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Research Paper

Probability of occurrence of high temperature events during reproductive phase of wheat in Punjab

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ABSTRACT

A study was conducted with an objective to analyze how often high temperature events occur during the reproductive phases of wheat (January-March) in Punjab. Historical temperature data was analyzed to understand the probability of occurrence of temperature higher than the mean and its different combinations (mean+0.5SD, mean+1.0SD, mean+1.5SD and mean+2SD) during different standard meteorological weeks (SMW). It was found that at Ludhiana (central Punjab) the highest probability of maximum temperature (Tmax) and minimum temperature (Tmin) being higher than range was 16.9% and 18.8% during 9th and 4th SMW, respectively. At Ballowal Saunkhri (northeastern Punjab) the maximum probability of occurrence of Tmax higher than range was 16.4% during 6th and 12th SMW, respectively and that for Tmin higher than range was 20% during 9th SMW. At Bathinda (southwestern Punjab) the highest probability of occurrence of Tmax and Tmin above range was 19.7% and 19.4% during 13th and 11th SMW, respectively. In northeastern and southwestern regions of Punjab the probability of having Tmax and Tmin above range was maximum during 12-13th and 9th-11th SMW, respectively, while in central region it was maximum during 9th and 4th SMW, respectively. This implies that wheat crop should be managed adequately during these periods to avoid damage due to heat stress.

Key words: Heat stress, Climate change, Wheat reproductive phase, Maximum temperature, Minimum temperature

Wheat holds a predominant position, serving as a primary source of human food and livestock feed. Wheat is a rabi season crop grown in the Indo-Gangetic plains of India, particularly in the state of Punjab. Despite occupying merely 1.54% of India's total land area, Punjab makes a substantial contribution of wheat (43%) to the national food grain pool (Anonymous, 2015). Wheat is susceptible to high temperature (Slafer and Satorre, 1999) and it experiences varying levels of heat stress during different growth stages, but heat stress during reproductive stage is very harmful for it. Heat stress during reproductive stage directly affects the number of grains and their weight, thereby affecting its yield negatively (Wollenweber *et al*., 2003). Regional climate model PRECIS (Providing Regional Climates for Impact Studies), forecasted an expansion of temperature ranges in Punjab, in the coming decades. A variation in maximum and minimum temperatures from normal profoundly affect agriculture sector. The incidence of extreme temperature events in recent times is noticeable and predicted to undergo severe, frequent and long-lasting changes than witnessed in the recent past (IPCC, 2007). It is anticipated that increase in extreme events like heat waves from March to June, and severe cold spells from December to January months in the state will pose significant challenges to wheat productivity (Kaur and Kaur, 2016).

As climate change continues to affect temperature patterns, therefore, it is essential to understand it. The present study examined the temperature data from different regions within Punjab state in order to understand the chances of occurrence of high temperature. The information about high temperature events during reproductive period of wheat will be important in designing strategies, such as optimizing planting dates, use of chemicals, etc. to mitigate the impact of heat stress. This information can assist farmers and policymakers in developing adaptative strategies to reduce the harmful effects of high temperature on wheat production in Punjab. Therefore, a study was conducted with an objective to analyze how often high temperature events occur during the reproductive phases of wheat in Punjab.

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MATERIALS AND METHODS

A study was conducted in Punjab, India and the analysis focused on the reproductive phase of wheat (January to March), a period highly sensitive to temperature fluctuations. The study sites were Ludhiana (30.9009°N, 75.8572°E) representing central Punjab, Ballowal Saunkhri (31.1567°N, 76.3834°E) representing northeastern Punjab and Bathinda (30.2111°N, 74.9454°E) representing the southwestern Punjab. The meteorological data was recorded at the respective observatories. This study analysed standard meteorological week (SMW) wise historical maximum (Tmax) and minimum (Tmin) temperature data of Ballowal Saunkhri (1985-2023), Ludhiana (1970-2023) and Bathinda (1977-2023).

