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Thermal requirement of wheat crop in different agroclimatic regions of Punjab under climate change scenarios

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सार – इस शोध पत्र में पंजाब राज्य के दो क्षेत्रों (जैसे : मध्य समतल क्षेत्र लुधियाना और दक्षिण पश्चिमी क्षेत्र भटिण्डा) में अलग-अलग परिस्थितियों में गेहूँ की प्रजातियों के घटना विज्ञान संबंधी आचरण का अध्ययन करने के लिए प्रयोग किया गया है। वर्ष 2011-2012 में रबी के समय गेहूँ की दो किस्मों जैसे वी-I: पी बी डब्ल्यू 343 और वी-2: पी बी डब्ल्यू 621 की तीन तिथियों को बुआई की गई (जैसे डी$_1$ 15 नवम्बर, डी$_2$ 25 नवम्बर और डी$_3$ 5 दिसम्बर) और चार चरणों में जैसे : प्रथम सिंचाई आई$_1$ (सी आर आई, ज्वाइनटिंग और मिल्किंग के समय सिंचाई), आई-$_2$ (सी आर आई, टिल्रिंग, बुटिंग और मिल्कंग के समय सिंचाई), आई-$_3$ (सी आर आई, टिल्रिंग, ज्वाइनटिंग, बुटिंग और मिल्किंग के समय सिंचाई) और आई-$_4$ (मौसम पूर्वानमान के अनुसार सिंचाई) उसकी सिंचाई की गई। इसमें ग्रोइंग डिग्री डेज (GDD), सौर ताप इकाईयों (HTU), प्रकाशीय ताप इकाईयों (PTU) और प्रयुक्त तापीय दक्षता (HUE) की गणना की गई है। ऐसा पाया गया है कि मध्य क्षेत्र अर्थात् लुधियाना क्षेत्र में जिस गेहूँ की फसल की बुआई की गई है उसको पकने में अधिक दिन लगे हैं और इसमें उष्णता का अच्छी तरह उपयोग हुआ है जिसके फलस्वरूप इस क्षेत्र में अनाज की पैदावार दक्षिण पश्चिमी क्षेत्र-भटिण्डा में उगाई गई फसल से अधिक हुई है। प्राप्त परिणमों से यह भी पता चला है कि पी बी डब्ल्यू 621 की किस्म ने विभिन्न पारिस्थितिकी चरणों को आरंभ करने तथा पूरा करने में पी बी डब्ल्यू 343 की किस्म से बहुत कम समय लिया है। पी बी डब्ल्यू 621 की किस्म में ग्रोइंग डिग्री डेज, सौर तापीय इकाई तथा प्रकाशीय तापीय इकाईयां कम लगी हैं परन्तु पी बी डब्ल्यू 343 की किस्म की तुलना में उष्मा का उपयोग इसमें अधिक दक्षता के साथ हुआ है। देर से फसल की बुआई करने पर विभिन्न पारिस्थितिकी चरणों को पूरा करने में कम समय लगा है । फसल की बढ़वार विभिन्न चरणों के लिए उसके आरंभ से पकने तक के दिनों में अधिक अंतर होने से सिंचाई के स्तर विफल रहे हैं और विभिन्न घटनाओं के पूरा होने में आवश्यक उष्मा इकाईयों की कमी रही है। इससे यह निष्कर्ष निकलता है कि समय से फसल की बुआई करने से उसका विकास एवं उपज बेहतर होती है क्योंकि पंजाब के मध्य क्षेत्र में पर्यावरण की परिस्थितियां गेहूँ की फसल की विभिन्न घटनाओं के लिए आवश्यक उष्मा इकाईयां पूरा करने के अनुकूल है।

