustard (*Brassica* spp.) holds a crucial position among oilseed crops, cultivated across 53 countries worldwide. India ranks as the third-largest producer of mustard, both in terms of cultivated area and production (DRMR, 2024). In India, rapeseed mustard covers approximately 5.99 million hectares, with a production of 6.31 million tonnes and productivity reaching 1053 kg/ha. Among the seven edible oilseed crops cultivated in India, mustard alone contributes a substantial 28.6% to the total oilseed production (Shekhawat *et al*., 2012).

Indian mustard is mostly cultivated as a temperate crop. But it is also grown in certain tropical and subtropical regions as a winter season crop. Mustard crop can tolerate annual temperature of 6 to 27°C and annual precipitation of 500 to 1200 mm. The crop is considerably sensitive to weather as evidenced from the variable response to different sowing dates (Kumar *et al*., 2007). Agrometeorological indices based on temperature, such as growing degree days (GDD), heliothermal units (HTU), and photo-thermal units (PTU), operate on the principle that the time taken for crops to reach various phenological stages is contingent upon the accumulation of thermal units. Therefore, all phenological stages of crop may be estimated more accurately based on GDD rather than calendar method (Warthington and Hatchinson, 2005). Mustard crop requires different amounts of GDD, HTU, PTU and PTI for different growth and developmental stages. Solanki and Mundra (2015) studied the effect of thermal regimes on phenology and productivity of mustard crop (*Brassica juncea* L.). It was found that with the successive delay in sowing date, growing degree days (GDD) and heliothermal units (HTU) were decreased significantly for reproductive phase and the grain yield was directly influenced by variations in yield contributing parameters. A delay of one month in sowing, starting from mid-October, resulted in a 40.6 per cent reduction in yield (Lallu *et al.,* 2010). Late sown crop suffers from exposure to low temperature during vegetative and early pod development stage and relatively higher temperature during maturity (Adak and Chakravarthy, 2010). Temperature-dependent agroclimatic indices can be employed to establish correlations with various crop growth parameters, including phenology and

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seed yield. Hence, in the current investigation, a field experiment was undertaken involving different sowing dates to explore their impact on crop phenology. Various agroclimatic indices were employed to examine the influence of different sowing dates on yield attributing characteristics and yield.

MATERIALS AND METHODS

Experimental details

To investigate the impact of weather variability, particularly concerning the timing of sowing, mustard crop was cultivated during the *rabi* 2020-21 and 2021-22 crop seasons at Bihar Agricultural University, Sabour.

Sabour is located in Indo-Gangetic plain at an altitude of 52.73 meters above mean sea level with a latitude 25°50' N and longitude 87°19' E. The soil of the experimental field was sandy loam with pH 7.42, having organic carbon 0.52%, available nitrogen 227.2 kg ha^{-1}, available phosphorus 24.2 kg P_2O_5 ha^{-1}, available potassium 152.1 kg K_2O ha^{-1} and available sulphur 10.31 ppm. The experiment consisted of six treatment combinations, involving three sowing dates (October 15th, November 10th, and December 5th) and two varieties (Pusa Bold and Varuna), replicated three times in a randomized block design during the *rabi* seasons of 2020-21 and 2021-22 under irrigated conditions. The spacing used for both the varieties of mustard was 30 x 10 cm. The crop was fertilized with recommended dose of N:P:K @ 40:40:20 kg ha^{-1}. Half the amount of N and full amount of P and K were applied at the time of sowing and the remaining half N was applied as top dressing in two splits at 30 and 60 days after sowing. The N, P & K nutrients were supplied through urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively.

Weather parameters

Weather data including maximum temperature, minimum temperature, morning and evening relative humidity, rainfall, bright sunshine hours, and day length were recorded from sowing till harvesting of the crop at the Agro-meteorological Observatory, BAU, Sabour. Agroclimatic indices such as growing degree days (GDD), heliothermal units (HTU), and photo-thermal units (PTU) were calculated using the following formulae:

Growing Degree Days (GDD)

Daily growing degree days (°C day) were calculated by summing the daily mean temperature above the base temperature (T_b=5°C) by using the following formula as per Nuttonson (1955) and was calculated by equation (i).

$$GDD = [(T_{max} + T_{min})/2] - T_{base} \qquad (i)$$

T_{max} – Daily maximum temperature (°C)

T_{min} – Daily minimum temperature (°C)

T_{base} – Base Temperature of 5°C

Helio thermal units (HTU): Another agroclimatic index which was calculated as per equation (ii).

