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Temperature-Based Agrometeorological Indices for Indian Mustard (*Brassica spp*. L.) under Different Growing Environments in Prayagraj Condition

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Field studies were carried out during the winter season at the Research Farm of the College of Forestry, SHUATS, Prayagraj ($25^{\circ}45'$N, $81^{\circ}84'$E, and 98.2 m amsl) during *rabi* season 2022. to compute the temperature-based agrometeorological indices for Indian mustard (*Brassica spp*. L.) sown under different growing environments. The experiment was laid out in the FRBD method with three different dates of sowing 17 Oct, 03 Nov, and 17 Nov., and four varieties of mustard (Jhalak, Sriram, Kalasona, and Ratna). The third date of sowing crop (D_3) had significantly higher

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agrometeorological indices (HU, PTU, and HTU,) values over the first (D_1) and third date (D_3). Among the varieties, Jhalak performed better concerning agrometeorological indices. HU (1886.2), HTU (6569.08), and PTU (11747.87) suggest there by a significant effect of these indices on the mustard crop. Once these correlations are measured and evaluated, these indices can consequently be used effectively as crop performance indicators.

Keywords: Heat unit; photothermal unit; heliotherml unit; mustard crops.

1. INTRODUCTION

Mustard crops are greatly affected by climatic conditions due to their specific characteristics. Changes in weather parameters can significantly impact the growth and productivity of mustard, making it sensitive to climate change. The purpose of this study was to analyze the thermal requirements of mustard crops and how they affect their growth stages and yield in different environments. The research also focused on evaluating the performance of various mustard varieties under proper irrigation and recommended cultural practices, specifically during the rabi season. The decline in mustard yield since 1997 can be attributed to unfavorable monsoon conditions, leading to moisture stress and increased temperatures. High temperatures during early sowing and crop growth resulted in poor initial growth and reduced plant population [1].

Furthermore, abnormal weather conditions during the establishment phase, including cold spells, fog, frost, leaf wetting, and intermittent rains during flowering and pod formation, have become concerning in major mustard-producing states such as Punjab, Haryana, Rajasthan, and Uttar Pradesh. Additionally, mustard crops in India face yield losses caused by physiological disorders and the spread of pests and diseases like aphids, white rust, downy mildew, and stem rot. Uttar Pradesh is the fourth largest producer of mustard in India, after Rajasthan, Haryana, and Madhya Pradesh. In 2022-23, the state produced 1.6 million tonnes of mustard, accounting for about 11% of the country's total production. The area under mustard cultivation in Uttar Pradesh is about 2.2 million hectares. The major mustard-growing districts in the state are Hardoi, Rae Bareli, Sitapur, Unnao, Lucknow, and Prayagraj. India is also expected to produce a record 115.25 lakh tonnes of mustard in 2022-23, up from 109.5 lakh tonnes in 2021-22. Agriculture production and productivity are governed by the local climate, which includes factors like temperature, rainfall, light intensity, radiation, and sunny duration. The phenology, growth, and yield of field crops are strongly influenced by temperature. To evaluate crop phenology, growth, and yield depending on temperature, agrometeorological indices including heat units, photo-thermal units, helio-thermal units, photo-thermal, and heat usage efficiency have been widely utilized. These indices consider the timing of biological processes in crops and provide more accurate predictions than calendar dates. Winter crops, including mustard, are susceptible to temperature, as variations affect the duration of different growth stages. However, limited information is available regarding the impact of temperature, day length, and bright sunshine hours on mustard yield in the region [2]. As a result, the primary goal of this study was to identify the best thermal conditions for mustard crops using a variety of temperature-based agrometeorological indices and to evaluate how these conditions affected the phenology and yield of three mustard varieties grown in various environments in Prayagraj, India, under subtropical conditions. The main goal of this study was to identify the best thermal conditions for mustard crops in the form of various temperature-based agrometeorological indices and to assess how these conditions affected the phenology and yield of three mustard varieties grown in various environments in Prayagraj.

2. MATERIALS AND METHODS

The present field study was conducted at Research Farm of the College of Forestry, SHUATS, Prayagraj (25°45'N, 81°84'E, and 98.2 m amsl) during *rabi* season 2022.