ABSTRACT. The experiment was conducted at two zones of the Punjab state (*i.e*., Central plain zone, Ludhiana and South-Western zone, Bathinda) to study the phenological behaviour of wheat cultivars under different environments. The two wheat varieties, *viz*., V_1: PBW 343 and V_2: PBW 621, were evaluated under three sowing dates (D_1: November 15, D_2: November 25 and D_3: December 5) and four irrigation levels I_1 (irrigation at CRI, Jointing and Milking), I_2 (irrigation at CRI, Tillering, Booting and Milking), I_3 (irrigation at CRI, Tillering, Jointing, Booting and Milking) and I_4 (irrigation according to weather forecast) during rabi 2011-12. The Growing Degree Days (GDD), Heliothermal units (HTU), Photo thermal units (PTU) and Heat use efficiency (HUE) were calculated. It was found that the wheat crop sown in central zone *i.e*., Ludhiana station acquired more number of days to reach physiological maturity and utilize heat more efficiently resulting in more grain yield as compared to south western zone *i.e*., Bathinda station grown wheat crop. The results also showed that the variety PBW 621 took significantly less time for initiation and completion of the various phenological stages than PBW 343. PBW 621 acquired less growing degree days, heliothermal units and photothermal units but was more efficient user of heat as compared to the variety PBW 343. The number of days required to attain different phenological stages decreased with late sowing condition. Irrigation levels failed to produce significant difference for days required for initiation and completion of various growth stages of crop as well as heat unit requirements for occurrence of the phenological events. It is concluded that timely sown crop exhibit best growth and yield as the favourable environmental conditions coincided with heat unit requirement of different phenophases of wheat in the central zone of Punjab.

Key words – Wheat, Agroclimatic zones, Phenology, Agroclimatic indices, Heat use efficiency (HUE).

1. Introduction

Wheat is a thermo-sensitive long-day crop. Temperature is a major determinant of its growth and productivity. Late sowing of wheat in rice-wheat system exposes pre-anthesis phenological events to high temperature that influence grain development and ultimately the yield (Nagarajan *et al.*, 2008). 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. Physiological and morphological development in plant is influenced by various meteorological factors such as temperature is an important environmental factor influencing the growth, development and yield of crops. During growth and development of a cereal crop several growth stages are distinguishable in which important physiological processes occur (Sikder, 2008).

Plants have a definite temperature requirement before they attain certain phenological stages. Several research findings noticed that temperature below (<10 °C) or above (>25 °C) the optimum (12-25 °C) alter phenology, growth and development and finally reduce the yield of wheat varieties (Hakim *et al.*, 2012). Influence of temperature on phenology and yield of crop plants can be studied under field condition through accumulated heat units system (Bishnoi *et al.*, 1995). Temperature stress intensity is severe under late sowing, causing reduction in the duration of later growth phases resulted in acquisition of less days to mature.

Air temperature based agromet indices, *viz.*, growing degree days (GDD), photothermal units (PTU), heliothermal units (HTU), phenothermal index (PTI) have been used to describe changes in phenological behaviour and growth parameters (Kumar *et al.*, 2010). The values of accumulated GDD, HTU and PTU for each phenophase are relatively constant and independent of sowing date but vary in a crop from variety to variety (Phadnawis and Saini, 1992). Agronomic application of temperature effect on plant is the concept of heat unit or growing degree days and heat stress in wheat can be mitigated in two ways: heat management or the development of heat-tolerant cultivars. Evaluation of high yielding, stable genotypes having good quality are considered pre-requisite for increasing crop production in any region. So there is a need to broader genetic base and to replace old varieties with new and improved ones (Jat *et al.*, 2003). Recommendation of several varieties will also help farmers to select best one and also adequate supply of improved varieties to farmers. Especially in wheat choice of varieties depends on the time of higher, unfavourable air temperature, where difference in crop agronomy lead to difference in sowing dates, longer duration varieties for earlier sowing and shorter duration varieties for late sowing are recommended. So this experiment was conducted to study the effect of hydrothermal regimes on the phenology, heat unit requirement and heat use efficiency of wheat cultivars at different locations of the state.

