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Thermal indices in relation to crop phenology of wheat (*Triticum aestivum* L.) crop grown under agro-climatic conditions of Eastern Uttar Pradesh

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Abstract
Field experiments were conducted during rabi seasons of 20021-22 and 20022-23 at Agrometeorological Research Farm, Acharya Narendra Dev University of Agriculture & Technology, Kumarganj ,Ayodhya, Uttar Pradesh to study phenology and GDD, PTU, HTU and PTI for wheat crop at Eastern zone of Uttar Pradesh. Wheat crop were sown on three date of sowings *viz.* 15th November 1st December and 15 December during rabi season in both year. Results revealed that mean GDD, HTU, PTU for wheat crop were 1476, 10272, 19657 and 1453, 10112, 19171 respectively. Physiological maturity can be predicted for wheat by using GDD, HTU, PTU with R^2 0.97. During 2021-2022 the HUE for wheat was 2.84 kg grain/ha degree days^{-1} with grain yield 4200 kg/ha and during 2022-2023 HUE was 2.81 kg grain/ha degree days^{-1} with grain yield 4089 kg/ha.

Keywords: GDD, HTU, PTU, PTI, thermal use efficiencies

1. Introduction
Wheat is a thermo-sensitive long-day crop. Temperature is a major determinant of its growth and productivity. Phenological development from sowing to maturity is related to accumulation of heat or temperature units above threshold or base temperature (below which no growth occurs). A quantified value of heat or temperature units is required to reach a particular phenophase. The various meteorological factors such as temperature influence the physiological and morphological development of plant.

Temperature plays significant role in physiological, chemical and biological processes of plants. Accrued heat units can be used to describe the occurrence of various phenological events during a crop's growing season as well as the impact of temperature on plant growth (Sunil and Sarma, 2005) [14]. Growing degree days are based on the concept that the real time to attain a phenological stage is linearly related to temperature in the range between base temperature and optimum temperature (Monteith, 1981) [8]. The heat unit concept assumes that a direct and linear relationship between growth and temperature is advantageous for the assessment of yield potential of a crop in different weather conditions Reaumur was the first to propose a direct relationship between temperature summation and the length of specific growth stages (Patel *et al*., 1999) [9]. Hundal (2004) [3] observed that 2 °C increase in temperature in wheat resulted in 15-17% decrease in grain yield. In India this concept has been applied to various crops like wheat, barley and mustard (Sastry and Chakravarty, 1982; Hundal *et al*., 1997; Kar and Chakravarty, 1999) [13, 4, 7] and was found to be useful as an input in crop growth studies. Influence of temperature on phenology and yield of crop plants can be studied under different field conditions through accumulated heat unit system (Bishnoi *et al*.,1995) [1] The duration of each phenophase of the crop determines the accumulation and partitioning of dry matter in different parts as well as crop responses to environmental and external factors (Dalton, 1967). In the present paper thermal indices for wheat has been carried out by using weather variables.

2. Data and methodology
Ayodhya is situated in the saline-alkaline belt of Indo-Gangatic plains alluvium of eastern Uttar

Pradesh, which is geographically located at 26°47' N latitude, 82.12° E longitude and at an altitude of 113 m above the mean sea level. The climate of Ayodhya is semi-arid with severe hot summer and cold during winter. Annual rainfall varies between 1001 mm and distributed over 50 to 60 rainy days. Wheat (*Triticum aestivum* L.), an important food grain crop in eastern zone of Uttar Pradesh, is sown during November/December and harvested in March/April. It is rabi season crop and amount of rainfall during this period is very low. Hence, the water requirement of the crop is fulfilled by irrigation. Field experiments were conducted during Rabi seasons of 2021 and 2022 at Agrometeorological Reasearch Farm, ANDUA&T, Kumarganj, Ayodhya, Uttar Pradesh with Wheat varieties K1317, Wb2 and K9423 crops. Weather data were collected form Agrometeorologcial observatory ANDUA&T, Ayodhya, U.P. which is close to experimental site. Wheat crop growth was divided into different phenophases, germination, CRI, tillering, jointing, ear emergence, anthesis, milking, dough, physiological maturity.

Growing degree days at different phenological stages were calculated by summation of daily mean temperature above base temperature for a corresponding period from sowing, as suggested by Monteith (1984) [8].

$$GDD = \Sigma \frac{(T_{max} + T_{min})}{2} - T_{base}$$

Where, T_{max}, T_{min} are maximum, minimum temperature and T_{base} is base temperature was taken as 5 °C.

The index Helio thermal unit (HTU) serves to be effective in taking into account and expressing the effect of varying ambient temperature on the duration between the phenological events for comparing the crop response to the ambient temperature between phenological stages. Helio thermal unit was calculated using the formula given by Rajput (1980) [15].

