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MICROCLIMATIC INFLUENCE ON THERMAL TIME REQUIREMENT, GROWTH DYNAMICS AND YIELD ATTRIBUTES OF COTTON IN THE SOUTH-WESTERN REGION OF PUNJAB

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ABSTRACT

To quantify thermal requirement for *Bt* cotton hybrid using Agrometeorological indices, multi-location field experiments were undertaken at Punjab Agricultural University (PAU) Regional Research Station, Bathinda and PAU Regional Research Station, Faridkot during *kharif* 2018. The experiment consisted of three sowing dates i.e. April 30th, May 15th and May 30th with two row orientations (North-South: N-S and East-west: E-W) and three row spacings (45 cm, 60 cm and 75 cm) in a factorial split-plot design, replicated thrice. Growing degree days (GDD), Photo thermal units (PTU), Heliothermal units (HTU), Relative temperature disparity (RTD) and Phenothermal index (PTI) were computed using daily meteorological data. The base temperature of 10°C was used for computation of Growing Degree Days (GDD) on a daily basis. The results revealed that seed cotton yield, as well as Agrometeorological indices like accumulated growing degree days, photo thermal units, heliothermal units and relative temperature disparity were highest in crop sown on April 30th (D_1) having maximum calendar days and reduced significantly by delay in sowing and recorded lowest values on May 30th sown crop. Moreover, Heat use efficiency (HUE) was also found higher for early sowing and decreased subsequently by delay in sowing at both study locations. Therefore, early sowing dates are preferable than late sowing dates. Also, a significant correlation coefficient and a positive linear relation (R^2= 0.942 for GDD and R^2= 0.952 for PTU) were observed between various thermal indices and yield and yield attributing characters of the cotton crop, indicating a positive effect on the growth and seed cotton yield.

Keywords: Agrometeorological indices, Heat use , Seed cotton yield

Cotton is an important *kharif* crop being grown in more than 70 countries around the globe and it accounts for 75% of the fibre used in the textile industry with 4% contribution to GDP (Fortucci, 2002). It is a major cash crop of Punjab, widely known as the 'White Gold' or 'king of fibers'. The main purpose of cotton cultivation is fiber production. Cotton production plays a vital role in the Indian economy, as it impact the lives of an estimated 60 million people in India. As per the estimate of Cotton Advisory Board, during the years 2021–2022, a total of 24.6 million MT of cotton was produced globally on 32.6 million hectares, with an average yield of 755 kg ha^{-1} (Anonymous, 2022). India, as one of the largest producer of cotton in the world accounting about 23% of the world cotton production (Anonymous, 2022). Cotton is the second most important *kharif* crop in Punjab after rice and also the most important cash crop in the state's south-western (S-W) area. Cotton crop occupied 3.04 lakh ha in Punjab during 2021-22 and produced 11.6 lakh bales of 170 kg along with 652 kg ha^{-1} productivity (Anonymous, 2022). In Punjab state, the districts of Barnala, Bathinda, Faridkot, Fazilika, Mansa and Shri Muktsar sahib are the most important cotton-growing areas. In which district Fazilka has the largest cotton growing area (84.4 thousand hectares), while the largest cotton production was in Bathinda with 385.9 thousand bales of 170 kg. Moreover, the highest cotton productivity was observed in Barnala having 863 kg ha^{-1} (Anonymous, 2023). Many variables impact a cotton plant's reproductive cycle, including climate, variety type, and agronomic and pest control measures. The effects of climatic conditions such as maximum air temperature, rainfall, and relative humidity on cotton flower and boll production are significant. Plant reproductive activities like pollen tube development, pollen germination, and fruit setting are all influenced by air temperature (Santosh *et al*., 2017).

Plants require a specific amount of heat units to attain different phenological stages in their life cycle, from sowing to the physiological maturity. Research has shown that measuring the heat accumulated over time provides a more accurate physiological estimate than counting calendar days. The Temperature and growing degree days (GDD) are two significant geographically dynamic climatic factors that impact crop development (by directly altering plant activities such as

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evapotranspiration, photosynthesis, plant respiration, plant water, and nutrient transport). Changes in sowing dates have a direct impact on both the thermal and photo periods, and so have a significant impact on phasic development and dry matter partitioning (Leela *et al.*, 2013).

The number of days required for cultivars to reach maturity depends primarily on location, date of planting and the temperature (Dhir *et al.,* 2021). Due to variations in daily minimum and maximum temperatures from year to year and between locations, number of days from planting to physiological maturity varies. The meteorological indices *viz.* GDD, PTU, HTU which are based on air temperature, are used to describe changes in phenological behavior and the growth parameters (Prakash *et al.*, 2017). The heat unit concept suggests that a direct and linear link between growth and temperature is beneficial for estimating a crop's production potential under various weather conditions (Kumar *et al.,* 2014). Alteration of sowing dates directly influences growth and development of crops (Dhir *et al*., 2020). Agrometeorological indicators based on temperature give a good forecast for crop development and production. The effect of temperature on crop phenology and yield may be examined in the field using an accumulated heat unit system (Pandey *et al.*, 2010). Therefore, in order to evaluate and quantify the effects of ambient temperature on phenological development; the present investigation was conducted on heat unit requirements of *Bt* cotton hybrid (RCH 773 BGII) as effected by sowing time.