2. Data methodology

A factorial experiment was laid under split-split plot design at the Research Farm of School of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana and Research Station, Bathinda during the winter season of 2011-12. The treatments included three sowing dates in main-plots (D_1: November 15, D_2 : November 25 and D_3: December 5), four irrigation levels in sub-plots I_1 (irrigation at CRI, Jointing and Milking), I_2 (irrigation at CRI, Tillering, Booting and Milking), I_3 (irrigation at CRI, Tillering, Jointing, Booting and Milking) and I_4 (irrigation according to weather forecast) and two wheat varieties in sub-sub plots (V_1: PBW 343 and V_2: PBW 621). The phenological stages of crop were recorded by visual observations. Growing degree days were calculated by simple arithmetic accumulation of daily mean temperature above the base temperature value of 5 °C considered for the wheat crop. The different indices for each stage were calculated as suggested by (Nuttonson, 1955).

$$\text{Growing degree days}\left(°\text{C days}\right) = \frac{(T_{\max} + T_{\max})}{2} - T_b$$

where,

$T_{\max}$ = Daily maximum temperature (°C)

$T_{\min}$ = Daily minimum temperature (°C)

T_b = Base temperature (5°C)

The heliothermal units (HTU) for a day represent the product of GDD and the bright sunshine hours for that day. The accumulated HTU for a particular phenophase was determined by using the following formula:

$$\begin{array}{c}\text{Accumulated}\\ \text{HTU (°C day hr)}\end{array} = \sum_{i=1}^{n} \text{GDD} \times \text{Bright sunshine hours}$$

The photothermal units (PTU) for a day represent the product of GDD and the day length for that day. The

TABLE 1

Crop phenology, AGDD, APTU and AHTU for crop sown on 15 November in Ludhiana and Bathinda

Phenology	Phenology (DAS)				AGDD (ºC day)				APTU (ºC day hr)				APTI (ºC day)				(ºC day hr)	
	PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343	PBW 621
	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	LDH
Sowing	0	0	0	0	15.1	15.7	15.1	15.7	160.1	168.9	160.1	168.9	-	-	-	-	68.6	68.6
Emergence	4	5	4	5	75.1	95.0	75.1	95.0	792.1	1000.4	792.1	1000.4	15.0	15.9	15.0	15.9	437.3	437.3
Emergence complete	12	8	12	8	188.7	137.8	188.7	137.8	1976.6	1440.1	1976.6	1440.1	14.2	14.3	14.2	14.3	529.8	529.8
CRI	20	19	20	19	288.9	279.7	288.9	279.7	3007.9	2888.2	3007.9	2888.2	12.5	12.9	12.5	12.9	1256.3	1256.3
Tillering	31	28	31	28	405.1	377.0	405.1	377.0	4191.8	3875.5	4191.8	3875.5	10.6	10.8	10.6	10.8	1975.8	1975.8
Jointing	79	71	79	71	714.2	633.3	714.2	633.3	7384.5	6498.6	7384.5	6498.6	6.4	6.0	6.4	6.0	3769.3	3769.3
Flag leaf	96	86	93	84	840.8	731.1	818.3	721.1	8775.7	7563.3	8524.0	7453.3	7.4	6.5	7.4	6.8	4469.5	4316.7
Booting	103	93	100	91	907.2	785.6	883.2	773.4	9527.8	8166.1	9254.2	8030.5	9.5	7.8	9.3	7.5	4927.2	4695.0
Heading	110	101	108	99	986.9	861.9	959.1	846.0	10448.0	9020.0	10125.5	8841.1	11.4	9.5	9.5	9.1	5578.2	5428.1
Anthesis	119	108	117	106	1101.9	951.1	1073.1	921.8	11801.3	9933.9	11459.6	9657.4	12.8	12.7	12.7	10.8	6507.2	6228.3
Milking	129	114	126	112	1246.4	1021.5	1209.8	1003.4	13545.7	10632.6	13100.1	10448.6	14.5	11.7	15.2	13.6	7505.1	7217.7
Physiological maturity	142	129	140	127	1497.8	1239.0	1454.6	1205.9	16673.5	13107.3	16129.2	12699.9	19.3	14.5	17.5	13.5	9552.7	9075.4