The weekly means, standard deviations (SD) and upper limit of statistical ranges and probability of occurrence of temperature higher than statistical ranges of mean+0.5 SD, mean+1.0 SD, mean+1.5 SD and mean+2.0 SD were worked out for Ludhiana, Ballowal Saunkhri and Bathinda, to find the likelihood of temperatures exceeding mean. The mean and standard deviation were calculated by taking average of all the values that fall in one SMW across the years (1985-2023, 1970-2023 and 1977-2023 for Ballowal Sankhri, Ludhiana and Bathinda, respectively) and SD was calculated using the formula:

$$SD = \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

Where: x_i: Daily temperature; μ: Weekly mean temperature; N: Number of observations

After calculating the upper limit of statistical ranges, the frequency (number of days) of daily temperatures falling above these ranges was calculated by determining the number of days exceeding these values over the study period. From these frequency values, the probability of occurrence of temperature exceeding the range during different SMW was calculated by using the following formula:

$$Probability(\%) = \frac{\text{Number of days with temperature higher than range}}{\text{Total number of days}} \text{ X } 100$$

RESULTS AND DISCUSSION

Probability of occurrence of higher temperature at Ludhiana

Maximum temperature (Tmax): The probability of occurrence of Tmax higher than mean+0.5 SD, mean+1.0 SD, mean+1.5 SD and mean+2.0 SD at Ludhiana is represented in the Table 1. The results revealed that the chances of occurrence of Tmax higher than mean+0.5 SD was maximum during 1st SMW with 35.7% probability followed by 2nd SMW with 34.7% probability. Similarly, chances of occurrence of Tmax higher than mean+1.0 SD was maximum during 9th SMW with 16.9% probability followed by 11th, 12th and 13th SMW with probability of 16.1% each. The chances of occurrence of Tmax higher than Mean+1.5 SD was maximum during 13th SMW with 7.7% probability. The chances of occurrence of Tmax higher than mean+2.0 SD was maximum during 6th SMW that is between 5th and 11th February with 2.7% probability. The results revealed that the months of February and March experienced maximum probability of occurrence of Tmax higher than range. Previous studies (Dhaliwal *et al*., 2022; Prabhjyot-Kaur *et al*., 2015) also identified February and March as critical months experiencing higher temperatures, their findings were primarily based on observation of general trends.

Minimum temperature (Tmin): The maximum probability of occurrence of Tmin higher than mean+0.5 SD was during 10th SMW and 12th SMW with each having 32.8% probability (Table 1). Similarly maximum chances of occurrence of Tmin higher than mean+1.0 SD was during 4th SMW with 18.8% probability followed by 7th SMW with a probability of 18.2%. The maximum chances of occurrence of Tmin higher than Mean+1.5 SD was during 4th SMW with 10.3% probability. The maximum chances of occurrence of Tmin higher than mean+2.0 SD was during 6th SMW that is between 5th and 11th February with 4.8% probability. The results indicated that the probability of occurrence of both Tmax and Tmin above mean+2.0SD (most severe case of heat stress) was during the 6th SMW and this period is very critical as it coincides with ear emergence, anthesis and grain development stages of wheat.

Probability of occurrence of higher temperature at Ballowal Saunkhri

Maximum temperature (Tmax): The chances of occurrence of Tmax higher than mean+0.5 SD, mean+1.0 SD, mean+1.5 SD and mean+2.0 SD at Ballowal Saunkhri (north eastern region of Punjab) is represented in Table 2. The results revealed that the probability of occurrence of Tmax higher than mean+0.5 SD was maximum during 2nd SMW with 37.5% probability followed by 1st SMW with 37.1% probability. Similarly, chances of occurrence of Tmax higher than mean+1.0 SD was maximum during 6th and 12th SMW with 16.4% probability for both, followed by 1st, 9th and 13th SMW with a probability of 15.7% for each. The maximum chances of occurrence of Tmax higher than mean+1.5 SD was during 5th SMW with 5.7% probability. The maximum chances of occurrence of Tmax higher than mean+2.0 SD was during 4th SMW with 2.5% probability. Kaur and Kaur (2016), also revealed in their study that in the future (mid to late 21st century) there will be hotter temperatures in the spring (March-June) and cooler temperatures in winter (December-January) which will result in more frequent heat waves and frost events that can damage the crops.

Minimum temperature (Tmin): The chances of occurrence of Tmin higher than mean+0.5 SD was maximum during 7th SMW with a probability of 32.1% (Table 2). Similarly maximum chances of occurrence of Tmin higher than mean+1.0 SD was during 9th SMW with 20% probability followed by 1st SMW with a probability of 18.9%. The chances of occurrence of Tmin higher than mean+1.5 SD was maximum during 6th SMW with a probability of 10%. The maximum chances of occurrence of Tmin higher than Mean+2.0 SD was during 4th SMW with 4.3% probability. This period is very critical to wheat as Rao *et al*., (2015) had revealed that high minimum temperature during month of February (post anthesis period) had a greater impact on wheat production.