MATERIALS AND METHODS

Experimental details

Multi-location experiment was conducted during *kharif* 2018 at Bathinda (latitude 30.58° N, longitude 74.18° E, altitude 211 m AMSL and Faridkot (latitude 30°40' N, longitude 74°44' E, altitude 200m AMSL to quantify the micro-climatic modification effects on thermal requirement and crop phenology. The experiment was conducted with a factorial split plot design with three replications. Treatments comprised three dates of sowing *viz.* D_1: (April 30th), D_2: (May 15th) and D_3: (May 30th) and two row orientations *viz.* O_1: North–South and O_2: East–West in the main plot and three plant spacings *viz.* P_1: 67.5×45cm, P_2: 67.5×60cm and P_3: 67.5×75cm in a sub plot. A total fifty-four treatment combination was tested. But, in the present study we have considered only different sowing environments for the derivation of various meteorological indices to quantify their effect on heat use efficiency, yield and indices. The study region lies in the extreme South-West portion of Punjab. The annual normal rainfall of Bathinda is about 454 mm (65% rainfall received during the S-W monsoon) and Faridkot is about 433 mm (71% rainfall received during the S-W monsoon season from July to September). Dust storms are a regular feature in the summer season when the mercury sometimes touches over 47.0 ^{O}C in the peak summer in May-June. There is moderately dark coloured and well drained sandy soil. The meteorological data (Maximum temperature (^{O}C), Minimum temperature (^{O}C), Maximum possible sunshine (hours) was recorded at Meteorological Observatory of PAU Regional Research Station, Bathinda and PAU Regional Research Station, Faridkot.

Phenological observations

Phenological observations were recorded by randomly selected ten plants from each plot and the observations were made for the number of seedlings emerged, commencement of first square, first flowering on the basis of squares turned into flowers, boll opening initiation similar to first flowering and boll maturation. Boll maturation of cotton was determined by counting the cracked bolls bearing the lint (termed as open bolls) and unopened or "green bolls".

Agrometeorological indices

Growing degree days (GDD)

A degrees-day (^{O}C days) or a heat unit is the departure of the mean daily temperature from the minimum threshold (base) temperature. GDD was calculated according to the equation (McMaster and Wilhelm, 1994).

$$GDD = \frac{T_{max} + T_{min}}{2} \quad T_{base}$$

Where, T_{max} and T_{min} represent a daily maximum and minimum temperatures and T_{base} are the base temperature or minimum threshold temperature taken as 10^{O}C for cotton crop.

Photothermal units (PTU)

Photo-thermal Units (°C day hours) was computed by taking the product of GDD and the corresponding day length for that day. This can be mathematically represented using the following formula:

$$PTU = (GDD \times N) \qquad (2)$$

Where, GDD = Growing degree days, N =Maximum possible sunshine hours or day length (hours).

Heliothermal units (HTU)

A Helio-thermal unit (°C day hours) is the product of the growing degree-days and the corresponding actual bright sunshine hours for that day. HTU were calculated using the following expression:

$$HTU = \{GDD \times BSS\ (n)\} \qquad (3)$$

Where, GDD = growing degree days, BSS (n) = bright sun shine hours (hours)

Relative temperature disparity (RTD)

Relative temperature disparity (RTD) in percent is a factor of temperature that significantly affects the sowing environments for several crops such as cotton, wheat etc. It was calculated by using the following formula

$$\text{RTD (\%)} = \frac{T_{max} - T_{min}\,(°C)}{\text{Average } T_{max}\,(°C)} \times 100 \quad (4)$$

Phenothermal index (PTI)

The phenothermal index (^{O}C days day^{-1}) is the ratio of degrees-days to the number of days between two phenological stages was calculated as

$$\text{PTI} = \frac{\text{Degree days consumed between two phenological stages}}{\text{Number of days between two phenological stages}} \quad (5)$$

Heat use efficiency (HUE)

Heat use efficiency (kg ha^{-1} per ^{O}C days) for seed cotton yield was obtained as under

$$\text{HUE} = \frac{\text{Seed cotton yield}}{\text{Accumulated growing degree days}} \quad (6)$$

Statistical analysis

Correlograms were plotted by applying Pearson's method for correlation coefficients among Agrometeorological indices and yield and yield attributes of cotton crop by using R studio and regression analysis is used to analyze the environmental factors and their influence on cotton phenology and yield for both the study locations.

RESULTS AND DISCUSSION

Meteorological conditions during study period

Monthly meteorological conditions during *kharif* 2018 cotton season indicated that the mean monthly maximum temperature ranged from 27.3-39.6 ^{O}C at both Bathinda and Faridkot, whereas the mean monthly minimum temperature ranged from 11.8-26.0 and 10.6-27.2 ^{O}C at Bathinda and Faridkot, respectively (Fig. 1). Total rainfall received during the entire growing period of cotton was 340 and 414 mm at Bathinda and Faridkot, respectively (Fig. 1). It was observed that April 30th sown crop experienced higher mean temperature and rainfall. However, during reproductive phase, May 15th and May 30th sown crop experienced less mean rainfall and temperature. Henceforth, the increase in yield during early sown crop might be due to increased growing period and optimum weather conditions.

The relationship between seed cotton yield and different weather parameters indicated a significant effect of prevailing weather conditions. Results indicated that seed cotton yield was positively related with the temperature and evaporation, but negatively with relative humidity. Maximum temperature *vs.* seed cotton yield showed the highest value of a positive regression coefficient between them (R^2= 0.557) whereas evening relative humidity *vs.* seed cotton yield showed the highest value of negative regression coefficient between them (R^2= 0.756) (Fig.5).