AGDD : Accumulated growing degree days, APTU : Accumulated photothermal units, APTI : Accumulated phenothermal index, AHTU : Accumulated heloithermal units; LDH : Ludhiana, BTH: Bathinda

accumulated PTU for a particular phenophase was determined by using the following formula:

$$\text{Accumulated PTU (°C day hr)} = \sum_{i=1}^{n} \text{GDD} \times \text{Day length}$$

Phenothermal index (PTI): It is the ratio of degree days to the number of days between two phenological stages, and was calculated as:

$$\text{PTI} = \frac{\text{GDD between two phenological stages}}{\text{number of days taken between two phenophases}}$$

The heat use efficiency was calculated using the following formula:

$$\text{Heat Use Efficiency (kg/ha/°C day)} = \frac{\text{Grain or dry matter yield (kg/ha)}}{\text{AGDD (°C day)}}$$

Where,

AGDD =Accumulated growing degree days (°C day)

3. Results and discussion

3.1. *Crop phenology*

The crop sown in central zone Ludhiana took 4 to 6 days to emerge under three sowing dates (November 15, November 25 and December 5) whereas the number of days taken for emergence were 5 - 8 days in crop sown in the south western zone Bathinda under the same sowing dates (Tables 1-3). The number of days taken by crop for the complete emergence were more on Ludhiana (8 - 9 days) as compared to Bathinda (3 - 4 days) under the three sowing dates. The November 15 sown crop acquired more days for reaching the physiological maturity (PBW 343 took 142 days at Ludhiana and 129 days in Bathinda whereas PBW 621 took 140 days in Ludhiana and 127 days in Bathinda) as compared to the other sowing dates. Late sown crop (December 5) required greater number of days for initiation and completion of CRI, tillering, lesser days for initiation and completion of jointing, boot, milk and harvest stages as compared to early sown crop [Tables (1, 2&3)]. Such behaviour of late sown wheat might be due to fall in temperature during vegetative phase and abrupt rise in temperature during reproductive phases. Our results corroborate with results of Ghosh *et al.* (2000)

TABLE 2

Crop phenology, AGDD, APTU and AHTU for crop sown on 25 November in Ludhiana and Bathinda

Phenology	Phenology (DAS)				AGDD (°C day)				APTU (°C day hr)				APTI (°C/day)				AHTU (°C day hr)	
	PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343	PBW 621
	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	LDH
Sowing	0	0	0	0	14	11.9	14	11.9	145.6	121.7	145.6	121.7	-	-	-	-	0.0	0.0
Emergence	6	7	6	7	86.0	102.7	86.0	102.7	890.2	1047.6	890.2	1047.6	12.0	13.0	12.0	13.0	273.0	273.0
Emergence complete	14	10	14	10	195.8	147.5	195.8	147.5	2014.2	1502.9	2014.2	1502.9	13.7	14.9	13.7	14.9	1001.5	1001.5
CRI	20	20	20	20	248.4	234.7	248.4	234.7	2549.1	2386.8	2549.1	2386.8	8.8	8.7	8.8	8.7	1396.4	1396.4
Tillering	34	30	34	30	341.2	292.9	341.2	292.9	4062.1	2975.7	4062.1	2975.7	6.6	5.8	6.6	5.8	1975.6	1975.6
Jointing	78	68	78	68	625.1	532.5	625.1	532.5	6471.4	5474.7	6471.4	5474.7	6.5	6.3	6.5	6.3	3528.0	3528.0
Flag leaf	93	83	91	82	757.2	632.1	741.9	623.2	7953.0	6573.1	7778.3	6473.9	8.8	6.6	9.0	6.5	4397.5	4235.7
Booting	97	89	95	88	798.5	691.3	779.0	683.6	8428.3	7235.5	8203.4	7149.0	10.3	9.9	9.3	10.1	4788.1	4600.0
Heading	107	97	105	94	923.1	788.7	901.8	748.0	9884.8	8153.8	9632.5	7838.2	12.5	12.2	12.3	10.7	5698.5	5484.0
Anthesis	112	102	111	100	988.6	850.4	974.9	830.2	10665.8	8663.4	10501.4	8492.6	13.1	12.3	12.2	13.7	6273.1	6208.7
Milking	122	105	119	103	1148.4	882.6	1096.4	859.1	12609.6	8944.2	11970.9	8738.1	16.0	10.7	15.2	9.6	7328.2	6975.3
Physiological maturity	135	123	133	120	1410.8	1171.8	1368.1	1115.9	15896.8	11938.9	15355.2	11294.3	20.2	16.1	19.4	15.1	9650.9	9226.0