Helio-thermal units (HTU) = GDD × Actual sunshine hours (ii)

Photothermal units (PTU): This agroclimatic index was calculated to see the effect of day length and was calculated as per equation (iii).

Photo-thermal units (PTU) = GDD × Day length. (iii)

Photothermal Index (PTI): It was calculated as per equation (iv).

$$\text{Photo-thermal Index (PTI)} = \frac{\text{Degree days consumed}}{\text{Number of days}} \qquad (iv)$$

RESULTS AND DISCUSSION

Days taken to attain different phenological stages

Total days taken from sowing to physiological maturity for both Pusa Bold and Varuna varieties decreased with delay in sowing. The numbers of days taken by the mustard crop for various phenological stages viz. starting of emergence, 5th true leaf exposed, first flower initiation, pod development (2 cm long), most seeds brown and physiological maturity under different growing environments were observed. Crop sown on 15th October took less number of days for emergence than later sowings (Table 1). It might be due to favourable soil and air temperature during that sowing time which fastened the seed germination process. However, early sown crop (15th October) took more number of days for 5th true leaf exposed, first flowering and physiological maturity as compared to timely sown (10th November) and late sown (5th December) crops. The early, timely and late sown crops attained physiological maturity in 154, 132 and 113 days respectively (Table 1). Late sown mustard crop took less number of days to reach different phenological stages. This might be due to higher temperature which fulfilled growing degree day requirement and thermal units of crop for achieving different phenological stages in lesser days as compared to early sown crop when maximum and minimum temperatures were lower. Gupta *et al*. (2017) also reported that there was decrease in number of calendar days taken from planting to physiological maturity with delay in sowing date. It was found that early sown crop took more days to reach physiological maturity as compared to late sowing crop (Hokmalipour

Table 1. Days taken to attain different phenological stages under different sowing dates and varieties (Mean of two years 2020-21 and 2021-22)

Treatment	First emergence	5th true leaf exposed	First flower initiation	Pod development (2 cm long)	Most seeds brown	Physiological maturity
			Sowing dates			
15 October	6.2	24.7	62.6	85.9	132.2	153.5
10 November	7.6	28.5	55.9	76.5	114.7	132.2
5 December	9.4	32.7	51.1	70.6	100.9	112.5
			Varieties			
Pusa bold	7.5	27.7	55.4	76.4	114.4	130.7
Varuna	7.9	29.5	57.6	79.1	117.5	135.0

et al., 2011). However, mustard variety Pusa Bold took less number of days (131 days) to complete different phenological stages than variety Varuna (135 days).

Agroclimatic indices

Agroclimatic indices viz. growing degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) were calculated for different durations of sowing to starting of emergence, sowing to 5th true leaf exposed, sowing to first flower initiation, sowing to pod development (2 cm long), sowing to most seeds brown and sowing to physiological maturity under different treatments.

The accumulated thermal unit requirement of mustard crop to attain different phenophases varied with sowing dates and varieties (Table 2). The crop sown on 15th October accumulated more GDD (3070°C days) to attain physiological maturity than 2nd (2536°C days) and 3rd dates of sowing (2139°C days). The early sown crop also accumulated more number of GDD at all the phenological stages as compared to timely and late sown crop. This clearly shows the effect of temperature on various phenological stages of mustard crop. These findings are similar to the results of Pandey *et al.* (2010) who reported that the requirement of heat units (GDD) for different phenological stages decreased with delay in sowing time. Regarding varieties, little variation in thermal requirement was also observed. Mustard variety Varuna recorded more thermal units (2643°C days) than variety Pusa Bold (2520°C days) to attain physiological maturity.