Agrometeorological indices *vs.* phenology of cotton as influenced by sowing time

Growing degree days (GDD)

The accumulated growing degree days (GDD) by *Bt* cotton hybrid under different dates of sowing for both Bathinda and Faridkot are shown in Table 1. So, to attain physiological maturity, accumulated growing degree days recorded in D_1, D_2 and D_3 were 3299, 3182 and 2914 ^{O}C days at Bathinda and 3422, 3259 and 3014 ^{O}C days at Faridkot, respectively. It was observed that there was a successive decrease in the accumulated growing degree days right from April 30th through May 30th in all the crop growth stages at both the research stations. The highest accumulated growing degree day was observed for April 30th (3299 at Bathinda and 3422 ^{O}C days at Faridkot) followed by May 15th (3182 at Bathinda and 3259 ^{O}C days at Faridkot) and 30th May (2914 at Bathinda and 3014 ^{O}C days at Faridkot) respectively. In general, the accumulated growing degree day values decreased with delayed sowing and it may be due to maximum air temperature prevailed for early sowing time. These results are in general agreement with the findings of (Dhir *et al*., 2021) who conducted an experiment on cotton crop at Bathinda and Faridkot districts of Punjab during *kharif* 2018 and Gill *et al*. (2018) on Moong at Ludhiana, Punjab during *kharif* 2014 and 2015. Under different dates of sowing the trend of GDD accumulated by cotton hybrid was in line with the trend under observed seed cotton yield (Fig. 2).

Heliothermal units (HTU)

The perusal of the data indicates that the crop sown on April 30th accrued more HTU followed by the crop sown on May 15th and May 30th at both the experimental fields (Table 1). To attain physiological maturity accumulated Heliothermal units recorded in D_1, D_2 and D_3 were 19736, 19094 and 16990 ^{O}C day hours at Bathinda and 16650, 15866 and 14092 ^{O}C day hours at Faridkot, respectively. Reduction in HTU under late sown conditions indicates that the crop used more heat units under early sown crop rather than in

Table 1. Accumulated GDD (°C days), PTU (°C day hours), HTU (°C day hours), RTD (%) and PTI (°C days day^{-1}) required for attainment of phenophases for *Bt* cotton hybrid during *kharif* 2018 under different dates of sowing

	Bathinda						Faridkot					
D_1: First date of sowing (30th April,2018)												
Phenology	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**
Emergence	8	194	1187	2628	41.7	24.3	9	221	1351	2995	35.5	24.6
First Square	52	1173	7345	16129	39.1	22.6	53	1228	6329	16891	35.2	23.2
Anthesis	63	1387	8272	19124	32.8	22.0	64	1446	7166	19935	23.1	22.6
Boll Opening	107	2254	12675	30946	30.2	21.1	107	2348	10872	32247	21.0	21.9
Maturity	162	3299	19736	44002	33.8	20.4	165	3422	16650	45641	28.6	20.7
D_2: Second date of sowing (15th May,2018)												
Phenology	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**
Emergence	8	219	1319	2975	40.1	27.4	8	219	1182	2983	39.8	27.4
First Square	50	1116	6423	15462	36.4	22.3	51	1172	5637	16242	30.3	22.9
Anthesis	61	1345	7986	18648	33.5	22.0	62	1418	6724	19667	20.7	22.8
Boll Opening	100	2122	11661	29104	28.0	21.2	101	2225	10115	30519	19.6	22.0
Maturity	160	3182	19094	42053	34.8	19.9	161	3259	15866	43129	33.2	20.2
D_3: Third date of sowing (30th May,2018)												
Phenology	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**	**Days after sowing (DAS)**	**AGDD**	**AHTU**	**APTU**	**RTD**	**PTI**
Emergence	6	191	1564	2660	39.0	31.8	7	223	1296	3107	38.7	31.9
First Square	47	1028	5549	14339	33.2	21.9	47	1082	4697	15094	25.3	23.0
Anthesis	55	1187	6209	16551	33.5	21.6	55	1251	5263	17441	21.1	22.7
Boll Opening	94	1974	10418	26983	26.1	21.0	95	2079	8784	28401	21.1	21.8
Maturity	150	2914	16990	38266	38.0	19.4	153	3014	14092	39601	38.4	19.6

later crop growth stages (Solanki and Mundra, 2015) at Udaipur, Rajasthan on Mustard crop during 2008-09 and 2009-10. Moreover, under different dates of sowing the trend of HTU accumulated by the cultivar was in line with the trend observed in cotton yield (Fig. 2).

Photo thermal units (PTU)

Accumulated photo thermal units (PTU) by RCH 773 BGII cotton hybrid under different dates of sowing are shown in Table 1. Total accumulated photo thermal unit recorded in D_1, D_2 and D_3. 44002, 42053, and 38266 at Bathinda compared to 45641, 43129, and 39601°C day hours at Faridkot respectively. Highest accumulated photo thermal unit was observed on D_1 and got reduced by delay in sowing at both the research areas. The accumulation of PTU decreased with the delay in date of sowing. These findings are also in conformity with findings of Bankar *et al.* (2018) who revealed that the green gram cultivar accumulated significantly higher GDDs, HTUs and PTUs on first date of sowing at Parbhani during 2017**.**

Relative temperature disparity (RTD)

At both the research stations, the relative temperature disparity (RTD) requirements were found to decrease from emergence to boll opening stage and increase thereafter at maturity stage significantly decreased with delay in sowing of crop (Table 1). The signal from the high RTD value indicates a higher mean temperature and a relatively low mean minimum temperature. These results are in general agreement with the findings of Subrahmaniyan *et al*. (2004) on rice at Tamil Nadu. The relative temperature disparity in D_1 was observed in the range between 30.2 – 41.7% at

