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Research Article

Effect of Different Sowing Dates on Helio-Thermal, Photo-Thermal, Heat Use Efficiencies and Productivity of Wheat (*Triticum aestivum* L.)

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ABSTRACT

The field experiments were conducted at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *rabi* seasons of 2017-18 and 2018-19. The wheat varieties *viz*. PBW-725, PBW 677 and HD 3086 were sown under three different dates i.e. 25^{th} October, 15^{th} November and 5^{th} December. Helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency were computed. Leaf area index and number of tillers were recorded periodically during both the crop seasons. The results indicated that leaf area index, periodic number of tillers, yield attributes contributing characteristics, grain yield and biological yield were significantly influenced by sowing dates. The highest LAI was recorded in 25^{th} October sown crop (4.11 and 4.49) as compared to 5^{th} December sown crop (3.21 and 3.56) at 90 days after sowing (DAS) during 2017-18 and 2018-19. The grain yield was significantly higher in 25^{th} October sowing (50.8 q/ha and 52.2 q/ha) as compared to 15^{th} November (48.3 q/ha and 49.9 q/ha) and 5^{th} December sowing (42.1 q/ha and 43.3 q/ha) during both the crop seasons. Reduction in biological, straw and grain yield was more in 2017-18 in comparison to 2018-19 due to high temperature during the reproductive stage of the crop. Helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency were higher in 25^{th} October sown crop followed by 15^{th} November and 5^{th} December sown crop for biomass and grain yield. The linear and positive relationships were computed between leaf area index and grain yield as well as heat use efficiency during *rabi* seasons of 2017-18 and 2018-19. It is concluded that timely sown crop exhibit proper growth and development due to favourable weather conditions and performed better in terms of accumulation and utilization of heat units.

Key words: Temperature, Helio-thermal use efficiency, Photo-thermal use efficiency, Heat use efficiency, Sowing date and Wheat grain yield

Introduction

Wheat is the second major staple food crop of India, predominantly in the north-western parts of the country. India ranks second in the production of wheat after China. It covers approximately 30.6 Mha area with 98.5 million tons of wheat production in India (FAO, 2017). In Punjab, wheat was cultivated on 35.0 lakh ha area with a production of 176.1 lakh tones and productivity of 47.5 q/ha during 2017-18 (Anonymous, 2018). Wheat crop has wider climate adaptability and it can be grown not only in tropical and sub-tropical zones but also in temperate and humid to dry environment. Under Punjab conditions, higher yield of wheat can be

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obtained with maximum and minimum temperature within the range of (18-22°C and 5-10°C) during vegetative stage, (17-20°C and 4-9°C) during anthesis stage and (20-25°C and 5-9°C) during the grain filling and reproductive stage of wheat crop (Bala and Prabhjyot-Kaur, 2013). The favourable temperature range for wheat is 3.5 to 35°C. Temperature is one of the most critical parameter that decides fate of productivity of wheat (Lenka, 2006). Plants have a definite temperature requirement before attaining certain phenological stages. A sudden rise in temperature during grain filling prior to maturity is a widely prevalent phenomenon in almost all parts of India, causing significant reduction in yield. For 1°C rise in temperature from normal, wheat production is estimated to reduced by 6 per cent (Akter and Islam, 2017).

Sowing of wheat crop at optimum time according to environmental conditions is the best way to increase growth and yield of crop. The influence of temperature on phenology and yield of crop are studied under the field conditions through accumulated heat unit system. The duration, growth and yield are decided by the thermal and photoperiod conditions experienced by the crop during its life cycle. Every crop has its own definite requirement for particular environmental conditions for its proper growth, development and yield. Heat and photo-periodic units are considered as the fundamental units used to examine the phenology of crop. Heat use efficiency *i.e*., the efficiency of utilization of heat in terms of dry matter accumulation, depends on crop type, genetic factors and sowing time. Heat use efficiency (HUE) is quite useful in predicting the growth and yield of different crops (Rajbongshi *et al.,* 2016). Helio-thermal, photo-thermal and heat use efficiencies in terms of biomass and grain yield are important aspects that have great practical applications. The amount of dry matter production by a crop depends on the distribution of leaf area in relation to solar energy utilization. The conversion of heat and radiant energy into the dry matter depends upon the genetic factors, sowing time and crop type (Sreenivas *et al.,* 2010). The concept of heat units has been applied to correlate the phenological development of different crops to predict grain yield and physiological maturity. Keeping all this in view, the experiments were planned to study the helio-thermal, photo-thermal and heat use efficiencies and yield of wheat as influenced by different sowing dates under Punjab conditions.

Materials and Methods

The field experiments were carried out at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. It is situated at the latitude of 30°55 N, longitude of 75°54 E and at an altitude of 247 m above mean sea level. Three wheat varieties PBW-725, PBW-677 and HD 3086 were sown under three different dates (25th October, 15th November and 5th December) during two consecutive *rabi* seasons of 2017-18 and 2018-19. The experiment was laid out in randomized complete block design with three replications. The recommended doses of fertilizers were applied at the rate of 90 kg N/acre in the form of urea, 55 kg P_2O_5/ acre in the form of DAP and 20 kg K_2O/ acre in the form of MOP.

The leaf area index was recorded at 15 days' interval with the help of Sun Scan Type SS1. The yield contributing characters *viz*., effective tiller count, 1000-grain weight and number of grains per ear as well as biological, straw, and grain yield were recorded at the time of harvesting.

The helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency were computed as under:

Helio-thermal use efficiency

Helio-thermal use efficiency is the amount of dry matter or grain yield produced per unit of accumulated helio-thermal units. It was calculated by using the following formula Dar *et al* (2018):

$$\text{Heliothermal use efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{Accumulated heliothermal units (°C day hours)}}$$

Photo-thermal use efficiency

Photo-thermal use efficiency is the amount of dry matter or grain yield produced per unit of accumulated photo-thermal units. It was calculated by using the following formula (Chakravarthy and Sastry, 1985):

$$\text{Photothermal use efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{Accumulated photothermal units (°C day hours)}}$$

Heat use efficiency

Heat use efficiency is the amount of dry matter or grain yield produced per unit of growing degree days or thermal time. It was calculated by using the following formula (Sastry *et al.,* 1985):

$$\text{Heat use efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{Accumulated growing degree days (°C day)}}$$

Results and Discussion

Leaf area index of wheat varieties under different dates of sowing

The fraction of incoming photosynthetic active radiation (PAR) that is absorbed by the canopy mainly depends on the LAI and crop geometry. The higher leaf area index is one of the way for increasing the capture of solar radiation within the canopy and higher production of dry matter.

The data on the periodic leaf area index of wheat varieties under different sowing dates are presented in Table 1. Leaf area index was lower during the early stages of crop growth and increased with the growth of crop reaching maximum at 90 days after sowing and after that, it started decreasing gradually as the crop reached senescence and maturity. The maximum leaf area index was recorded at 90 days after sowing (DAS) in 25th October sown crop (4.11) followed by 15th November (3.90) and 5th December sown crop (3.21) during 2017-18. In 25th October sown crop, it was 4.49 in comparison to 4.10 and 3.56 in 15th November and 5th December sown crop during 2018-19. The leaf area index under 25th October sown crop was statistically at par with 15th November sown crop and was recorded the lowest under 5th December sown crop during both the years. In delayed sowing (5th December), high-temperature stress conditions reduced the leaf area expansion and pre-mature leaf senescence resulting in reduced photosynthesis and wheat production. Dubey *et al.* (2019) and Kamrozzaman *et al.* (2016) also reported that timely sown wheat crop recorded higher leaf area index as compared to delayed sowing. Gupta *et al.* (2017) also concluded that the leaf area gets reduced with delayed sowing which may be due to a decline in photosynthetic rate and poor leaf development leading to lower leaf area index (LAI).

The non-significant differences in leaf area index were recorded in all three varieties but variety HD 3086 had higher leaf area index (3.82) followed by PBW 725 (3.77) and PBW 677 (3.63) during *rabi* 2017-18. The same trend was also observed during *rabi* 2018-19 but no significant differences were observed in varieties although variety HD 3086 had higher leaf area index (4.23) followed by PBW 725 (4.06) and PBW 677 (3.87).

Periodic number of tillers of wheat varieties under different dates of sowing

Tillering is one of the most important yield contributing character that determines the shoot architecture and grain yield production in wheat. Good tillering leads to the production of more number of ears per unit area, which ultimately results in higher grain yield. The number of tillers has a direct relationship with grain yield of wheat.

The tiller production and yield of wheat are greatly influenced by sowing dates. The different dates of sowing had a significant effect on periodic tiller production (Table 2). With delay in sowing date the number of tillers reduced significantly during both crop growing seasons. The periodic number of tillers recorded in 25th October sowing was statistically at par with 15th November sowing during both the crop seasons of 2017-18 and 2018-19. The highest number of tillers was recorded at 90 days after sowing (DAS) in 25th October sown crop (220.3) followed by 15th November (214.9) and 5th December sown crop (205.4) during 2017-18. During 2018-19

Table 1. Effect of date of sowing on leaf area index in different wheat varieties during *rabi* 2017-18 and 2018-19

Treatments	Leaf area index																	
	45 DAS			60 DAS			75 DAS			90 DAS			105 DAS			120 DAS		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Dates of sowing																		
October 25	1.49	1.88	1.69	2.41	2.53	2.47	3.12	3.55	3.34	4.11	4.49	4.30	3.52	4.08	3.79	3.12	3.40	3.26
November 15	1.30	1.61	1.46	2.09	2.31	2.21	2.83	3.44	3.14	3.90	4.10	4.00	3.31	3.75	3.52	2.96	3.19	3.08
December 5	1.09	1.32	1.20	1.85	1.88	1.87	2.25	2.55	2.40	3.21	3.56	3.39	3.11	3.34	3.21	2.50	2.70	2.61
CD (p=0.05)	0.21	0.31	0.20	0.35	0.33	0.21	0.29	0.40	0.23	0.22	0.42	0.21	0.21	0.31	0.17	0.21	0.25	0.14
Varieties																		
PBW 725	1.37	1.59	1.48	2.12	2.21	2.17	2.75	3.19	2.97	3.77	4.06	3.92	3.33	3.73	3.54	2.82	3.05	2.94
PBW 677	1.06	1.56	1.31	2.04	2.15	2.09	2.64	2.96	2.81	3.63	3.87	3.75	3.21	3.56	3.35	2.77	3.02	2.90
HD 3086	1.47	1.66	1.57	2.19	2.36	2.28	2.82	3.39	3.11	3.82	4.23	4.03	3.41	3.88	3.65	2.99	3.21	3.10
CD (p=0.05)	0.21	NS	0.2	NS	NS	NS	NS	NS	0.23	NS	NS	0.21	NS	NS	0.17	NS	NS	0.14