Earlier sown crop required higher accumulated heliothermal units (AHTU) to reach maturity. However, HTU consumption deceased with delay in sowing. At physiological maturity, accumulated HTU was 15602, 12471 and 10837°C days hours when mustard was sown early (15 October), timely (10 November) and late (5 December), respectively. AHTU for variety Pusa Bold and variety Varuna were 12611 and 13329°C days hours, respectively (Table 3). Kingra and Kaur (2012) also reported that the growing degree days (GDD), photothermal units (PTU) and heliothermal units (HTU) were highest in early sown mustard crop followed by timely and late sown mustard crops.

Photo-thermal unit (PTU) increased linearly with increase in plant age up to physiological maturity of the crop (Table 4). Based on pooled analysis the highest value of accumulated photo-thermal unit (APTU) was

Table 2. Accumulated growing-degree days (AGDD) (°C days) for various phenological stages under different sowing dates and mustard varieties (mean of two years 2020-21 and 2021-22)

Treatment	First emergence	5th true leaf exposed	First flower initiation	Pod development (2 cm long)	Most seeds brown	Physiological maturity
			Sowing dates			
15 October	147	520	1135	1401	1925	2303
10 November	139	477	817	1045	1516	1873
5 December	146	414	620	823	1306	1577
Mean	144	470	857	1089	1582	1917
			Varieties			
Pusa bold	140	459	842	1072	1554	1867
Varuna	147	481	872	1106	1610	1968
Mean	144	470	857	1089	1582	1917

Table 3. Accumulated helio-thermal units (AHTU) (°C days hours) for various phenological stages under different sowing dates and mustard varieties (mean of two years 2020-21 and 2021-22)

Treatment	First emergence	5th true leaf exposed	First flower initiation	Pod development (2 cm long)	Most seeds brown	Physiological maturity
			Sowing dates			
15 October	517	2900	5938	6764	9138	11832
10 November	801	2159	3496	4079	6888	9327
5 December	736	1636	2225	2995	6532	8116
Mean	685	2231	3886	4613	7519	9758
			Varieties			
Pusa bold	666	2161	3820	4532	7320	9463
Varuna	703	2302	3952	4693	7718	10053
Mean	685	2231	3886	4613	7519	9758

observed from sowing to maturity under early sown (33984°C days hours) followed by timely sown (28034°C days hours), while the lowest APTU were recorded under late sown condition (2386°C day hours). It was reported that the photo-thermal units (PTU) were the highest in early sowing (15 October), followed by late sowings (10 November and 5 December) (Khushu *et al.,* 2008). It was reported that with the successive delay in number of sowing days growing degree days (GDD) and heliothermal units (HTU) were decreased significantly for reproductive phase. Between the varieties, Varuna acquired higher PTU (29359°C days hours) than Pusa Bold (27893°C days hours) (Solanki and Mundra, 2015). Under late sowing condition, the highest amount of GDD, HTU and PTU were required for starting of emergence because seeds took more days to germinate.

Photo-thermal index (PTI)

PTI gradually decreased from emergence to later phenological stages in all three dates of sowing, being the lowest at pod development stage (2 cm long). This might be due to gradual decrease in maximum and minimum temperature resulting decrease in PTI of those phenophases (Neog *et al.,* 2008). However, PTI increased slightly from pod development stage (2 cm long) to physiological maturity of the crop (Table 5) which indicates a decrease in daily heat consumption towards maturity. In all three sowing dates the values of PTI at physiological maturity were almost similar to emergence stage. Among different dates of sowing 15th October sown crop recorded higher values of PTI from emergence to pod development stage but 5th December sown crop recorded higher PTI values from pod development stage to physical maturity. This might be because of comparatively less number of days were taken to complete later phenological stages by 5th December sown crop.