The experiment was laid out in split plot and consisted of three growing environments imposed through different sowing dates (D_1: Oct. 17, 2022; D_2: Nov. 03, 2022; and D_3: Nov. 17, 2022) in the main plots and four mustard variety (V1: Jhalak, V2: Kalasona and V3: Sriram V4: Ratna) in sub-plots and replicated three time. The weather data recorded at Agrometeorology Observatory of the college of forestry, SHUATS and observations on crop phenology, seed and biological yield have been used to compute temperature based agrometeorological indices and establish their relationship with phenology, seed and biological yield of mustard at Prayagraj. The crop phenology was recorded by visual observation in experimental plots on every alternate day during the crop growing period and the number of days taken for occurrence of different pheno-phases viz., P_1: Emergence, P_2: four-leaf stage, P_3: Early vegetative phase, P_4: 50% flowering, P_5: 50% pod development, P_6: Start of seed filling, P_7: End of seed filling, P_8: Physiological maturity**.**

2.1 Temperature Based Agrometeorological Indices

Growing degree days (GDD)/Heat unit (HU) at different phenological stages were determined by summing the daily mean temperature above base temperature (T_b), expressed in °C Day. For *Brassica* species, T_b is considered as 5°C following Morrison (1996). This was calculated by using the following formula:

$$\text{HU (°C day)} = \sum_i^j \frac{\text{Tmax} + \text{Tmin}}{2} - T_b$$

Were,

T_{max} = Daily maximum temperature (°C)
T_{min} = Daily minimum temperature (°C),
T_b = Minimum threshold/base temperature (°C).

Cumulative photo-thermal units (PTU) were determined by multiplying the HU to the maximum possible sunshine hours, expressed in °C Day hours.

$$\text{PTU (°C day hours)} = \sum_i^j \text{HU x maximum bright sunshine hour}$$
(ii)

Cumulative helio-thermal unit were (HTU) determined by multiplying the HU to the actual bright sunshine hours, expressed in ºC day hours.

$$\text{HTU (°C day hours)} = \sum_i^j \text{HU x actual bright sunshine hours}$$
(iii)

3. RESULTS AND DISCUSSION

The agrometeorological indices were generated from meteorological data reported by the Agromet observatory. The phenology, yield, and biomass production of crops can all be predicted using these indices.

Heat Unit

The Heat Unit (HU) is a measurement used to track the accumulation of heat during different stages of crop growth. The HU values were observed in different treatments and crop seasons. HU varied depending on the growing conditions and the specific stages of crop growth. The HU accumulated for the occurrence of different phenophase among the treatments during two crop seasons is presented in Fig. 1. Fig. 1 revealed that growing environments varied for accumulated HU over different phenophases. Accumulation of HU to attain crop maturity was higher under the 17th Nov. sown crop as compared to the other sowing dates and the respective values for three sowing dates were 1806.4, 1669.3, and 1645.4°C Day in 17th Nov., 03rd Nov. and 17th Oct. In the seasons the accumulated HU increase with successive delay in sowing and the findings conform with those reported by Roy et al*.* [3] and Neogi et al. [4]. The late sown crop accumulated fewer HU during early phenophase than early sown crop due to prevalence of comparatively lower temperature [5,6]. Different varieties had a marked influence on the Thermal unit/Heat unit/growing degree days of Indian mustard at all the phenophase. Maximum Thermal unit/G.D. D/heat unit requirement from sowing to maturity 1500.5^{o}C days were obtained in Jhalak variety. while minimum thermal unit was obtained in Ratna Variety (1201.2^{o}C days) from sowing to maturity of different date of sowing and verities.

3.2 Helio-Thermal Unit (HTU)

Helio thermal units consumed for the completion of different phenological stage mustard varieties under different growing environments were worked out and are present in Table 2. The cumulative Helio thermal unit different phenophase requirement were maximum in D3 18787.92 day was observed. And the minimum Helio thermal unit in D2 17013.52 ^{o}C day was observed. Different varieties had a marked influence on the Helio thermal unit of Indian mustard at all the phenophase. Maximum heliothermal unit requirements from sowing to maturity 19146.11^{o}C days were obtained in the Jhalak variety. while the minimum thermal unit was obtained in Ratna Variety (12864.56^{o}C days) from sowing to a different date of sowing and variety. These findings are in line with those reported earlier by Kumar et al. [7]; Kingra and Kaur [8], and Neogi et al*.* [4]. HTU accumulation was higher at all growth phases during 2012-13 as compared to 2013-14 due to the availability of higher mean numbers of sunshine hours in this year.