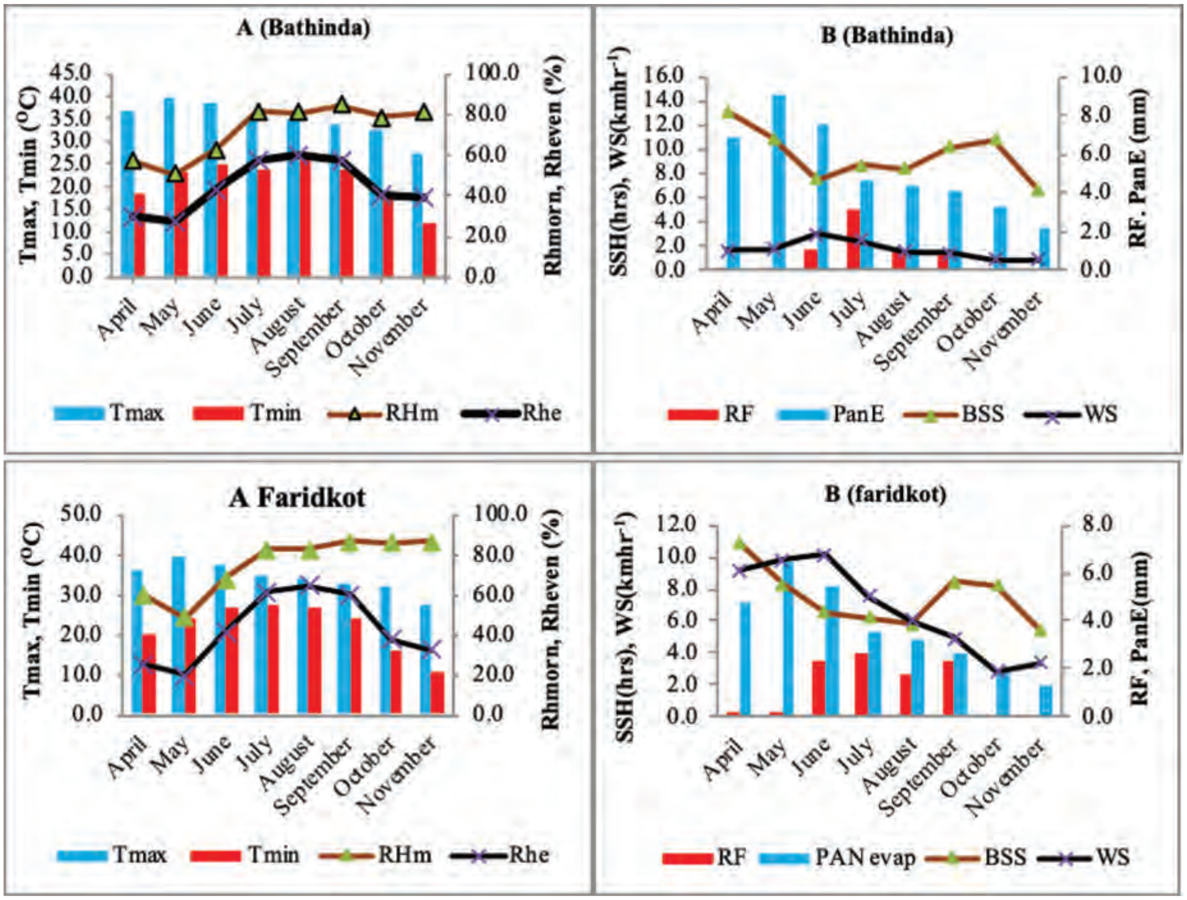


Fig. 1. Monthly meteorological conditions during *kharif* 2018 cotton at Bathinda and Faridkot

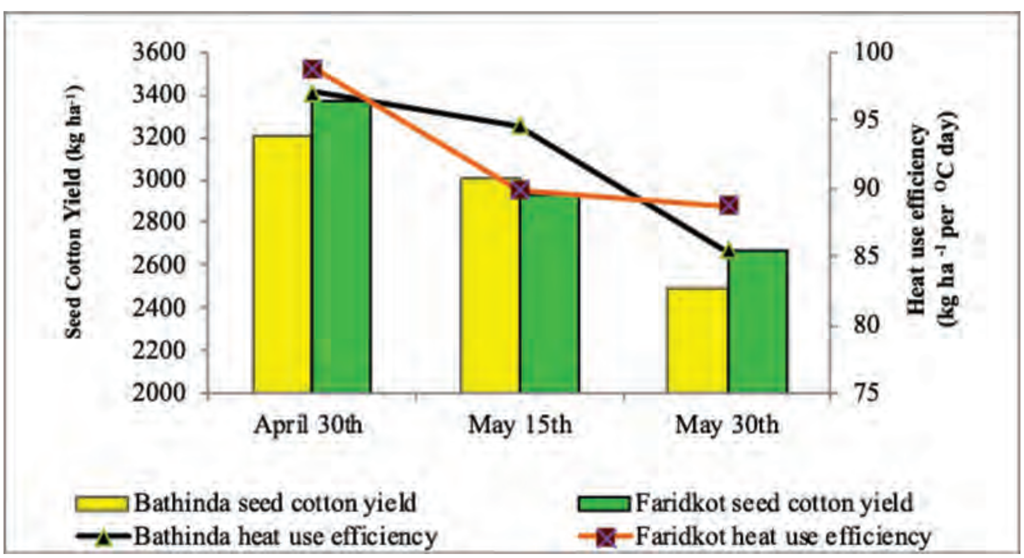


Fig. 2. Seed Cotton Yield (kg ha^{-1}) and Heat use efficiency (kg ha^{-1} per ^{O}C days) of *Bt* cotton hybrid at Bathinda and Faridkot during *kharif* 2018.

Bathinda and 21.0 - 35.5% at Faridkot followed by D_2 (28.0 – 40.1% at Bathinda and 20.7 – 39.8% at Faridkot) and D_3 (26.1 – 39.0% at Bathinda and 21.1 – 38.7% at Faridkot), respectively. As a result, the RTD pattern acquired by the cultivar corresponded to the trend in seed cotton production at various sowing dates (Fig. 2).