Table 2. Effect of date of sowing on periodic number of tillers (per m row length) in different wheat varieties during *rabi* 2017-18 and 2018-19

Treatments	Number of tillers/m row length																				
	45 DAS			60 DAS			75 DAS			90 DAS			105 DAS			120 DAS			At Harvesting		
	17-18	18-19	pooled	17-18	18-19	Pooled	17-18	18-19	pooled	17-18	18-19	Pooled	17-18	18-19	pooled	17-18	18-19	pooled	17-18	18-19	pooled
Dates of sowing																					
October 25	180.1	191.0	187.9	196.3	208.4	202.4	216.7	224.0	220.3	220.3	231.1	225.7	213.8	222.2	218.0	202.9	214.9	208.9	195.3	208.7	202.0
November 15	177.7	187.2	185.1	190.9	202.3	196.7	212.8	218.1	215.5	214.9	225.4	220.2	206.7	216.6	211.6	199.9	208.9	204.4	190.7	204.2	197.4
December 5	169.9	182.4	178.7	181.3	192.4	186.9	200.1	209.8	204.9	205.4	216.6	211.0	197.4	207.3	202.4	188.2	197.6	192.9	180.9	190.9	185.9
CD (p=0.05)	4.6	5.3	3.8	10.2	8.8	5.8	9.0	10.1	5.8	9.8	7.2	5.2	7.6	5.8	4.1	3.6	6.4	3.2	4.8	6.4	3.5
Varieties																					
PBW 725	176.3	186.6	184.0	190.0	200.6	195.3	210.0	217.4	213.7	213.6	224.4	219.1	205.4	215.3	210.4	196.6	206.7	201.6	188.7	201.1	194.9
PBW 677	173.1	185.7	181.9	187.8	200.0	193.9	208.3	215.6	211.9	211.9	223.0	217.4	204.9	213.9	209.4	195.3	205.6	200.5	187.0	199.6	193.3
HD 3086	178.2	188.7	185.7	190.7	202.8	196.8	211.3	218.9	215.1	215.1	225.7	220.4	207.6	216.9	212.2	199.1	209.0	204.1	191.2	203.1	197.2
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

crop growing season, the data showed that significantly higher number of tillers were produced at 90 days after sowing (DAS) in 25th October sowing (231.1) and was at par with 15th November sowing (225.4) and was lower when sowing was done on 5th December (216.6). The higher number of tillers recorded in 25th October sowing date during both the years was due to low temperature prevailed at the tillering stage and more number of days taken for different phenophases. Early sowing (25th October) accumulated more degree days from sowing to physiological maturity for tiller production as compared to delayed sowing (5th December). Prasad *et al.* (2016) also reported that at tillering stage, with an increase in temperature by 5.6°C and 4.2°C in rainfed and irrigated wheat causes reduction in tillers by 24.4 and 11.5 per cent, respectively. Joshi *et al.* (2016) also reported that early sowing of wheat produced significantly more number of tillers as compared to delayed sowing.

Among the varieties, non-significant differences in the number of tillers were observed but variety HD 3086 had higher number of tillers (215.1) followed by PBW 725 (213.6) and PBW 677 (211.9) during *rabi season* 2017-18. The same trend was observed for the crop growing season of 2018-19, although variety HD 3086 had a higher number of tillers (225.7) followed by PBW 725 (224.4) and PBW 677 (223.0).

Yield contributing characteristics

Number of effective tillers

The growth, development and yield of wheat are significantly influenced by sowing dates under field conditions. The data pertaining to the number of effective tillers per meter row length under different dates of sowing are presented in Table 3. The data showed that significantly higher number of effective tillers were produced when crop was sown on 25th October sowing (193.2) and was statistically at par with the crop sown on 15th November (188.7) whereas the crop sown on 5th December produced significantly low number of effective tillers (175.8) during 2017-18. For the crop growing season of 2018-19**,** significantly higher number of effective tillers were recorded in 25th October (202.8) sown crop followed by 15th November (198.9) and 5th December (186.9) sown crop. The differences among number of effective tillers in wheat varieties were found non-significant. The number of effective tillers were higher in normal sown crop might be due to favourable temperature requirement as per crop and boosting the crop growth in the form of higher photosynthates accumulation and resulted in higher number of effective tillers in normal sown crop (25th October) than late sown crop (5th December). Solanki *et al* (2017) also reported that an increase in 6.0°C mean temperature between 90 and 105 days after sowing (DAS) caused the reduction in number of effective tillers/m row by 15 per cent. Similar results was reported by Tomar *et al.* (2015) and concluded that decrease in the number of effective tillers with delayed sowing.

Number of grains per ear

The number of grains per ear is determined at anthesis stage, a period that coincides with the maturation of florets that reach the fertile stage. High temperature accelerates the development of the ear and reduces the number of spikelets and grains per spike. The increase in temperature from sowing to anthesis stage causes shortening of phenophases duration and affects the number of grains per ear and grain yield of the crop.

