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Heat unit requirement of mustard (*Brassica Juncea* L.) under different thermal regimes and irrigated conditions of Namsai region of Arunachal Pradesh

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Abstract
Field experiments were conducted under Arunachal University of Studies, Namsai, Arunachal Pradesh during 2017-18 to 2018-19 on mustard crop was sown on three dates (10th October, 20th October, and 30th October) with three irrigation treatments. The results indicated that the number of days required for attaining different phenological stages decreased with the delay in sowing. For all the phenological stages, crop sown on 10th October consumed higher heat units and consequently resulted in higher yield and heat use efficiency (HUE) than that of another sowing. However, higher pheno-thermal index (PTI) values were observed for the late sown crop i.e. 10th October. Further, among the irrigation treatments, three irrigations throughout the growing period showed an increase in days to physiological maturity as well as heat units and HUE for grain and biological yield as compared to other treatments. Three irrigations throughout the growing period increased the grain yield by 72 percent and biological yield by 54 percent than that of one irrigation at before flowering stage. The GDD also showed a highly significant positive correlation with grain and biological yield. Therefore, it may be used for forecasting the phenological stages and yield under different sowing date and stage-based irrigation scheduling for mustard.

Keywords: Phenological stages, pheno-thermal index, growing degree days, and heat use efficiency

Introduction
Mustard is one of the most prominent oilseed crops next to groundnut in India. It contributes to a large extent in the national economy and accounts for nearly 28.6% of the total oilseeds production in the country. Wheat being a thermo-sensitive and moisture sensitive crop, the sowing time and irrigation management are two most critical factors that need proper identification for proper crop growth achieving better yield. The crop sown on different sowing dates exposed to a variety of weather conditions during phenological stages affects its growth rate and yield. Mustard is grown in the tropical and temperate climate and is grown in a winter season. Among all the weather parameters, temperature plays a significant role in better establishment, growth, development and finally the yield of the crop. It requires about 18-25 ^{0}C temperature and low humidity for better crop growth. During seed germination and maturity stage slightly high temperature is required. Optimum temperature is 25 ^{0}C. Rainfall, cloudiness and extreme cold and frost are harmful to the crop (Mukherjee *et. al.*, 2014) [4].
Rapeseed-mustard crop needs assured amount of accumulated heat at various phenophase to meet the proper growth and development. Agrometeorological 3 indices such as growing degree days (GDD), photo-thermal unit (PTU), heliothermal unit (HTU), photo-thermal index (PTI) and heat use efficiency (HUE) mostly used as weather-based parameters for accurate estimation of the timing of occurrence of different crop phenophase. The quantification of heat use efficiency is helpful for the assessment of yield potential of any crop under different thermal environments. Due to less time available for transport of photosynthate to sink, yield reduction occurs in late sown crops as compared to early and normal sown crop (Roy *et. al.*, 2005) [7].
Kaur *et al.*, (2006) [3] reported that delayed sowing of the crop greatly suppressed various growth and yield components including plant height, numbers of flowers and siliquae and the number of seeds per siliqua. The seed yield decreased by 46% in the delayed sown crop.

The dry matter accumulation and yield also declined due to delayed sowing. As irrigation is one of the important factors for proper establishment of wheat and protects the crop from heat stress during reproductive stage, it becomes imperative to generate knowledge of the interactive effect of heat and moisture on growth and yield of wheat. Therefore, keeping this in view, the present study was conducted to determine agrometeorological indices at different phenological stages and to evaluate the correlation between these indices and grain yield.

Materials and Methods

The mustard cultivar Pusa swarnim was sown during rabi 2017-18 and 2018-19 in the research farm of Arunachal University of Studies, Namsai, Arunachal Pradesh of located at latitude: 27^0 30' to 28^0 45' N, longitude: $95^0$45' to $96^0$45' E and altitude: 1380 m above MSL. The experiment was laid out in split plot design with three replications and 9 treatment combinations consisting of 3 dates of sowing and 3irrigation. A recommended common fertilizer dose of 80, 60 and 40 kg ha-1 of N, P and K, respectively was applied during both the experimental years. Full P and K and N were applied as basal doses.