AGDD : Accumulated growing degree days, APTU : Accumulated photothermal units, APTI : Accumulated phenothermal index, AHTU : Accumulated heloithermal units; LDH : Ludhiana, BTH : Bathinda

and Singh *et al.* (2001). Irrigation levels had no influence on days required for initiation and completion of various phenological phases. The variety PBW 621 took lesser days for initiation as well as completion of CRI, tillering, boot, ear emergence, milk and maturity stages in the crop as compared to the varieties PBW 343 at both Ludhiana and Bathinda. This is obvious because of genetic behaviour of each variety of a crop had specific requirement of heat units for initiation and completion of its phonological stages under particular environmental conditions.

3.2. *Agroclimatic indices*

3.2.1. *Growing degree days*

The accumulated growing degree days (AGDD) taken from the date of sowing to maturity are given for different dates and varieties [Tables (1,2 and 3)]. Different phenological stages of both the cultivars required different heat units, with the lowest GDD requirement for CRI followed by an increasing trend for other stages till maturity under all dates of sowing. The highest requirement of GDD was observed at maturity for both the cultivars. GDD requirement was maximum in November 15 sowing among the sowing dates and decreased with delay in sowing followed by November 25 and December 5. The variety PBW 343 recorded more heat units as compared to variety PBW 621. The accumulated GDD units taken by PBW 343 to mature under sowing dates November 15, November 25 and December 5 were 1497.8, 1410.8 and 1329.7 in Ludhiana and 1239.0, 1179.8 and 1164.2 in Bathinda, respectively while variety PBW 621 accumulated 1454.6, 1368.1 and 1285.1 GDD units in Ludhiana and 1205.9, 1115.9 and 1096.6 in Bathinda to mature under the consequent three sowing dates of sowing, *viz*., November 15, November 25 and December 5. The requirement of heat unit was higher for timely sown crop than late sown crop due to longer period for all the phenological stages in the timely sown crop. The late sowing decreased the duration of phenophases which caused a decrease in agroclimatic indices during various phenophases and forced the crop to attain early maturity. This decline in agroclimatic indices accumulation was due to prevailing low temperature Figs. (1-2) during vegetative phases and high temperature during reproductive phases of development in late-sown crop. Our results were similar to those of (Khichar and Niwas, 2007). The cultivar PBW 343 accumulated higher value of agroclimatic indices than PBW 621 for their

TABLE 3

Crop phenology, AGDD, APTU and AHTU for crop sown on 5 December in Ludhiana and Bathinda