The data pertaining to the number of grains per ear revealed that sowing dates significantly affected the number of grains per ear (Table 3). The number of grains per ear was significantly higher for the crop sown on 25th October (61.2) and was statistically at par with the crop sown on 15th November (56.8) whereas the crop sown on 5th December produced significantly low number of grains per ear (51.9) during 2017-18. A similar trend was recorded during 2018-19 where the 25th October sowing recorded the higher number of grains per ear (65.1) in comparison to 15th November sowing (60.2) and 5th December sowing (52.4). The data revealed the significant differences among sowing dates, indicating

Table 3. Details of yield contributing characteristics of varieties PBW 725, PBW 677 and HD 3086 under different dates of sowing during *rabi* 2017-18 and 2018-19

Treatments	No. of effective tillers/m row length			No. of grains per ear			1000-grain weight (g)		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Dates of sowing									
October 25	193.2	202.8	198.0	61.2	65.1	63.1	46.1	48.1	47.1
November 15	188.7	198.9	193.8	56.8	60.2	58.5	42.8	43.9	43.3
December 5	175.8	186.9	181.3	51.9	52.4	52.2	36.3	38.6	37.4
CD (p=0.05)	4.8	4.2	2.8	4.8	5.5	3.2	4.4	4.7	2.8
Varieties									
PBW 725	185.9	196.6	191.2	57.4	59.4	58.4	41.7	43.9	42.8
PBW 677	184.4	194.1	189.3	53.9	57.1	55.5	39.7	41.1	40.4
HD 3086	187.3	197.9	192.6	58.5	61.2	59.8	43.9	45.6	44.7
CD (p=0.05)	NS	NS	NS	NS	NS	3.2	NS	NS	2.8

sensitivity to heat stress. The high-temperature stress at the reproductive stage under delayed sowing of crop results in poor grain yield due to the reduced number of grains per ear and shriveled grain with poor quality. Similarly, Joshi *et al* (2016) also reported that early sowing of wheat produced significantly more grains per ear as compared to the delayed sowing. Vishwanathan and Chopra (2001) also reported that late sown crops experienced 6-8^{o}C warmer temperature during grain filling stage than normal sowing crop. There was no significant effect of wheat varieties for number of grains per ear but it was higher in HD 3086 during both the crop seasons.

1000-grain weight

The potential number of grains is determined from initiation of floral development to anthesis, while the final grain weight can be expressed as a function of duration and rate of grain filling. Temperature is the most important environmental factor affecting number of grains per ear and 1000-grain weight. The 1000-grain weight and grain yield of wheat are greatly influenced by sowing dates.

The data pertaining to 1000-grain weight under different dates of sowing is presented in Table 3. During *rabi* 2017-18, the 1000-grain weight (46.1 g) was recorded on 25th October sowing date which was significantly higher than (42.8 g) 15th November and (36.3 g) 5th December sowing dates. The 1000-grain weight of 25th October sowing was statistically at par with 15th November sowing but significantly higher than 5th December sowing. The significantly higher 1000-grain weight was recorded in 25th October (48.1g) sown crop followed by 15th November (43.9g) and 5th December (38.6g) sown crop during *rabi* 2018-19. The higher 1000-grain weight in 25th October sown crop was statistically at par with 15th November sown crop while the lower 1000-grain weight was produced when sowing was done on 5th December. Higher 1000-grain weight in early sowing i.e. 25th October might be due to longer duration of crop. The reduction in 1000-grain weight in delayed sowing was mainly due to less production of photo-synthates due to shorter growth period. Delayed sowing also decreased the size of endosperm cells in grains and reduced the starch deposition thus decreased the grain weight. Narayanan (2018) also reported that high-temperature stress (>32^{o}C) from anthesis to maturity caused 20% reduction in average grain weight of wheat. Fayed *et al.* (2015) also concluded that significantly higher 1000-grain weight was obtained under early sowing (15th October) than delayed sowing. Lagheri *et al.* (2012) also suggested that 1000-grain weight showed 33.2% reduction under delayed sowing (1st January).

Among the varieties, no significant difference in the 1000-grain weight was recorded but variety HD 3086 had a higher 1000-grain weight followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19.

Biological, straw and grain yield of different wheat varieties under different dates of sowing

Biological yield

Optimum date of sowing is one of the most important factors determining the yield of wheat. The growth, development and yield of wheat are significantly influenced by sowing dates under field conditions. The biological, straw yield, grain yield and various yield contributing characteristics *viz.,* number of effective tillers, number of grains per ear and 1000-grain weight. were affected by different dates of sowing (Table 4).

The data indicates that sowing time significantly affected the biological yield. Significantly higher biological yield was produced when crop was sown on 25th October (144.9 q/ha) as compared to 15th November sowing (139.7 q/ha) and 5th December sowing (127.6 q/ha) during *rabi* 2017-18. A similar trend was observed in 2018-19, the biological yield was significantly higher for the crop sown in 25th October (150.5 q/ha) and was statistically at par with the crop sown in 15th November (144.3 q/ha) whereas the delayed sowing (5th December) produced significantly low biological yield (130.9 q/ha). The early sown crop (25th October) recorded higher biological yield due to long duration of crop whereas delayed sowing recorded the lowest biological yield due to high-temperature stress conditions at reproductive stages and thus the duration of crop reduced. Dubey *et al.* (2019) reported that the reduction in biomass yield can be attributed to heat stress at reproductive stages under late sowing (15th December) which resulted in an overall decrease in grain weight and ultimately yield. Sial *et al.* (2005) also reported that late sowing in wheat resulted in yield reduction by 55 to 70 per cent among the wheat varieties. Non-significant difference in biological yield was recorded in all three varieties but variety HD 3086 had a higher biological yield followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19.