Days to different phenological stages were recorded from each sub-plot when approximately 60 percent of the plants reached that particular stage. After physiological maturity, an area of 1 × 1m^2 from each sub-plot was harvested manually. Biomass yield was determined by taking the weight of above-ground plant parts including the grain. After threshing, the grain weight (gm^{-2}) was measured and was upscaled to kg ha^{-1}.

Meteorological data viz. maximum and minimum temperature, bright sunshine hours and day length during the experiment period were acquired from the agrometeorological observatory located within the AUS farm. The agrometeorological indices such as heat units or growing degree days (GDD), phenol-thermal index (PTI) and heat use efficiency for biological yield (HUEBY) as well as for grain yield (HUEGY) were calculated using following equations:

GDD = (Tmax + Tmin) / 2 - Tb......................... (1)

Where,
Tmax = Daily maximum temperature (°C)
Tmin= Daily minimum temperature (°C)
Tb= Base temperature (5°C used for mustard) were calculated using by Rajput (1980).

PTI =GDD consumed between two phenological stages/Number of days taken……………………… (2)

HUE_{GY}=Grain yield (kg ha^{-1})/Accumulated GDD
HUE_{BY} = Biological yield/Accumulated GDD

Attainment of different phenological stages Effect of date of sowing and irrigation levels on the number of days to attain different phenological stages shown in Table 1. Sowing dates significantly affected days to attain different phenological stages. The statistical analysis indicated that 10th October sown crop took more days to the emergence and first flower as compared to other two sowing dates. This may be due to relatively less temperature experienced at these stages by the 10^{th} October crop as compared to other sowing dates and after emergence i.e. first flowering to physiological maturity stage, the 10^{th} October sown crop took more days to attain these stages followed by 20th October and 30th October sown crop. The days to physiological maturity were 182 days, 164 days and 154 days for crop sown on 10^{th} October, 20th October, and 30th October, respectively. After emergence stage, the least days to first flowering, 60 percent flowering, siliquae filling and physiological maturity was observed for one irrigation at first flowering. Whereas the two irrigations supplied during different growth stages showed the longest time to maturity.

Table 1: Effect of date of sowing on days to attain different phenological stages of mustard (Pooled data of 2017-18 and 2018-19)

Treatment	Emergence	First Flowering	60% Flowering	Siliquae Filling	Physiological Maturity
Date of Sowing					
10^{th} Oct	12	86	118	166	182
20^{th} Oct	8	90	106	149	164
30^{th} Oct	7	85	101	140	154
CD at 5%	0.5	0.5	1.9	2.9	3.1

Table 2: Effect of date of sowing on accumulated heat units (°C day) of mustard (Pooled data of 2017-18 and 2018-19).

Treatment	Emergence	First Flower	60% Flowering	Siliquae Filling	Physiological Maturity
Date of Sowing					
10^{th} Oct	133	729	911	1373	1577
20^{th} Oct	89	702	806	1232	1435
30^{th} Oct	64	622	722	1126	1318
CD at 5%	7.7	12.2	20.9	27.3	28.6

Accumulated heat units

Accumulated heat units pertaining to different phenological stages of mustard varied with date of sowing and irrigation levels (Table 2). The results indicated that 10^{th} October sown crop availed higher heat units at all the stages and with the successive delay in sowing, heat unit consumption decreased significantly. On average, the 10^{th} October sown crop required the heat units of 133°C day for emergence stage, 729°C day for first flowering stage, 911°C day for 60 percent flowering stage, 1373°C day for siliquae stage, 1577°C day for physiological maturity stage and lower consumption of heat units under delayed sowing. Biomass production is mainly governed by the genetic potential of any variety grown under different thermal conditions. But the extent of decrease in dry matter production under delayed sowing was due to thermal stress and tolerance capacity of the particular variety. Similar findings were also reported by Goyal, (2006) [2] and Alam *et al.*, (2014) [1] in which dry matter accumulation decreased with delayed sowing in all the varieties. Among different irrigation levels, the maximum values of heat units were noticed under full irrigation treatment and with the increase in moisture stress from emergence to 60 percent flowering stage a significant reduction in heat units was noticed. At physiological maturity, the maximum heat units of 1577 °C day at were consumed by the crop under three irrigations while the minimum values of 1318 °C day were recorded under one irrigation treatment. The lower HUE in delayed sowing can be expected due to the accumulation of comparably higher GDD to that of early sowing at later crop growth stages. Since both maximum and minimum temperature remained higher during the reproductive phase causing a detrimental effect on dry matter accumulation. The results are in close agreement with the findings of Pandey *et al*. (2010) [5].