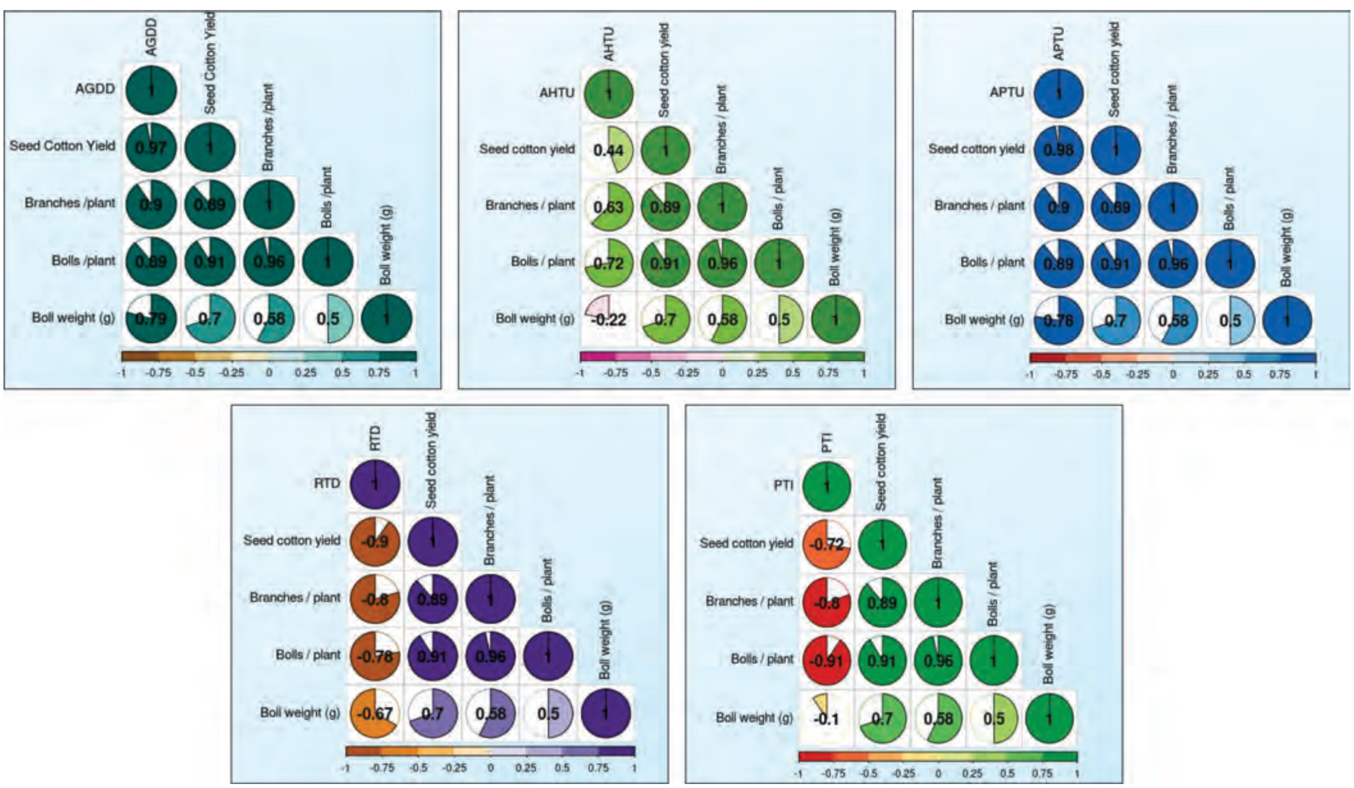
Phenothermal index (PTI)

The phenothermal index (PTI) varied from 19.4 to 31.9 (^{O}C days day^{-1}) throughout emergence to physiological maturity at both study locations for all sowing dates (Table 1). From emergence to maturity, a decrease in the accumulation of the degree days per growth day between two phonological events and decrease in PTI due to delay in emergence to physiological maturity stage. To attain physiological maturity, PTI recorded in D_1, D_2 and D_3 were 20.4, 19.9 and 19.4 ^{o}C days day^{-1}at Bathinda and 20.7, 20.2 and 19.6 ^{o}C days day^{-1}at Faridkot, respectively. It was observed that there was a successive decrease in the PTI right from emergence to maturity among all sowing dates at both the research station indicating a decrease in heat consumption toward maturity. The findings are in accordance with the findings of Chaudhari *et al.* (2019) on rice crop during 2016 at Gujarat. The low value of PTI from sowing to maturity by delay in sowing might be the reason for low seed cotton yield in the south west region of Punjab.

A positive and linear regression was found when the accumulated GDD, HTU, PTU, and RTD values were compared. The accumulated GDD and PTU revealed a substantial positive regression relation (R^2= 0.997) indicating good agreement among the indices utilized in the study. Similarly, there was a substantial positive relation between RTD and accumulated GDD (R^2= 0.854) and significant negative regression relation between RTD *vs*. accumulated PTU (R^2= 0.887) was found. On the other hand, accumulated HTU *vs*. accumulated GDD, RTD *vs.* accumulated HTU and accumulated PTU *vs.* accumulated HTU indicated lesser closeness between them (Fig.6).