Phenology	Phenology (DAS)				AGDD (°C day)				APTU (°C day hr)				APTI (°C/day)				AHTU (°C day hr)	
	PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343		PBW 621		PBW 343	PBW 621
	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	BTH	LDH	LDH
Sowing	0	0	0	0	13.2	15.2	13.2	15.2	186.1	154.4	186.1	154.4	-	-	-	-	114.8	68.6
Emergence	6	8	6	8	91.5	97.3	91.5	97.3	934.3	987.2	934.3	987.2	13.1	10.3	13.1	10.3	540.3	540.3
Emergence complete	15	12	15	12	157.1	124.2	157.1	124.2	2201.1	1259.5	2201.1	1259.5	7.3	6.7	7.3	6.7	1010.7	453.1
CRI	21	21	21	21	192.5	175.6	192.5	175.6	1958.5	1779.6	1958.5	1779.6	5.9	5.7	5.9	5.7	1239.6	1239.6
Tillering	36	31	36	31	293.4	243.3	293.4	243.3	4062.1	2467.1	4062.1	2467.1	6.7	6.8	6.7	6.8	1689.7	1689.7
Jointing	76	65	76	65	565.1	447.7	565.1	447.7	7536.9	4634.3	7536.9	4634.3	6.8	6.0	6.8	6.0	3328.1	2944.5
Flag leaf	92	80	90	77	742.3	574.0	711.2	547.8	9634.6	6039.4	9271.8	5745.4	11.1	8.4	10.4	8.3	4567.3	3328.1
Booting	95	86	93	83	776.1	642.1	754.0	605.2	8334.7	6699.5	8075.3	6408.9	11.3	11.4	14.3	9.6	4872.4	4680.8
Heading	104	93	102	90	896.3	733.1	862.9	701.1	11466.6	7331.3	11064.4	7100.1	13.4	13.0	12.1	13.7	5950.2	4772.5
Anthesis	108	98	106	94	956.7	789.2	934.1	741.8	12198.7	7761.5	11923.9	7395.9	15.1	11.2	17.8	10.2	6241.9	5661.4
Milking	113	102	111	100	1039.1	851.7	1003.1	817.0	13209.8	8279.3	12766.5	7986.7	16.5	15.6	13.8	12.5	6716.5	6076.3
Physiological maturity	127	119	125	116	1350.0	1164.2	1308.5	1096.6	16864.0	11550.5	16295.4	10716.7	22.2	18.4	21.8	17.5	9270.6	6637.9

AGDD : Accumulated growing degree days, APTU : Accumulated photothermal units, APTI : Accumulated phenothermal index, AHTU : Accumulated heloithermal units; LDH : Ludhiana, BTH : Bathinda

longer phenological stages. Paul and Sarker (2000) also reported that the requirement of heat units decreased for different phenological stages with delay in sowing.

3.2.2. *Heliothermal units*

The accumulated heloithermal units (HTU) taken from the date of sowing to maturity are given for different dates and varieties for Ludhiana station only because sunshine data was not available for Bathinda station [Tables (1, 2 and 3)]. Different phenological stages of both the cultivars required different heliothermal units, with the lowest HTU requirement for CRI followed by an increasing trend for other stages till maturity under all dates of sowing. The highest requirement of HTU was observed at maturity for both the cultivars.

HTU requirement was maximum in November 15 sowing among the sowing dates and decreased with delay in sowing followed by November 25 and December 5. The variety PBW 343 recorded more heat units as compared to variety PBW 621. The HTU accumulated by the variety PBW 343 from sowing till maturity at Ludhiana station remained 9552.71, 9650.94 and 9270.59 and for variety PBW 621 9075.39, 9225.93 and 9039.31 HTU units were recorded for November 15, November 25 and December 5 respectively.

3.2.3. *Photothermal units*

The accumulated photothermal units (PTU) taken from the date of sowing to maturity have been given for different dates and varieties [Tables (1-3)]. Different phenological stages of both the cultivars required different heat units, with the lowest PTU requirement for CRI followed by an increasing trend for other stages till maturity under all dates of sowing. The highest requirement of PTU was observed at maturity for both the cultivars. Accumulated PTU were maximum in November 15 sowing among the sowing dates and decreased with delay in sowing followed by November 25 and December 5. The variety PBW 343 recorded more heat units as compared to variety PBW 621. The accumulated PTU by the variety PBW 343 under November 15, November 25 and December 5 sowings were higher, *i.e.*, 16673.49, 15896.75 and 15167.6 in Ludhiana and 13107.3, 11938.9