Table 3: Effect of date of sowing on yield and heat use efficiency (HUE) of mustard (Pooled data of 2017-18 and 2018-19)

Treatment	Grain yield (kg ha^{-1})	Biological Yield (kg ha^{-1})	HUE on the grain yield basis (kg ha^{-1} °C day^{-1})	HUE on biological yield (kg ha^{-1} °C day^{-1})
Date of Sowing				
10th Oct	1810	5890	1.14	3.73
20th Oct	1551	4995	1.08	3.48
30th Oct	1326	4580	1.00	3.47
CD at 5%	53.4	147.8	0.01	0.03

Yield and heat use efficiency (HUE)

The results indicated that sowing dates significantly affected the grain yield of mustard (Table 3). Mustard crop sown on October 10, recorded significantly higher grain and biological yield ever other sowing dates. Three irrigations produced significantly higher yield over other irrigation treatments. The heat use efficiency (HUE) for grain yield and biological yield were computed by using accumulated values of GDD at physiological maturity (Table 3). The highest HUE for grain yield (1.14 kg ha-1°C days) as well as for biological yield (3.73 kg ha-1°C days) recorded under 10th October sown and the minimum values were observed for late sown i.e. 30th October crop. However, there was no significant difference observed between 20th October and 30th October sown the crop. The higher HUE in 10th October sown crop could be attributed to the proportionate increase in dry matter per each heating unit absorbed. The lower HUE in delayed sowing can be expected due to the accumulation of comparable GDD to that of 10th October sowing at later crop growth stages. The less heat use efficiency for water stress conditions may be ascribed by less yield as well as growing degree days as compared to full irrigation.

Table 4: Effect of date of sowing on the pheno-thermal index (PTI) of mustard (Pooled data of 2017-18 and 2018-19)

Treatment	Emergence	First Flower	60% Flowering	Siliquae Filling	Physiological Maturity
Date of Sowing					
10th Oct	11.0	8.7	7.6	8.0	8.4
20th Oct	11.1	8.0	7.6	7.9	8.5
30th Oct	9.1	8.4	7.2	7.6	8.3
CD at 5%	0.24	0.07	0.05	0.04	0.02

Pheno-thermal index (PTI)

The pheno-thermal index (PTI) *for consecutive* phenological stages was also computed and is presented in Table 4. It was observed that the emergence stage the phenol-thermal index gradually increased from first flowering to physiological maturity stage in all three dates of sowing and the highest value of PTI was observed at the physiological maturity. Among the sowing dates, the maximum PTI was observed at 60 percent flowering (7.6), siliquae filling (8.0), physiological maturity (8.4) for 10th October sown crop followed by 20th October and 30th December. This may be due to an increase in temperature at the reproductive stage reduced the days taken to reach different reproductive stages for 30th October sown crop as compared to 20th October and 1oth October sown crops. Results indicated that GDD was positively correlated with biological as well as grain yield. The GDD showed a highly significant relationship with biological yield and grain yield. While PTI showed a negative relationship with both grain yield and biological yield but it was not statistically significant.

Conclusions

The crop sown on 10th October took maximum days to attain different phenological stages and required maximum heat units which got reduced with a subsequent delay in sowing and the lowest values were noticed for crop sown on 30th October. The 10th October sown crop recorded the highest grain yield and HUE which was statistically at par with 10th October, which suggested that with similar management practices the mustard cultivar Pusa swarnim can be sown up to 30th November. Among the irrigations, three irrigations treatment took maximum days to attain physiological maturity and consumed more heat units or GDD during total crop period resulted in more yield, HUE, and PTI as compared to other treatments. The GDD also showed a highly significant positive correlation with grain and biological yield. Therefore, it may be used for forecasting the phenological stages and yield under different sowing date and stage-based irrigation scheduling for mustard.

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