Agrometeorological indices *vs.* yield and yield attributes of cotton

Seed cotton yield was significantly influenced by different sowing dates and the highest seed cotton yield was recorded (at Bathinda and Faridkot) for crop sown



AGDD – Accumulated Growing Degree Days (^{o}C days), AHTU – Accumulated Heliothermal Units (^{o}C day hours), APTU – Accumuated Photothermal Units (^{o}C day hours), RTD – Relative Temperature Disparity (%), PTI – Phenothermal Index (^{o}C days day^{-1})

Fig. 3. Correlation coefficient between Agrometeorological indices and yield and yield attributes of cotton during *kharif* 2018 (*Significant at 0.05 P level)

during April 30th (3,203-3,370 kg ha^{-1}) followed by May 15th (2,929-3,010 kg ha^{-1}) and the lowest seed cotton yield was observed when crop was sown during May 30th (2,487-2,673 kg ha^{-1}) at both the research locations (Fig. 2). The maximum seed cotton yield in 30th April may be due to higher GDD, PTU, HTU and RTD than the rest of sowing dates. The growing degree day, photo-thermal unit for the entire crop growing period decreased with subsequent delay in sowing. Delay in sowing times negatively influenced its seed cotton yield. Therefore, an early sowing produced higher seed cotton yield than late sowing. These results are in general agreement with the findings of Waghmare *et al.* (2016) on cotton crop during 2013 at Parbhani, Maharashtra.

Statistics in terms of correlation coefficient between the agromet indices used for the study i.e. accumulated GDD, accumulated HTU, accumulated PTU, RTD and PTI to the yield attributing characters of cotton like branches/plant, bolls/plant, boll weight (g) and seed cotton yield (kg ha^{-1}) indicated close proximity between them (Fig. 3). Accumulated GDD and PTU, showed the highest value of a positive correlation coefficient and RTD with highest value of negative correlation coefficient for the seed cotton yield followed by branches/plant while, the lowest value of correlation coefficient was found with boll weight (Fig. 3). Similarly, for the accumulated HTU, the highest value of correlation coefficient was found with bolls/plant while the boll weight was found to have lowest and negative correlation coefficient. In respect to seed cotton yield, a significant correlation was found for GDD (0.97) as well as accumulated PTU (0.98). Among the Agrometeorological indices, the lowest correlation coefficient was found for accumulated HTU, while highest for accumulated GDD indicated better relationship between them (Fig. 3). But phenothermal index (PTI) was found to be negatively correlated with the yield attributing characters and seed cotton yield. Among the yield attributing parameter showed the highest value of negative correlation coefficient for the bolls/plant followed by branches/plant while, the lowest value of correlation coefficient was found with boll weight (Fig. 3).

The relationship between seed cotton yield *vs.* accumulated GDD, HTU and PTU values indicated positive and linear relation that basically indicated increment in seed cotton yield along with the respective indices (Fig. 4). Similarly, among the indices used for the study, GDD as well as PTU showed significantly positive relation (R^2= 0.942 for GDD and R^2= 0.952 for PTU) between the compared parameters, while, RTD showed significantly negative relation with R^2=0.817. Additionally, seed cotton yield while compared to accumulated HTU as well as PTI indicated lesser closeness but positive relation between the compared parameters having R^2= 0.195 for Accumulated HTU