Straw yield

The straw yield is reflected by growth parameters like number of tillers, leaf area index and plant height. The data related to the straw yield are influenced by the different dates of sowing and presented in Table 4. Among sowing dates, the maximum straw yield (94.1 q/ha) was recorded in 25th October sown crop followed by

Table 4. Total biological, straw and grain yield of varieties PBW 725, PBW 677 and HD 3086 under different dates of sowing during *rabi* 2017-18 and 2018-19

Treatments	Yield								
	Biological yield (qha^{-1})			Straw yield (qha^{-1})			Grain yield (qha^{-1})		
	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled	2017-18	2018-19	Pooled
Dates of sowing									
October 25	144.9	150.5	147.7	94.1	98.3	96.2	50.8	52.2	51.5
November 15	139.7	144.3	142.0	91.4	94.4	92.9	48.3	49.9	49.1
December 5	127.6	130.9	129.3	85.5	87.6	86.6	42.1	43.3	42.7
CD (p=0.05)	6.5	6.8	4.0	6.0	5.8	3.6	4.9	4.1	2.7
Varieties									
PBW 725	137.9	141.9	139.9	90.5	93.6	92.1	47.5	48.29	47.9
PBW 677	135.3	139.5	137.4	90.0	92.7	91.4	45.3	46.8	46.1
HD 3086	138.9	144.3	141.7	90.6	93.9	92.3	48.4	50.4	49.4
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

15th November sowing (91.4 q/ha) and 5th December sowing (85.5 q/ha) during *rabi* 2017-18. The significantly higher straw yield was recorded in 25th October sown crop (98.3 q/ha) followed by 15th November sown crop (94.4 q/ha) and 5th December sown crop (87.6 q/ha) during *rabi* 2018-19.

The higher straw yield observed under 25th October sowing was due to more LAI and number of periodic tillers which contributed towards straw yield. Straw yield decreased with delayed sowing as plant got unfavourable environment at different phenological stages and produced less number of tillers and number of effective tillers which in turn decreased the straw yield. The results were supported by the findings of Gupta *et al.* (2017) and Bisht *et al.* (2019) also reported that the straw yield reduced significantly with each delay in sowing.

Among the varieties, no significant difference in the straw yield was recorded but variety HD 3086 had a higher straw yield (90.6 q/ha) followed by PBW 725 (90.5 q/ha) and PBW 677 (90.0 q/ha) during *rabi* 2017-18. The same trend was also observed during 2018-19 but no significant differences were observed in varieties although variety HD 3086 had a higher value of straw yield (93.9 q/ha) followed by PBW 725 (93.6 q/ha) and PBW 677 (92.7 q/ha).

Grain yield

Optimum sowing time provides favourable conditions for wheat growth and development. The data related to the grain yield are influenced by the different dates of sowing and presented in Table 4. The data showed that significantly higher grain yield was produced when crop was sown in 25th October (50.8 q/ha) and statistically at par with 15th November (48.3 q/ha) sown crop while the lower grain yield was produced when crop was sown in 5th December (42.1 q/ha) during 2017-18. Significantly higher grain yield was recorded in 25th October sown crop (52.2 q/ha) followed by 15th November (49.9 q/ha) and 5th December sown crop (43.3 q/ha) during 2018-19 crop season. The early sown crop obtained higher grain yield due to long duration of different phenological stages. But in delayed sowing, the warmer conditions reduced the growing season length that leads to a decrease in grain yield. Under delayed sowing i.e. 5th December during high-temperature stress condition, large amount of energy is lost through the process of transpiration by plant and reduced the residual energy results in poor grain formation and decreased grain yield. Bisht *et al.* (2019), Dubey *et al.* (2019) and Roy *et al.* (2018) also concluded that the crop sown in 15th November took maximum number of days to attain different phenological stages and required maximum heat units which got reduced with subsequent delay in sowing and less number of days was taken by the crop sown on 15th December. Narayanan (2018) also reported that high-temperature stress (>35°C maximum temperature and >20°C minimum temperature) from anthesis to physiological maturity decreased the grain yield by 78 per cent, grain number by 63 per cent and grain weight by 29 per cent. Among the varieties, no significant difference in the grain yield was recorded but variety HD 3086 had a higher grain yield followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19.

Helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency of wheat varieties under different sowing dates during *rabi* 2017-18 and 2018-19.

Helio-thermal use efficiency

The helio-thermal use efficiency (HTUE) indicates the efficiency of the crop to utilize the available bright sunshine hours. Helio-thermal use efficiency was computed for grain and biomass of wheat and presented in Table 5. Among the dates of sowing, higher helio-thermal use efficiency in timely sowing could be attributed to the highest grain yield. The highest helio-thermal use efficiency (1.41 kg/ha/°C/day hour for biomass and 0.49 kg/ha/°C/day hour for grain) was recorded in 25th October sown crop followed by 15th November (1.17 kg/ha/°C/day hour for biomass and 0.40 kg/ha/°C/day hour for grain) and 5th December sown crop (1.04 kg/ha/°C/day hour for biomass and 0.34 kg/ha/°C/day hour for grain) during *rabi* 2017-18. The highest helio-thermal use efficiency (1.49 kg/ha/°C/day hour for biomass and 0.52 kg/ha/°C/day hour for grain) was recorded in 25th October sown crop followed by 15th November (1.30 kg/ha/°C/day hour for biomass and 0.45 kg/ha/°C/day hour for grain) and 5th December sown crop (1.13 kg/ha/°C/day hour for biomass and 0.38 kg/ha/°C/day hour for grain) during 2018-19. The helio-thermal use efficiency was higher in early sowing date i.e. 25th October due to higher yield as compared to delayed sowing. As the temperature was optimum throughout the growing period, crop utilized heat more efficiently and increased biological activity that confirms higher yield. The timely sowing of wheat crop seems to be essential for harnessing the good impact of prevailing weather conditions. Subsequently delay in sowing resulted in decrease in the heat use efficiency. Due to high temperature hampered the normal metabolic activities resulted in decrease grain yield as well as heat use efficiency in late sown crop. Dar *et al.* (2018) also reported that decrease in all the efficiencies with late sown crop from the early sowing i.e. 25th October and 10th November at Ludhiana. Similar relationships were also expressed by Bisht *et al.* (2019) and Singh *et al.* (2018) under different dates of sowing.