Yield attributing characteristics and yield

Seed yield is the major factor determining the commercial success of grain crop. Date of sowing

Table 4. Accumulated photo-thermal units (APTU) (°C days hours) for various phenological stages under different sowing dates and mustard varieties (mean of two years 2020-21 and 2021-22)

Treatment	First emergence	5th true leaf exposed	First flower initiation	Pod development (2 cm long)	Most seeds brown	Physical maturity
			Sowing dates			
15 October	1691	5884	12529	15338	21046	25533
10 November	1525	5181	8758	11200	16462	20751
5 December	1536	4363	6569	8770	14389	17641
Mean	1584	5142	9285	11769	17299	21308
			Varieties			
Pusa bold	1545	5024	9126	11588	16963	20705
Varuna	1622	5261	9444	11949	17634	21911
Mean	1584	5142	9285	11769	17299	21308

Table 5. Photothermal index (PTI) (°C days day^{-1}) for various phenological stages under different sowing dates and mustard varieties (mean of two years 2020-21 and 2021-22)

Treatment	First emergence	5th true leaf exposed	First flower initiation	Pod development (2 cm long)	Most seeds brown	Physiological maturity
			Sowing dates			
15 October	23.9	20.1	16.2	11.4	11.5	17.7
10 November	18.2	16.2	12.4	10.8	12.3	20.0
5 December	15.5	11.5	11.2	10.4	15.9	23.4
Mean	19.2	15.9	13.3	10.9	13.2	20.4
			Varieties			
Pusa bold	19.3	16.0	13.3	10.9	13.0	19.8
Varuna	19.2	15.8	13.2	10.8	13.5	21.0
Mean	19.2	15.9	13.3	10.9	13.2	20.4

influenced the yield and yield attributes of mustard. Higher seed yield (13.71 q/ha), biological yield (61.98 q/ha) and yield attributes viz. number of siliquae/ plant, number of seeds/ siliqua and 1000-seed weight (300.4, 12.94, 6.83 g, respectively) were observed under early sowing (15th October) followed by normal (10th November) and late sowing (5st December) (Table 6). Delayed sowing of mustard crop resulted in significant decline in the seed yield and yield contributing components i.e. number of siliquae/ plant, number of seeds per siliqua and 1000 seed weight (Akhter *et al.*, 2015). Higher seed yield of mustard crop under 15 October sowing may be due to accumulation of higher thermal units. Significantly higher seed yield and biological yield under early and timely sowing dates may be due to the fact that the early sown crop got longer time period to utilize available resources and favourable temperature, whereas, shorter time was available for the late sown crop to utilize available growth factors leading to decline in yield. These results are similar to the findings of Akhter *et al.* (2016). It was reported that the early sowing of mustard resulted in extended reproductive phase and ultimately higher seed yield (Tripathi *et al.*, 2007). It was also revealed that with delay in sowing from early October to end of October the number of seeds per siliqua was reduced significantly (Panwar *et al.,* 2000). The optimum sowing time can provide favourable conditions to get maximum light interception, best utilization of resources (moisture and nutrients) from emergence to pod development stage (Mondal *et al.,* 1999). Under delayed sowing, the crop is exposed to high temperatures at grain development stages, which forces to early maturity and reduction in grain yield.

Regarding the varieties, Varuna (12.54 q/ha) produced significantly higher seed yield (Table 6) as compared to Pusa Bold (11.85 q/ha). The yield enhancement of variety Varuna over Pusa Bold was about 5.8%. Better seed yield of variety Varuna may be due to higher accumulation of thermal units, which may be genotypic character of this variety.

Table 6 Yield and yield attributes under different sowing dates and mustard varieties (mean of two years 2020-21 and 2021-22)

Treatment	No. of siliqua/plant	No. of seed/siliqua	1000 seed weight (g)	Seed yield (q/ha)	Biological yield (q/ha)
			Sowing dates		
15 October	300.40	12.94	6.83	13.71	61.98
10 November	273.91	11.39	6.26	12.48	45.79
5 December	200.76	10.15	5.34	10.42	36.96
CD (5%)	10.47	0.70	0.13	0.28	1.28
			Varieties		
Pusa bold	233.19	11.51	5.54	11.85	46.04
Varuna	235.10	11.69	6.10	12.54	49.23
CD (5%)	0.96	0.18	0.52	0.32	2.20