Table 1: Mean, standard deviation (SD), upper limit of statistical range and probability at Ludhiana

SMW	Temperature (°C)		Mean+0.5 SD		Mean+1.0 SD		Mean+1.5 SD		Mean+2.0 SD	
	Mean	SD	Temp. (°C)	Probability (%)	Temp. (°C)	Probability (%)	Temp. (°C)	Probability (%)	Temp. (°C)	Probability (%)
Maximum temperature (Tmax)										
1st	17.5	18.1	19.1	35.7	20.8	15.1	22.4	5.0	24.0	0.5
2nd	17.7	18.2	19.2	34.7	20.7	13.2	22.2	3.4	23.6	0.3
3rd	17.6	17.6	19.0	32.0	20.4	14.0	21.7	5.0	23.1	0.5
4th	18.5	18.7	19.8	30.7	21.2	13.5	22.6	4.2	23.9	2.1
5th	19.4	19.8	20.6	28.3	21.8	14.0	23.1	5.8	24.3	2.1
6th	20.3	20.0	21.6	32.0	22.9	14.0	24.2	5.8	25.5	2.7
7th	21.5	20.9	22.9	33.6	24.4	15.6	25.8	6.4	27.3	2.1
8th	22.5	22.1	24.1	29.4	25.6	13.5	27.2	6.9	28.8	2.1
9th	23.4	23.1	25.0	32.8	26.5	16.9	28.1	6.6	29.7	1.9
10th	25.1	25.1	26.6	34.1	28.1	12.4	29.6	4.2	31.0	1.3
11th	26.4	26.5	28.1	32.3	29.7	16.1	31.4	6.6	33.0	1.3
12th	28.1	28.3	29.7	31.8	31.3	16.1	33.0	6.6	34.6	1.9
13th	30.1	29.8	31.7	32.8	33.3	16.1	34.9	7.7	36.5	1.3
Minimum temperature (Tmin)										
1st	5.7	5.4	7.1	29.9	8.6	16.1	10.0	7.7	11.5	3.7
2nd	5.6	5.2	7.0	32.0	8.3	17.2	9.7	8.7	11.1	2.9
3rd	5.9	5.5	7.3	29.4	8.8	17.5	10.2	9.5	11.6	3.4
4th	6.0	5.1	7.6	28.6	9.1	18.8	10.6	10.3	12.2	3.7
5th	6.4	5.6	7.8	29.4	9.2	17.7	10.6	7.1	12.0	3.2
6th	6.9	6.2	8.6	27.5	10.2	15.1	11.9	10.0	13.5	4.8
7th	8.3	7.2	9.9	30.4	11.4	18.2	12.9	8.2	14.5	2.1
8th	9.0	8.0	10.6	29.6	12.1	15.9	13.7	7.9	15.3	2.9
9th	9.7	8.3	11.1	32.0	12.5	17.7	14.0	7.4	15.4	1.6
10th	10.9	10.2	12.4	32.8	13.9	16.9	15.4	7.9	16.9	2.9
11th	11.9	11.6	13.5	31.7	15.1	16.9	16.7	6.6	18.3	1.3
12th	13.3	12.9	14.7	32.8	16.2	16.9	17.7	6.1	19.1	2.1
13th	14.6	14.4	16.0	29.9	17.4	16.1	18.7	6.3	20.1	1.6

Probability of occurrence of higher temperature at Bathinda

Maximum temperature (Tmax): The probability of occurrence of Tmax higher than mean+0.5 SD, mean+1.0 SD, mean+1.5 SD and mean+2.0 SD at Bathinda (in south western region of Punjab) are represented in Table 3. The findings highlights that the chances of occurrence of Tmax higher than mean+0.5 SD was maximum during 3rd SMW with a probability of 38.6%. Similarly maximum chances of occurrence of Tmax higher than mean+1.0 SD was during 13th SMW with 19.7% probability followed by 11th SMW with a probability of 17.9%. The chances of occurrence of Tmax higher than mean+1.5 SD was maximum during 12th SMW with probability of 6.7%. The maximum chances of occurrence of Tmax higher than mean+2.0 SD was during 12th SMW that is between 19th and 25th March with 3.0% probability. The findings of the results revealed that the maximum probability of occurrence of high temperature was during March. The effect of high maximum temperature on wheat can be mitigated by advancing the time of sowing in this region. Dubey *et al*., (2019) reported that the timely sowing of wheat ensures that grain filling stage finishes before arrival of high temperature and delayed sowing results in reduction in grain yield.