Among the varieties, no significant difference in the heat use efficiency was recorded but variety HD 3086 had a higher grain yield followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19. The early sown crop accumulated heat more efficiently and increased the biological activities that confirmed the higher grain yield. Dar *et al.* (2018) also reported that helio-thermal use efficiency was higher in early sowing (25th October) as compared to delayed sowing (December 10).

Photo-thermal use efficiency

The photo-thermal use efficiency (PTUE) indicates the efficiency of crop to utilize the available maximum possible bright sunshine hours. Photo-thermal use efficiency was computed for grain and biomass of wheat and presented in Table 5. Among the dates of sowing, higher

Table 5. Helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency of different wheat varieties under different sowing dates during *rabi* 2017-18 and 2018-19

Treatments	Helio-thermal use efficiency (kg/ha/°C/day hour)				Photo-thermal use efficiency (kg/ha/°C/day hour)				Heat use efficiency (kg/ha/°C/day)			
	Biomass yield		Grain yield		Biomass yield		Grain yield		Biomass yield		Grain yield	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Dates of sowing												
October 25	1.41	1.49	0.49	0.52	0.79	0.81	0.28	0.28	8.52	8.77	2.99	3.04
November 15	1.17	1.30	0.40	0.45	0.75	0.76	0.25	0.26	8.45	8.55	2.92	2.96
December 5	1.04	1.13	0.34	0.38	0.67	0.68	0.22	0.23	7.77	7.86	2.56	2.60
CD (p=0.05)	0.07	0.06	0.04	0.04	0.04	0.04	0.03	0.02	0.38	0.39	0.29	0.24
Varieties												
PBW 725	1.23	1.34	0.42	0.46	0.74	0.76	0.25	0.26	8.40	8.53	2.89	2.90
PBW 677	1.16	1.26	0.39	0.42	0.72	0.73	0.23	0.24	8.01	8.13	2.68	2.73
HD 3086	1.22	1.33	0.42	0.46	0.75	0.76	0.26	0.27	8.33	8.53	2.90	2.97
CD (p=0.05)	NS	0.06	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

photo-thermal use efficiency in timely sowing could be attributed to the highest grain yield. The highest photo-thermal use efficiency (0.79 kg/ha/°C/day hour for biomass and 0.28 kg/ha/°C/day hour for grain) was recorded in 25th October sown crop followed by 15th November (0.75 kg/ha/°C/day hour for biomass and 0.25 kg/ha/°C/day hour for grain) and 5th December sown crop (0.67 kg/ha/°C/day hour for biomass and 0.22 kg/ha/°C/day hour for grain) during *rabi* 2017-18.

The highest photo-thermal use efficiency (0.81 kg/ha/°C/day hour for biomass and 0.28 kg/ha/°C/day hour for grain) was recorded in 25th October sown crop followed by 15th November (0.76 kg/ha/°C/day hour for biomass and 0.26 kg/ha/°C/day hour for grain) and 5th December sown crop (0.68 kg/ha/°C/day hour for biomass and 0.23 kg/ha/°C/day hour for grain) during *rabi* 2018-19. Among the varieties, no significant difference in the heat use efficiency was recorded but variety HD 3086 had a higher grain yield followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19. The timely sowing of wheat crop seems to be essential for harnessing the good impact of prevailing weather conditions. The early sown crop accumulated heat more efficiently and increased the biological activities that confirmed the higher grain yield. Dar *et al.* (2018) and Bisht *et al.* (2019) also reported that photo-thermal use efficiency was higher in early sowing date (25th October) as compared to delayed sowing (10th December).

Heat use efficiency

The heat use efficiency (HUE) indicates the efficiency of crop to utilize the available heat energy. The quantification of heat use efficiency is useful for the assessment of yield potential of a crop in different environment. The heat use efficiency increases from vegetative stage to physiological maturity of the crop. Heat use efficiency was computed for grain and biomass yield of wheat and presented in Table 5. Among the dates of sowing, higher heat use efficiency in timely sowing could be attributed to the highest grain yield. As the temperature was optimum throughout the growing period, crop utilized heat more efficiently and increased biological activity that confirms higher yield. The highest heat use efficiency (8.52 kg/ha/°C/day for biomass and 2.99 kg/ha/°C/day for grain) was recorded in 25th October sown crop followed by 15th November (8.45 kg/ha/°C/day for biomass and 2.92 kg/ha/°C/day for grain) and 5th December sown crop (7.77 kg/ha/°C/day for biomass and 2.56 kg/ha/°C/day for grain) during *rabi* 2017-18.