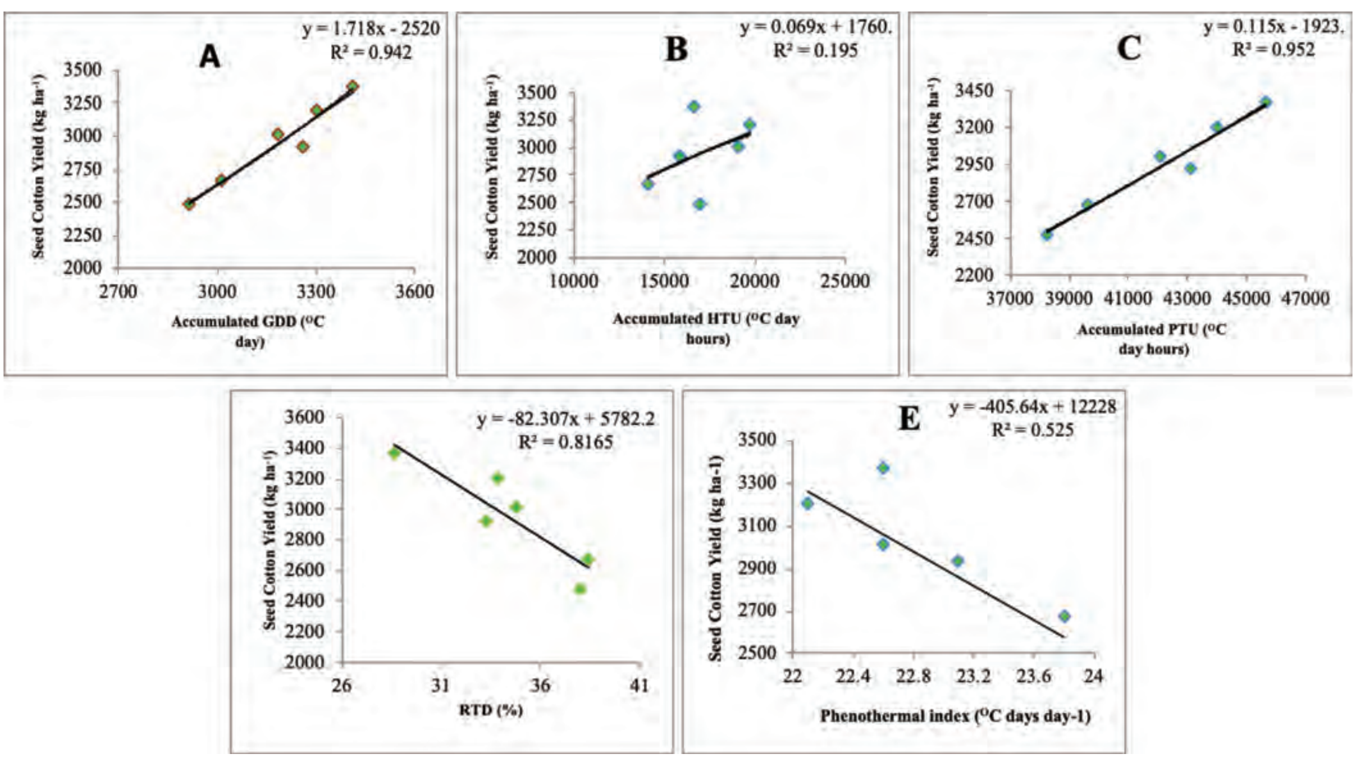


Fig. 4. Relationship between different Agrometeorological indices and seed cotton yield

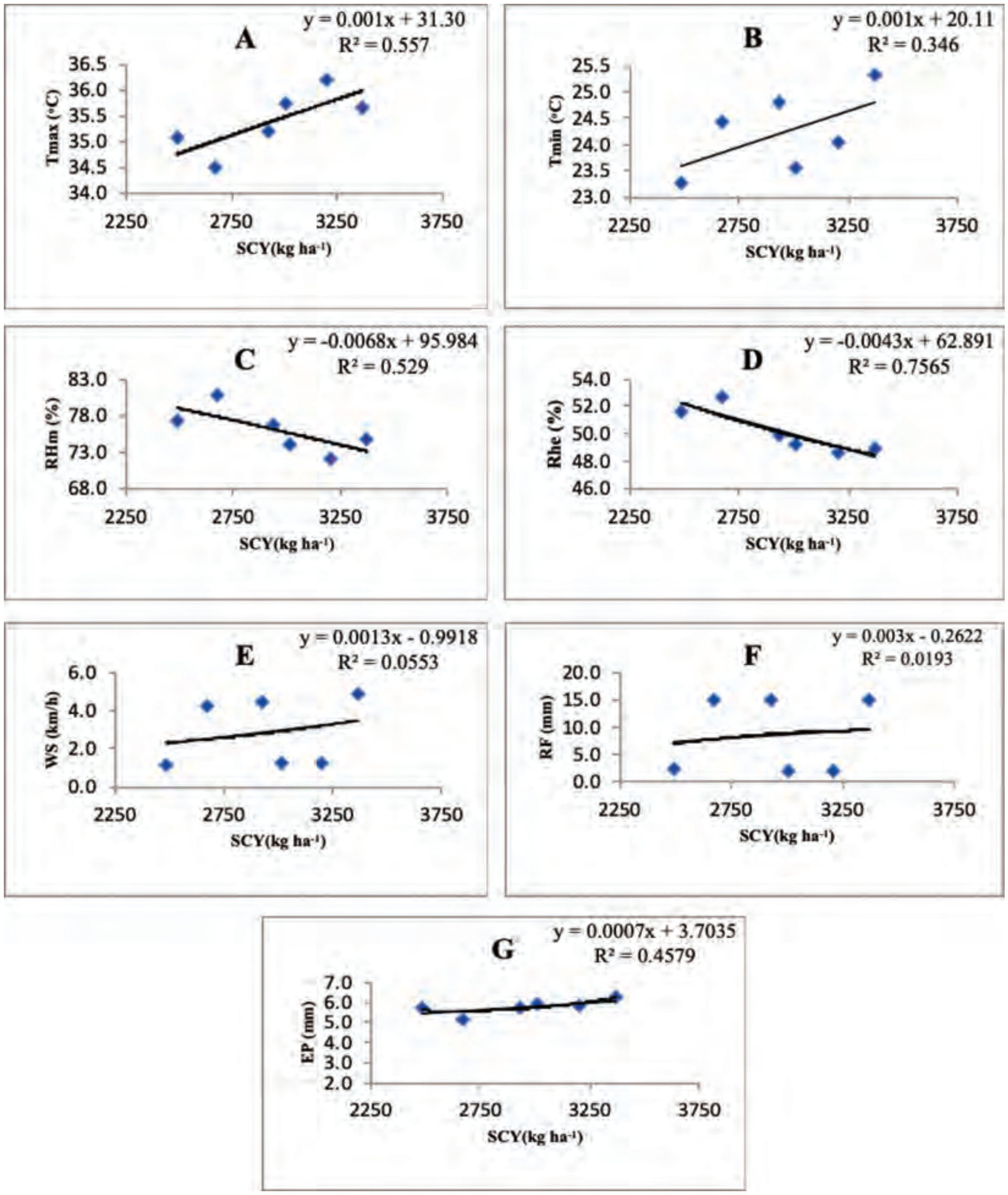


Fig. 5. Relationship between various weather parameters i.e. maximum temperature (T_{max}°C), minimume temperature (T_{min}°C), morning relative humidity (Rh_m %), evening relative humidity (Rh_e %), wind speed (kmh^{-1}), Rainfall (RF mm), evaporation (EP mm) and seed cotton yield (SCY kg ha^{-1}) during the study period of *kharif* 2018

and R^2= 0.525 for PTI (Fig. 4).

Heat Use Efficiency (HUE)

The heat use efficiency (kg ha^{-1} per °C days) is the capacity of the plant to harvest dry matter per unit of heat use which depends on genetic factors and sowing time and has a wide range of practical applications. Among the sowing dates, the highest heat use efficiency was recorded in an early sown (97.1 at Bathinda and 98.9 at Faridkot) followed by mid sown i.e. 15th May (89.9 at Bathinda and 94.6 at Faridkot) and late sown i.e. 30th May (85.3 at Bathinda and 88.7 at Faridkot) (Fig. 2). With delay in sowing, heat use efficiency decreased subsequently at vegetative, flowering and reproductive stages of the crop. Reduction in HUE under late sown conditions indicates that the crop used heat more efficiently under early sown crop as compared to late sown conditions. Singh *et al*. (2018) also revealed that early sown Brassica crop has attained highest heat use efficiency and it decreased by delay in sowing at Ludhiana, Punjab conditions.