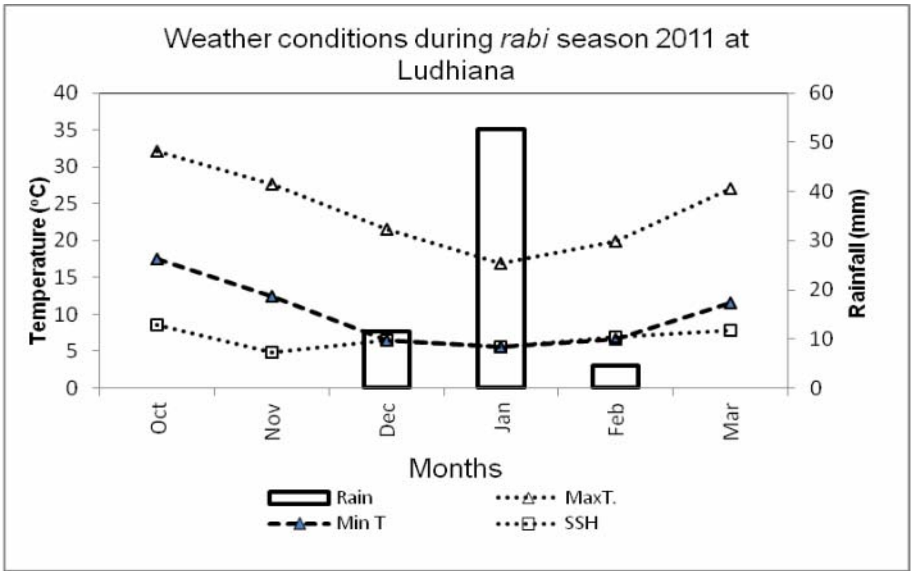

Fig. 1. Temperature, sunshine hours and rainfall conditions at Ludhiana during 2011-12

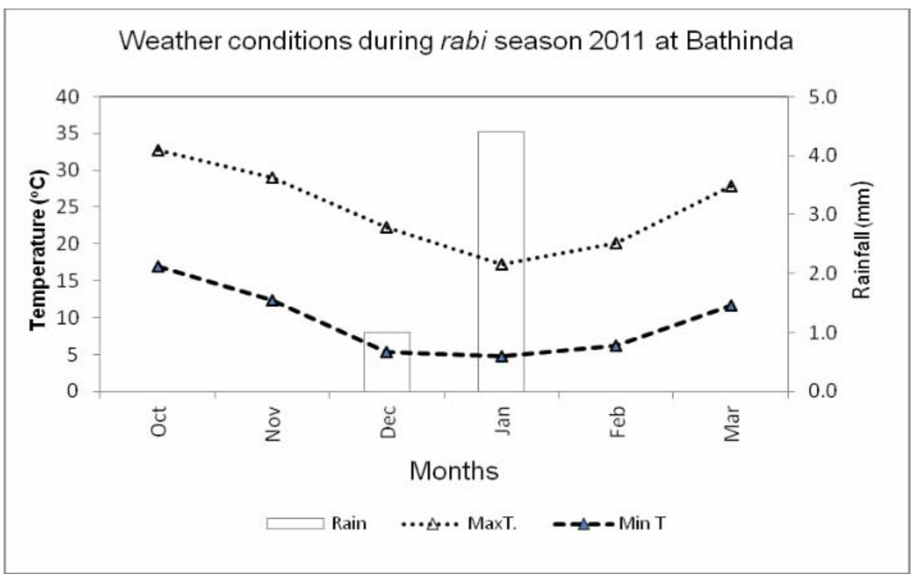

Fig. 2 Temperature and rainfall conditions at Bathinda during 2011-12

and 11550.5 in Bathinda respectively. Whereas, variety PBW 621 accumulated 16129.16, 15355.17 and 14598.9 photothermal units in Ludhiana and 12699.9, 11294.3 and 10716.7 in Bathinda under three different sowing dates.