During *rabi* 2018-19, the highest heat use efficiency (8.77 kg/ha/°C/day for biomass and 3.04 kg/ha/°C/day for grain) was recorded in 25th October sown crop followed by 15th November (8.55 kg/ha/°C/day for biomass and 2.96 kg/ha/°C/day for grain) and 5th December sown crop (7.86 kg/ha/°C/day for biomass and 2.60 kg/ha/°C/day for grain). Among the varieties, no significant difference in the heat use efficiency was recorded but variety HD 3086 had a higher grain yield followed by PBW 725 and PBW 677 during *rabi* 2017-18 and 2018-19. The heat use efficiency was higher in early sowing date i.e. 25th October due to higher yield as compared to delayed sowing. As the temperature was optimum throughout the growing period, crop utilized heat more efficiently and increased biological activity that confirms higher yield. The timely sowing of wheat crop seems to be essential for harnessing the good impact of prevailing weather conditions. Subsequently delay in sowing resulted in decrease in the heat use efficiency. Due to high temperature hampered the normal metabolic activities resulted in decrease grain yield as well as heat use efficiency in late sown crop. Dar *et al.* (2018) also reported that decrease in all the efficiencies with late sown crop from the early sowing i.e. 25th October and 10th November at Ludhiana. Jhanji and Gill (2011) also concluded that decrease in heat use efficiency in late sown crop might be due to higher temperature remained in reproductive phase caused detrimental effect on dry-matter and grain yield. Similar relationships were also expressed by Bisht *et al.* (2019) and Singh *et al.* (2018) under different dates of sowing.

Relationship between growth parameters and grain yield of wheat (rabi 2017-18 and 2018-19)

Regression analysis was conducted by fitting linear response function between grain yield and growth parameters i.e. maximum leaf area index and heat use efficiency. Grain yield invariably shows a high degree of relationship with growth components as yield is a function of expression of sum total of the effects of various growth components.

Relationship between leaf area index (LAI) and grain yield

Leaf area is an important index of plant growth, which ultimately related to the yield. Higher the LAI of the crop, healthy the crop and gives the higher yield. LAI increases with an increase in crop age and declines at maturity due to senescence of leaves. The rate of photo-synthesis depends upon the leaf area index. So the relationship between LAI and grain yield was computed.

A positive and significant relationship was observed between grain yield and leaf area index under different dates of sowing and varieties. It indicated that with an increase in leaf area index, the grain yield increased (Fig. 1). The linear regression equations between the leaf area index and grain yield under different treatments indicate that the grain yield of wheat crop increased with an increase in leaf area index during both the seasons.

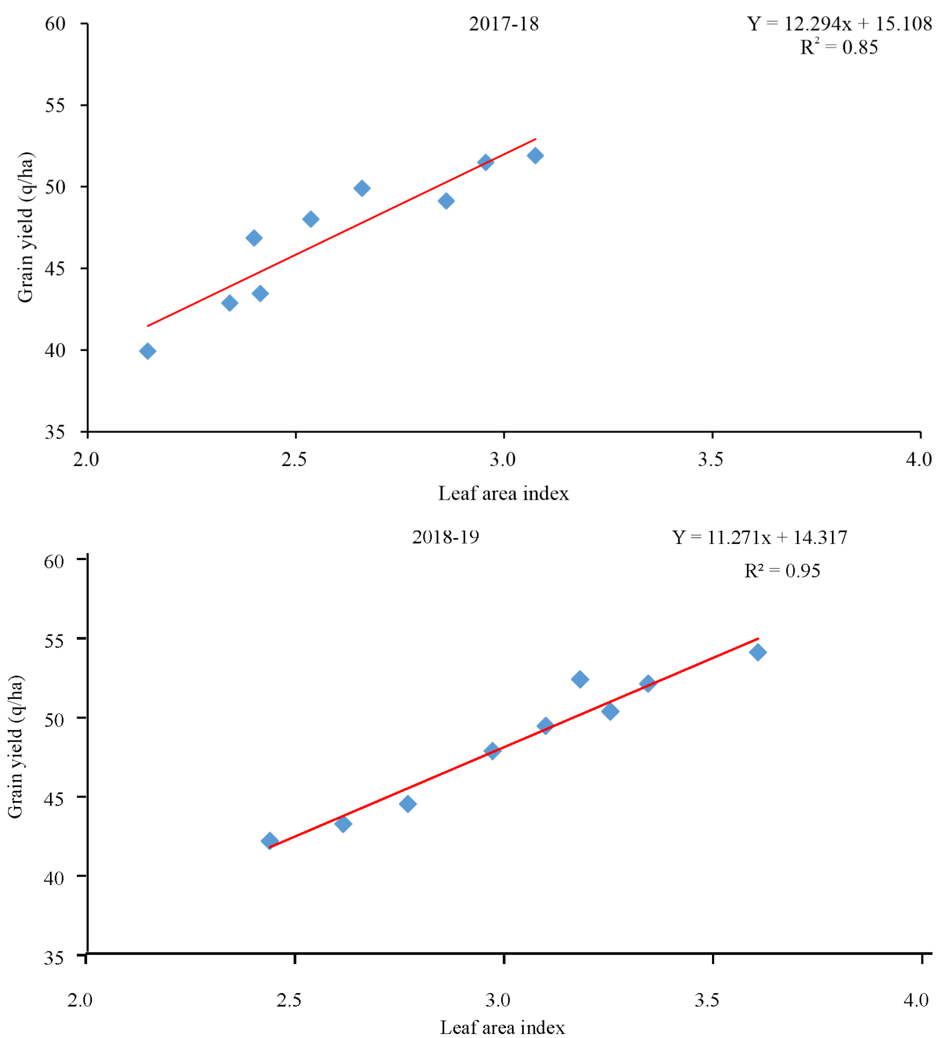

Fig. 1. Relationship between grain yield and leaf area index of wheat during *rabi* 2017-18 and 2018-19