Table 1. Effect of microclimate on GDD different varieties and different dates of sowing of mustard crop under Prayagraj conditions

Treatment	Phenophase							
	Germination	Stem elongation	Inflorences	flowering	Fruit development	Ripening	Senescence	Total
17/10/2022	209.4	349.9	311.5	241.3	204.8	240.6	87.9	1886.2
03/11/2022	236.9	257.6	276.6	212.4	240.6	314.9	130.3	1392.7
17/11/22	222.1	216.6	233.4	253.1	314.9	419	659.9	2319
Varieties								
Jhalak	189.3	332.1	282.2	216.6	177.9	225.9	75.5	1500.5
Kala sona	169.4	313.8	269.9	201.6	185.9	198.5	63.1	1401.9
Shri ram	149.2	276.8	253.3	155.7	191.7	168.1	50.5	1245.3
Ratna	128.7	256.8	223.6	171.7	170.7	212.1	37.6	1201.2

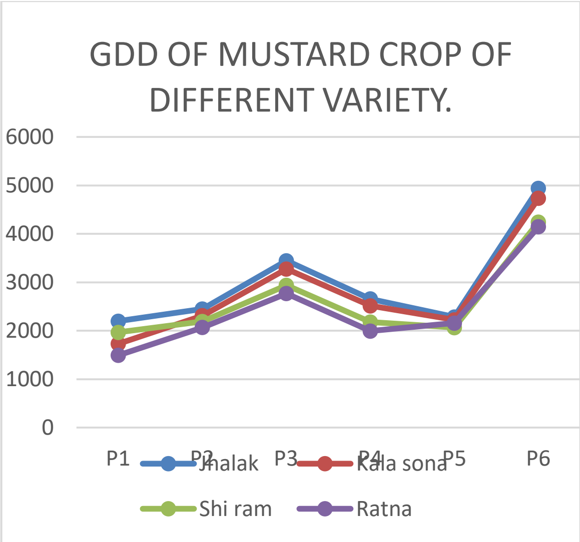

Fig. 1.

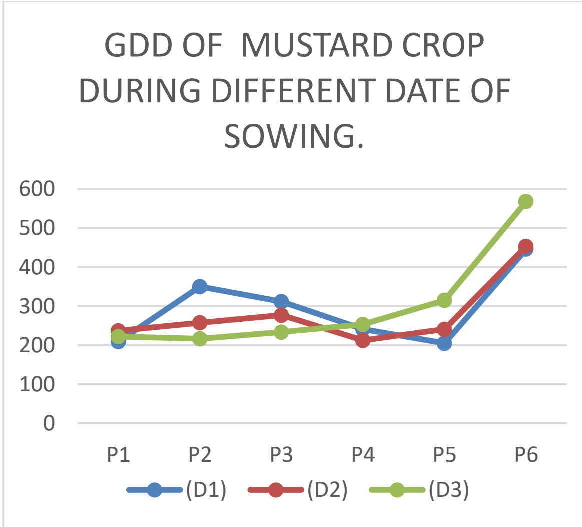

Fig. 1B.

Fig. 1. a&b Effect of microclimate on GDD different varieties and different dates of sowing of mustard crop under Prayagraj conditions

Table 2. Effect on HTU of different varieties and different dates of sowing of mustard crop under Prayagraj conditions

			Phenophase			
DATES	P1	P2	P3	P4	P5	P6
D1	2429.04	2564.49	3613.4	2798.08	2375.68	3750.6
D2	2748.04	2818.8	3208.56	2463.84	2790.96	5164.32
D3	2576.36	2512.56	2707.56	2935.96	3652.84	6569.08
			Varieties			
Jhalak	2195.88	2448.79	3444.04	2657.56	2282.8	4940.36
Kala sona	1730.72	2311.54	3273.52	2512.56	2223.7	4736.26
Shi ram	1965.04	2190.64	2938.28	2179.64	2063.6	4243.24
Ratna	1492.92	2068.44	2768.96	1991.72	2156.4	4148.12

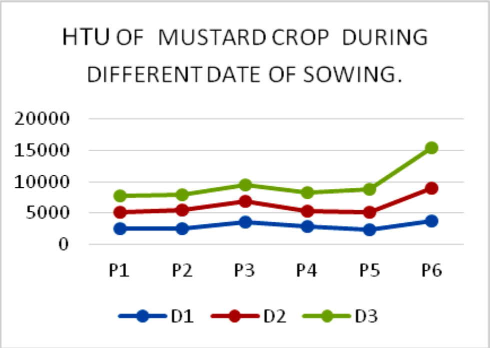

Fig. 2A.