Seed cotton yield, as well as heat units such as

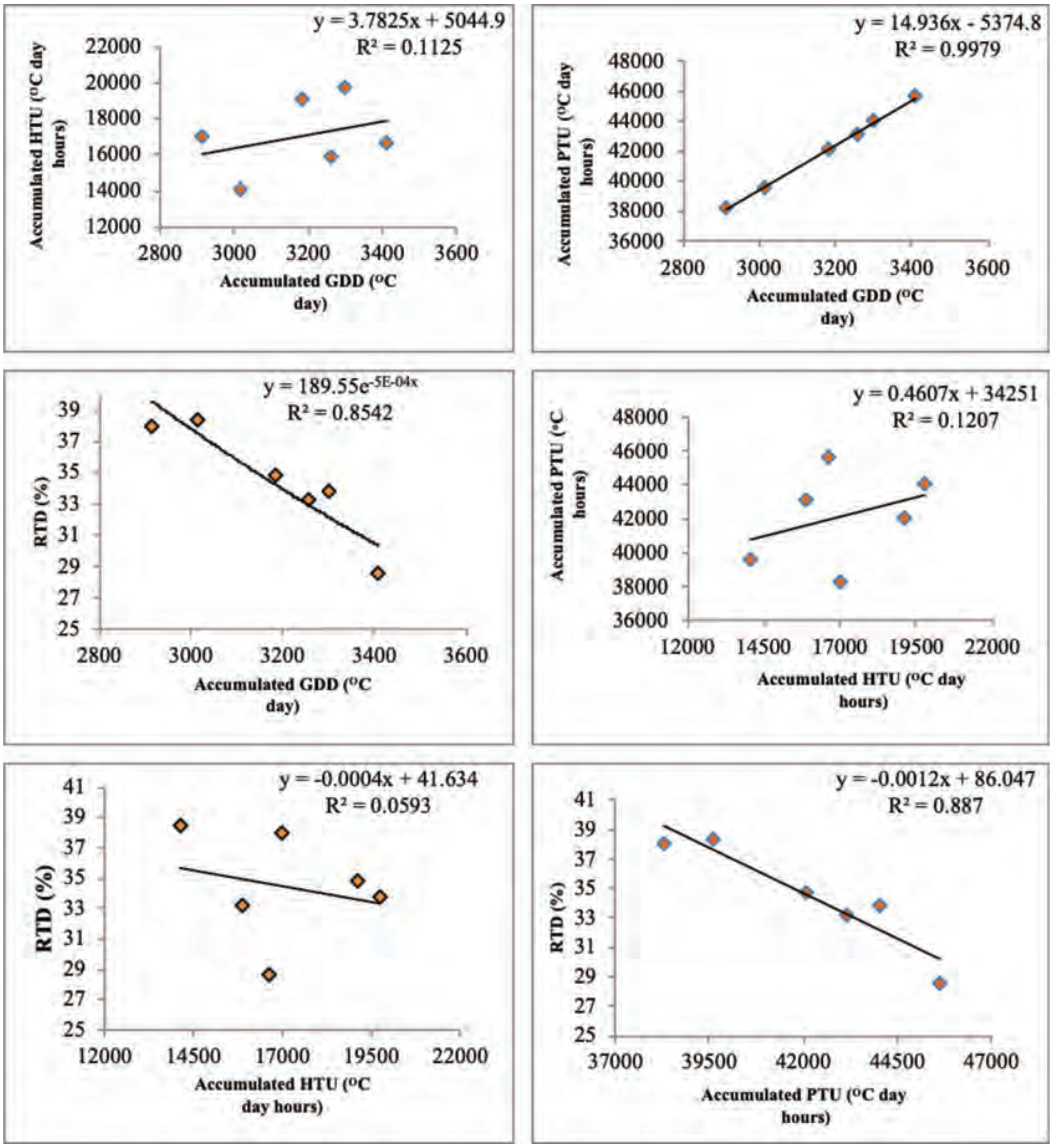


Fig. 6. Relationship between Accumulated GDD, Accumulated HTU, Accumulated PTU and RTD during the study period of *kharif* 2018

accumulated growing degree days, photo thermal unit, heliothermal unit and relative temperature disparity were highest in crops sown on April 30th (D_1) having maximum calendar day and reduced significantly by delay in sowing and recorded lesser value on May 30th (D_3) sown crop. Moreover, HUE was also found higher for early sowing and decreased subsequently by delay in sowing at both study locations. Therefore, an early sowing dates are preferable than late sowing dates. Also, it was concluded that a significant correlation coefficient and a positive linear regression relation existed between the Agrometeorological indices and yield and the yield attributing characters of the cotton crop. GDD and PTU, two of the indices employed in the study, demonstrated a significantly favorable relationship between the examined parameters. With respect to temperature and evaporation, seed cotton yield was positively associated, in which maximum temperature showed highest positive correlation with seed cotton yield.

Authors' contribution

Conceptualization of research work and designing of experiments (AD, RKP, PKK, SKM); Execution of field/lab experiments and data collection (AD, RKP, PKK, SKM); Analysis of data and interpretation (AD, RKP, PKK, SKM); Preparation of manuscript (AD, RKP, PKK, SKM)

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