Rabi season 2017-18

Y = 15.12 + 12.294X (R^2 = 0.85)

Rabi season 2018-19

Y = 14.32 + 11.271X (R^2 = 0.95)

Where,

Y – Grain yield (q/ha)

X- Leaf area index (LAI)

The coefficient of determination showed that leaf area index explained 85 and 95 per cent variation in the grain yield during *rabi* 2017-18 and 2018-19, respectively. The leaf area index is determined by number of tillers, number of leaves per tiller and leaf size etc. In case of late sown crop, the tiller number reduced due to the shortening of vegetative growth period. That is why higher leaf area was produced in case of 25th October sown crop and it decreased with the delay in sowing in 15th November and 5th December sown crop. Ahmed *et al.* (2016) also found a positive relationship between LAI and grain yield.

Relationship between heat use efficiency and grain yield

Heat use efficiency *i.e.*, the efficiency of utilization of heat in terms of dry matter accumulation, depends on crop type, genetic factors and sowing time. The heat use efficiency started increasing from vegetative growth up to physiological maturity of the crop. The heat use efficiency was found to be higher for early sowing and it decreased with delay in sowing. The timely sowing of wheat crop seems to be essential for harnessing the good impact of prevailing weather conditions. The relationship between heat use efficiency for grains and grain yield was calculated for *rabi* season 2017-18 and 2018-19 respectively (Fig. 2).

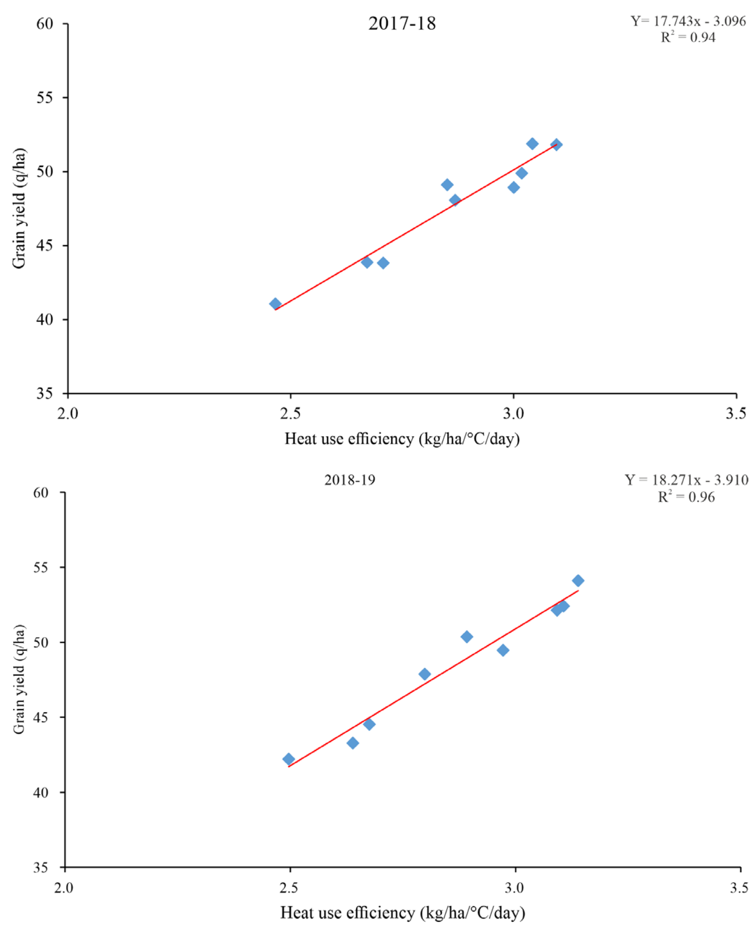

Fig. 2. Relationship between grain yield and heat use efficiency of wheat during *rabi* 2017-18 and 2018-19

A positive and significant relationship was observed between grain yield and heat use efficiency under different dates of sowing and varieties. The linear regression equations between the heat use efficiency and grain yield under different treatments indicate that the grain yield of wheat crop increased with an increase in heat use efficiency during both the seasons.

Rabi season 2017-18

$Y = 17.743X – 3.09$ ($R^2 = 0.94$)

Rabi season 2018-19

$Y = 18.271X – 3.91$ ($R^2 = 0.96$)

Where,

Y – Grain yield (q/ha)

X- Heat use efficiency (HUE)

The coefficient of determination showed that heat use efficiency explained 94 and 96 per cent variation in the grain yield during *rabi* 2017-18 and 2018-19, respectively. The timely sown wheat crop performed better in terms of accumulation and utilization of heat units and enhances the grain yield. As the temperature was favourable throughout the growing condition, it accumulated higher heat efficiently and increased physiological activities that confirmed higher grain yield. Kaur *et al.* (2017) also reported that heat use efficiency was found to be higher for early sown crop (October 30) and it decreased with delay in sowing (November 30).

Conclusion

The helio-thermal use efficiency, photo-thermal use efficiency, heat use efficiency, grain yield as well as biological yield were higher in early sowing date (25^{th} October) as compared to delayed sowing (5^{th} December). The highest helio-thermal use efficiency, photo-thermal use efficiency and heat use efficiency were recorded in 25^{th} October sowing followed by 15^{th} November and 5^{th} December sowing. The timely sown wheat crop performed better in terms of accumulation and utilization of heat units and enhances the grain yield. Positive and significant relationships of grain yield with leaf area index and heat use efficiency were observed.

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