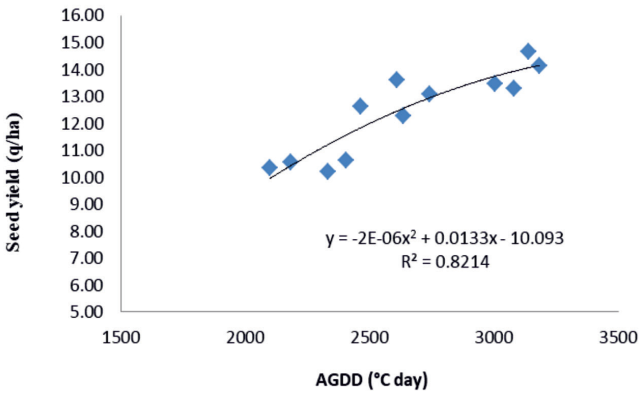

Fig. 1. Relationship between seed yield and accumulated growing degree days

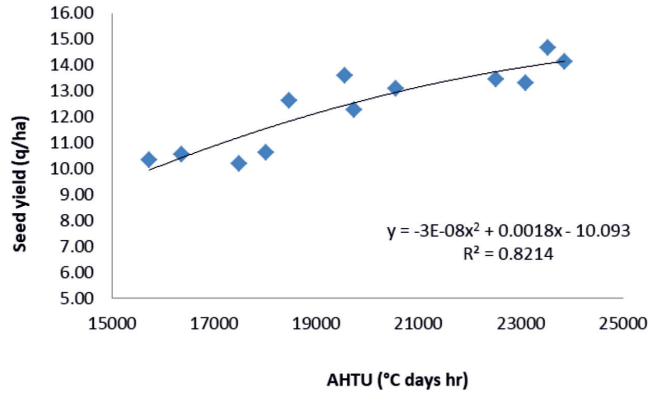

Fig. 2. Relationship between seed yield and accumulated helio-thermal units

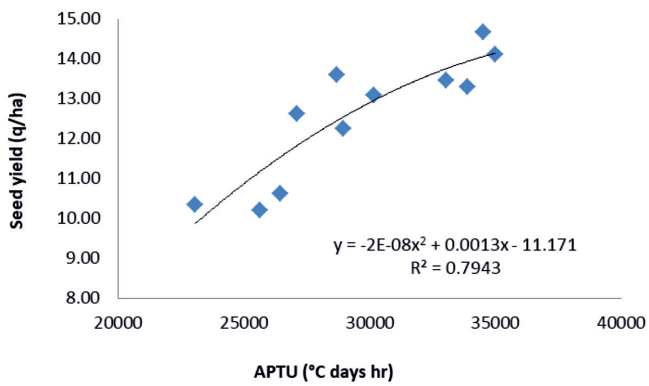

Fig. 3. Relationship between seed yield and accumulated photo-thermal units

Relationship between agroclimatic indices and grain yield

The polynomial regression equations were developed between different thermal indices and seed yield to find out variability in seed yield due to different agroclimatic indices. It was observed that the thermal indices (GDD, HTU and PTU) were able to explain the variability of seed yield by 82, 83 and 79 per cent respectively (Fig.1, 2 and 3). Srivastava *et al.* (2013) conducted a field experiment focusing on various thermal indices, including GDD, HTU, and PTU. Their findings revealed that GDD accounted for 66% of the variation in seed yield, while PTU similarly explained 66% of the variation.

It was concluded that the early sown mustard (15th October) took more number of days to reach physiological maturity and thus acquired more heat units throughout its growing period. But delay in sowing time reduced the accumulated GDD, HTU and PTU values as the crop duration reduced with delay in sowing time. The timely sown mustard crop performed better in terms of accumulation and utilization of heat units and hence resulted in higher seed yield and biological yield. In case of varieties Pusa bold and Varuna, both the varieties showed similar trends for different agroclimatic indices.

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Authors' contribution: Conceptualisation and designing of the research work (SK); Execution of field/ lab experiments and data collection (SK); Analysis of data interpretation (SK); Preparation of manuscript (SK).

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LITERATURE CITED

Adak T and Chakravarthy N V K 2010. Quantifying the thermal heat requirement of Brassica in assessing biophysical parameters under semiarid microenvironment. *Int J Bimeteorol* **54**(4): 365-77.