3.2.4. *Phenothermal index*

Phenothermal index (PTI) from sowing till maturity was influenced by the combination of growing conditions and cultivars [Tables (1-3)]. Both the cultivars had higher PTI up to tillering. Late sown crop showed higher PTI compared to timely sown crop. Under three sowing dates (November 15, November 25 and December 5), the cultivar PBW 343 had the highest PTI (19.3, 20.2 and 22.2 in Ludhiana whereas 14.5, 16.1 and 18.4 in Bathinda) at grain filling to maturity as compared to cultivar PBW 621 (17.5, 19.4 and 21.8 in Ludhiana whereas 13.5, 15.1 and 17.5 in Bathinda). There was variation in PTI upto tillering stage in both the cultivars under November 15,

TABLE 4

Heat use efficiency of wheat crop under different treatments for Ludhiana and Bathinda in 2011-12

Treatment	Heat Use Efficiency (kg/ha/°C day)			
	Grain		Biomass	
	LDH	BTH	LDH	BTH
Sowing time				
November 15	2.28	2.19	8.24	8.15
November 25	2.17	2.16	7.88	7.70
December 5	2.13	1.82	7.30	6.95
CD (p = 0.05)	NS	0.27	0.52	0.52
Irrigation levels				
CRI + Jointing + Milk	2.00	1.80	7.10	6.87
CRI + Tillering + Boot + Milk	2.17	1.96	7.52	7.50
CRI + Tillering + Jointing + Boot + Milk	2.32	2.23	8.63	8.07
According to weather forecast	2.28	2.22	7.97	7.97
CD (p = 0.05)	0.16	0.31	0.60	0.61
Varieties				
PBW 343	2.13	2.00	7.23	7.23
PBW 621	2.26	2.11	8.38	7.98
CD (p = 0.05)	0.77	0.11	0.29	0.32

November 25 and December 5. But thereafter, late-sown crop showed PTI compared to timely-sown crop. There was less variation in PTI between the two cultivars. The duration of different phenophases of vegetative growth was lower in late sown crop as compared to timely sown crop and then growth duration increased with plant age.

3.3. *Heat use efficiency*

The heat use efficiency of the wheat under different treatments for both the years has been given in Table 4. The crop sown on November 15 has shown higher heat use efficiency (HUE). HUE decreased with the delay in sowing. The effect of sowing dates on heat use efficiency was not significant at Ludhiana. However, heat use efficiency at Bathinda was significantly different among dates of sowing. In Bathinda, highest heat use efficiency was obtained in November 15 sowing, which was statistically at par with November 25 but significantly higher than December 5. Pragyan Kumari *et al.* (2009) also reported that timely sown wheat crop exhibited maximum heat use efficiency. Similar results were reported by Paul & Sarker (2000) and Haque (2000). The normal growing plants produced higher grain yield by using accumulated heat units efficiently. As the temperature was favourable throughout normal growing condition, it has utilized more heat efficiently and increased physiological activities that results in higher grain yield. Under the irrigation treatments, the irrigation treatment with five levels of irrigation exhibited maximum heat use efficiency as compared to the other irrigation treatments with three irrigation, four irrigations and irrigation according to weather forecast and it was at par with the second and fourth irrigation treatment in both Ludhiana and Bathinda for both grain and biomass. Among the varieties, PBW 621 exhibited significantly higher heat use efficiency as compared to PBW 343 for grain and biomass under Ludhiana and Bathinda. Similar results were reported by Paul and Sarker (2000).

4. Conclusion

The variety PBW 343 had longer phenophases, more GDD, PTU and HTU requirement for different phenol phases than PBW 621 irrespective of sowing time. Whereas, PBW 621 had high HUE and produced higher yield at both the locations. There was decline in yield of both the cultivars when sown under late sown conditions. The timely sown wheat crop performed better in terms of accumulation and utilization of heat units at central zone as compared to south-western zone of the state as indicated by the meteorological condition attained during the crop season at both the location Figs. (1&2).

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