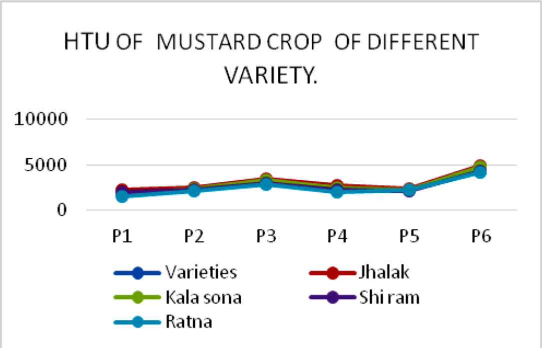

Fig. 2B.

Fig. 2. a&b Effect of microclimate on GDD different varieties and different dates of sowing of mustard crop under Prayagraj conditions

3.3 Photothermal Units (PTU)

The photothermal units (PTU) (a product of HU and maximum possible sunshine) accumulation by mustard crop to attain different phenophase. Photothermal units consumed for the completion of different phenological stage mustard varieties under different dates of sowing and variety were worked out and are present in Table 3. The cumulative photo thermal unit different phenophase requirements were maximum in D3 11747.87°C day was observed. And the minimum photo thermal unit in D1 8017.86°C day was observed. Different varieties had a marked influence on the photothermal unit of Indian mustard at all the phenophase. The maximum photothermal unit requirement from sowing to maturity 10873.99°C days was obtained in the Jhalak variety. while the minimum thermal unit was obtained in Kalasona Variety (5984.76 °C days) from sowing to maturity of Indian mustard. The PTU accumulation increased from emergence to physiological maturity and the highest values were recorded at physiological maturity in all treatments. Similar findings have also been reported by Srivastava et al. [5].

Temperature-based agrometeorological indices hold significant scientific importance for the cultivation of Indian Mustard (Brassica spp. L.) in Prayagraj, India, due to their crucial role in understanding and optimizing crop growth, development, and yield. The unique climatic conditions of Prayagraj, characterized by temperature fluctuations and varying growing environments, make the application of these indices vital for sustainable and productive agriculture. The scientific importance can be highlighted through the following aspects:

Phenological Timing: Temperature-based indices, such as Growing Degree Days (GDD), Chill Units (CU), and Heat Units (HU), help determine the timing of key phenological stages in Indian Mustard, such as flowering, bolting, and maturation. These stages are critical for predicting crop growth trajectories and optimizing management practices, including irrigation, fertilization, and pest control.

Table 3. Effect of PTU on different varieties and different dates of sowing of mustard crop under Prayagraj conditions

Treatment	Phenophase						
	Germination	**Stem elongation**	**Inflorescences**	**flowering**	**Fruit development**	**Ripening**	**Total**
17-10-2022	1649.52	4058.84	1883.3	1439.1	833.63	1806.47	8017.86
03-11-2022	1800.44	1772.82	1632.82	875.64	1170.67	3830.63	11083.02
17-11-2022	1519.3	1246.44	1095.89	1238.77	2643.05	4004.42	11747.87
Verities							
Jhalak	1478.67	3852.36	1777.34	1343.94	808.03	1613.65	10873.99
Kala sona	1156.03	3640.08	1873.59	1246.44	804.97	539.65	5984.76
Shi ram	1307.53	3424.32	1669.84	996.62	746.01	1252.01	9396.33
Ratna	987.93	3206.24	1659.62	909.14	774.81	1039.37	8577.11

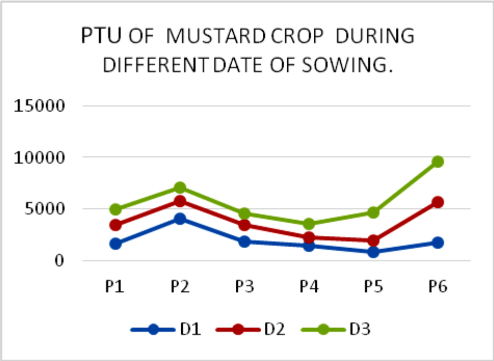

Fig. 3A.