HTU = Σ GDD × Cumulative Sunshine hours (stage wise from sowing to physiological maturity)

Photothermal units (PTU), the product of GDD and corresponding day length for that day were computed on daily basis by using the formula:

PTU = GDD × Daylength (stage wise from sowing to physiological maturity)

The PTI were computed on stages basis as follows:

$$PTI = \frac{\text{GDD Consumed between two phenological stages}}{\text{Number of days between two Phenological stages}}$$

3. Results and Discussion

3.1 Wheat phenology and thermal indices

Wheat crop were sown on three date of sowings *viz.* 15th November 1st December and 15 December during rabi season in both year (2022,2023). The crop took 65-66 days for jointing stage. Flowering occurred mostly in the last week of February. The average crop duration was 129 days of three dates of sowing in 2021-2022. During 2021-22 ear emergence was observed at 79 days after sowing (DAS) while in 2022-23 it occurs at 77 DAS.

Table 1: Accumulated units required for attainment of phenophases and indices for wheat crop

Crop Stages	Days to attain phonological stages	GDD (°C day)	HTU (°C day)	PTU (°C day)	PTI (°C)
2021-22					
Germination	7	87	447	929	13.2
CRI	21	259	1301	2752	12.3
Tillering	45	466	2376	4941	9.4
Jointing	66	633	3221	6829	8.7
Ear emergence	79	744	2507	8220	9.5
Anthesis	90	866	2606	9813	11.1
Milking stage	104	1027	3430	11981	13.4
Dough stage	117	1242	7029	15285	16.0
Phy-maturity	129	1476	10272	19657	19.1
2022-23					
Germination	6	81	416	867	12.3
CRI	21	240	1205	2553	11.4
Tillering	45	424	2162	4210	8.3
Jointing	65	590	3003	6772	8.9
Ear emergence	77	724	2439	8245	11.9
Anthesis	88	866	2606	10029	13.7
Milking stage	101	1036	3460	12726	14.0
Dough stage	114	1247	7058	15393	17.2
Phy-maturity	126	1453	10112	19171	18.8

3.2 Growing Degree Days (GDD) for wheat

During 2021-2022 crop took 1476 units accumulated GDD with total 129 days till physiological maturity and during 2022-23 crop took 1453 units accumulated GDD with total 126 days till physiological maturity. This explains the direct impact of temperature on crop growth; every crop requires a certain amount of GDD to enter its next crop stage (Table 1). It has been documented that under various crop growth conditions, winter crops are susceptible to temperature during the reproductive stage (Kalra, 2008) [6]. Heat unit concept was utilized to establish a correlation between phenological development and maturity dates in crops (Rao *et al*., 1999) [10]. Ram *et al.* (2012) [11] reported higher GDD requirement for wheat crop for normal sowing conditions than the later growing conditions. Late sowing decreased the duration of phenology as compared to normal sowing due to fluctuated un-favourable high temperature during the growing period.

3.3 Photo Thermal Unit (PTU) for wheat

During 2021-22 crop took 19657 units of accumulated PTU with total 129 days till physiological maturity and during 2022-23 crop accumulated 19171 units in 114 days till physiological maturity (Table 1). Wheat was among the most temperature sensitive crops and production could fluctuate with a slight change in temperature.

3.4 Heliothermal Thermal Unit (HTU) for wheat
During 2021-2022 crop took 10273 accumulated HTU with total 129 days till physiological maturity and during 2022-2023 crop took 10112 units with total 114 days till physiological maturity (Table 1). HTU is the product of GDD and actual bright sun shine hours, higher BSS results in more units of helio thermal. Several studies in India have shown that a delay of 20 days in sowing could cause a delay in flowering by 8 days or upto 13 days. (Brar *et al*., 2011) [2].

3.5 Phenothermal Index (PTI) for wheat
During 2021-22 and 2022-23 PTI ranged between 8.7 to 19.0 °C and 8.3 to 18.8 °C respectively. In both the stages anthesis and dough stage showed relatively higher PTI, tillering and jointing stages indicating for lower values (Table 1).

3.6 Thermal use efficiencies for wheat
Thermal use efficiencies have been shown in Table 3, during 2007-08 the HUE, PTUE and HTUE were 2.84 kg grain/ha degree day-1, 0.21 kg grain/ha degree day-1, 0.40 kg grain/ha degree day-1 with grain yield 4200 kg/ha and during 2008 - 09 the HUE, PTUE and HTUE were 2.81 kg grain/ha degree day-1,0.21 kg grain/ha degree day-1, 0.40 kg grain/ha degree day-1 with grain yield 4089 kg/ha. Rani *et al*. (2012) [12] reported that the heat and radiation use efficiencies decreased with delay in sowing.
Ptu 10.
Htu3.0

3.7 Prevailing weather conditions during wheat seasons
In eastern zone of Uttar Pradesh wheat is grown normally from October to March. It largely depends upon monsoon rain and availability of irrigation facilities. The wheat-growing season was characterized by mild weather. The mean air temperature of the wheat season was about 27.3 to 30 °C and slightly declined after mid September in both years. The maximum temperature varied between 30 to 32 °C. However, minimum temperature remained in the range of 3 to 4 °C. Average duration of bright sunshine hours in the rabi seasons were 5.9 hr day^{-1}.

4. Conclusions
The present study indicates that the application of agroclimatic indicies provides a scientific basis for determining the effect of temperature, radiation or photoperiod on phonological behavior of standing crop. Those provide extremely clear picture of the amount, pattern and efficiency of heat energy consumption during various phonological stages of the crop. These can also be used very effectively for forecasting the occurrence of different phenophase of the crops.

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