Akhter S, Singh L, Rasool R and Ramzan S 2015. Effect of date of sowing and varieties on yield of brown *sarson*

(*Brassica rapa* L.) under temperate Kashmir. *Int J Engg Sci Invent* **4**: 65-69.

Akhter S, Singh L, Saxena A, Rasool R, Ramzan S and Showqi I 2016. Agrometeorological indices for brown *sarson* (*Brassica rapa* L.) sown under different dates of sowing in temperate region of Kashmir. *The Bioscan* **11**(1**)**: 279-83.

DRMR 2024. ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, Rajasthan. https://drmr.res.in (Date of access: 05.01.2024)

Gupta M, Sharma C, Sharma R, Gupta V and Khushu M K 2017. Effect of time on productivity and thermal utilization of mustard (*Brassica juncea*) under sub-tropical irrigated conditions of Jammu. *J Agrometeorol* **19**(2): 137-41.

Hokmalipour S, Tobe A, Jafarabad B and Darbandi M H 2011. Effect of sowing date on dry matter accumulation trend yield and some agronomic characteristics in canola (*Brassica napus* L.) cultivars. *World Appl Sci J* **19**(7): 996-1002.

Khushu M K, Naseer U R, Singh M, Tiku A P, Bali A K and Singh A 2008. Thermal time indices for some mustard genotypes in the Jammu region. *J Agrometeorol* **10**: 224-27.

Kingra P K and Kaur P 2012. Effect of dates of sowing on thermal utilization and heat use efficiency of groundnut cultivars in central Punjab. *J Agric Phy* **12**(1): 54-62.

Kumar G, Adak T, Chakravarty N V K, Chamola R, Katiyar R K and Singh H B 2007. Effect of ambient thermal on growth and yield of Brassica cultivars *Brassica* **9**(1-4): 47-52.

Lallu R S, Baghel V S and Srivastava S B L 2010. Assessment of mustard genotypes for thermotolerance at seed development stage. *Indian J Plant Physiol* **15**(10): 36-43.

Mondal R I, Biswas M, Hyder A M K and Akbar M A 1999. Response of rapeseed genotypes to seed rate and seeding date. *Bangladesh J Agric Res* **24**(1): 83-90.

Neog P and Chakravarty N V K 2005. Thermal time and phenological model for *Brassica juncea. J Agrometeorol* **7**: 174-81.

Neog P, Bhuyan J and Baruah N 2008. Thermal indices in relation to crop phenology and seed yield of soybean (*Glycine max* L.). *J Agrometerol* (Spl issue) **2**: 388-92.

Nuttonson M Y 1955. Wheat climate relationships and the use of phenology in ascertaining the thermal and photothermal requirement of wheat. American Institute of Crop Ecology, Washington DC, USA, 388p.

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 environments. *Indian J Agric Sci* **80**(2):135-41.

Panwar K S, Sharma S K and Nanwal R K 2000. Influence of sowing time on yield of different mustard cultivars (*Brassica* species) under conserved soil moisture conditions. *Indian J Agric Sci* **70**: 398-99.

Shekhawat K, Rathore S S, Premi O P, Kandpal B K and Chauhan J S 2012. Advances in agronomic management of Indian mustard (*Brassica juncea* (L.) Czernj Cosson): An Overview. *Int J Agron* **1**: 1-14*.*

Solanki N S and Mundra S L 2015. Phenology and productivity of mustard (*Brassica juncea* L.) under varying sowing environments and irrigation levels. *Ann Agric Res New Series* **36**: 312-17.

Srivastava A K, Adak T and Chakravarty N V K 2013. Quantification of growth and yield of oilseed Brassica using thermal indices under semi-arid environment. *J Agrometeorol* **13**(2): 135-40.

Tripathi M K, Rao V U M and Singh D 2007. Effect of sowing time and in-season growth manipulations on phenology of Indian mustard (*Brassica juncea*). *Indian J Agric Sci* **77**(4): 253-57.

Warthinhton C M and Hatchinson C M 2005. Accumulated degree days as a model to determine key development stages and evacuate yield and quality of potato in Northeast Florida. *Proc State Hortic Soc* **118**: 98-101.