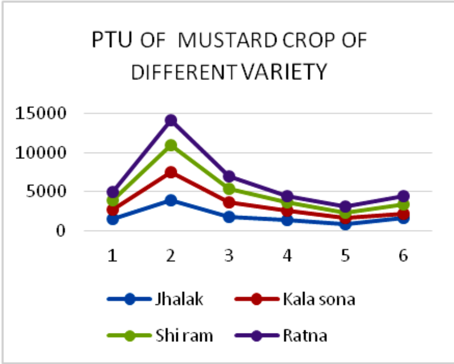

Fig. 3B.

Fig. 3. A&B Effect of PTU on different varieties and different dates of sowing of mustard crop under Prayagraj conditions

Crop Management: The precise estimation of GDD, CU, and HU assists farmers in making informed decisions about planting dates, ensuring that crops are sown during optimal temperature conditions for efficient growth. This management strategy can mitigate the risk of frost damage, enhance crop establishment, and contribute to higher yields.

Resource Optimization: By incorporating temperature-based indices, farmers can optimize the use of resources, such as water and nutrients, based on the crop's developmental needs. This approach promotes sustainable agriculture by reducing wastage and minimizing environmental impacts.

Varietal Selection: Different Indian Mustard varieties may have varying temperature requirements for optimal growth. Temperature-based indices enable researchers and farmers to select suitable varieties that are better adapted to Prayagraj's specific climate, ultimately leading to improved crop performance.

Climate Change Resilience: As climate patterns evolve, temperature-based indices provide a tool for assessing the impact of changing temperatures on Indian Mustard cultivation. This knowledge can aid in developing climate-resilient agricultural strategies to ensure food security in the face of a shifting climate.

Comparing the influence of agro-environmental factors on Latin American crops further emphasizes the scientific importance of temperature-based agrometeorological indices. Latin American countries exhibit a wide range of agroecological conditions [9,10], and the utilization of these indices underscores their versatility and significance:

Crop-Specific Applications: Temperature-based indices are applied to various Latin American crops, including coffee, maize, wheat, and sugarcane [11,12] (Hernandez et al. 2018). These indices assist in predicting optimal planting times, estimating crop development stages, and managing post-harvest activities.

Regional Adaptation: Each Latin American country faces unique climate challenges [13,14]. Temperature-based indices offer a standardized framework for adapting crop management practices to local conditions, contributing to increased agricultural productivity and food security [15] (Bertorelli and Olivares, 2019).

Risk Mitigation: In regions prone to extreme weather events, temperature-based indices enhance the ability to predict and mitigate risks, such as heat stress, drought, and frost damage [16,17]. This proactive approach minimizes yield losses and economic setbacks [18,12].

Economic Impact: The integration of temperature-based indices into agricultural practices improves resource allocation, reduces production costs, and enhances market competitiveness for Latin American crops [19,20].

Sustainability: By optimizing crop management using temperature-based indices, Latin American farmers can adopt sustainable practices that align with environmental conservation and resource stewardship goals [21] (Olivares et al. 2021).

Temperature-based agrometeorological indices hold significant scientific importance for Indian Mustard cultivation in Prayagraj and offer a powerful tool for enhancing agricultural productivity and resilience. The comparison with their application in Latin American crops highlights their universal relevance in optimizing crop management, mitigating climate risks, and promoting sustainable agricultural practices across diverse agroecological contexts. As agriculture faces the challenges of a changing climate and global food demand, the scientific insights provided by these indices contribute to informed decision-making and the advancement of sustainable food systems. Further research and collaborative efforts are crucial to refining these indices and maximizing their impact on agricultural sustainability and food security [22-27].

4. CONCLUSION

Based on the findings of the present research work it can be concluded that the 1st (17 Oct 2022) and 2nd (03 Nov 2022) date of sowing was the most suitable time for the mustard crop because at that time sown crop are consume optimum heat units and change timely phenological stages. Heat units (GDD, HTU, PTU) play the most important role in plant growth and production. 3rd date of sowing (1st Oct. 2022) was found most suitable period for sowing mustard which resulted in maximum growth and yield attributes. & In case of variety md rani super gold is the most suitable variety for the Prayagraj region. Based on this study we can recommend farmers around Prayagraj prefer the use of the Ratna variety and sowing of mustard on the 1st (17 Oct 2022) and 2nd (03 Nov 2022) for better results and yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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