Minimum temperature (Tmin): The chances of occurrence of Tmin higher than mean+0.5 SD, mean+1.0 SD, mean+1.5 SD and mean+2.0 SD are represented in Table 3. The maximum chances of occurrence of Tmin higher than mean+0.5 SD was during 11th SMW with a probability of 34.3% followed by 12th SMW with a probability of 34.0%. Similarly, the probability of occurrence of Tmin higher than mean+1.0 SD was maximum during 11th SMW with a probability of 19.4%. The maximum chances of occurrence of Tmin higher than mean+1.5 SD was during 1st SMW with probability of 10.3%. The chances of occurrence of Tmin higher

Table 2: Mean, standard deviation (SD), upper limit of statistical range and probability at Ballowal Saunkhri

SMW	Temperature (°C)		Mean+0.5 SD		Mean+1.0 SD		Mean+1.5 SD		Mean+2.0 SD	
	Mean	SD	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)
Maximum temperature (Tmax)										
1st	17.9	4.0	19.9	37.1	21.8	15.7	23.8	3.2	25.8	0.7
2nd	18.2	3.7	20.1	37.5	21.9	13.9	23.7	1.8	25.6	0.0
3rd	18.3	3.2	20.0	33.2	21.6	14.6	23.2	4.6	24.8	1.8
4th	19.9	3.1	21.5	28.6	23.0	12.8	24.6	4.6	26.2	2.5
5th	21.2	2.6	22.6	26.1	23.9	14.3	25.2	5.7	26.5	1.4
6th	21.9	2.9	23.3	34.6	24.7	16.4	26.2	5.0	27.6	0.0
7th	22.8	3.1	24.4	30.4	25.9	15.4	27.4	5.4	29.0	1.1
8th	23.6	3.5	25.4	29.6	27.1	14.3	28.8	4.3	30.6	1.8
9th	24.9	3.3	26.6	33.2	28.3	15.7	29.9	5.0	31.6	0.7
10th	26.9	2.7	28.3	33.6	29.6	12.1	31.0	5.0	32.3	0.7
11th	27.6	3.4	29.3	33.7	31.0	15.4	32.7	3.6	34.4	0.4
12th	28.9	3.4	30.6	30.0	32.3	16.4	34.0	5.0	35.7	1.4
13th	30.4	3.5	32.2	33.6	33.9	15.7	35.7	4.6	37.4	0.0
Minimum temperature (Tmin)										
1st	5.4	3.0	6.9	29.3	8.4	18.9	9.9	8.2	11.4	3.9
2nd	5.2	2.8	6.6	28.6	8.0	16.1	9.4	7.5	10.8	3.2
3rd	5.4	3.0	6.9	31.4	8.4	17.1	9.9	7.8	11.3	2.5
4th	5.7	3.3	7.3	27.5	8.9	17.8	10.6	8.6	12.2	4.3
5th	6.4	2.7	7.8	31.8	9.1	15.4	10.5	7.5	11.9	2.9
6th	7.6	3.0	9.1	29.3	10.6	15.7	12.1	10.0	13.7	2.5
7th	8.4	2.9	9.8	32.1	11.3	16.8	12.7	8.2	14.2	1.1
8th	9.2	3.2	10.8	29.3	12.4	17.8	14.0	9.3	15.6	3.6
9th	10.1	2.8	11.5	30.0	12.8	20.0	14.2	6.4	15.6	1.8
10th	11.2	3.0	12.7	31.8	14.2	17.8	15.7	5.3	17.2	1.8
11th	12.5	3.0	14.0	31.8	15.5	15.3	17.0	4.3	18.5	1.4
12th	13.9	2.8	15.3	28.2	16.7	16.1	18.1	5.7	19.5	2.1
13th	14.7	2.9	16.2	27.8	17.6	13.6	19.1	5.0	20.5	2.5

than mean+2.0 SD was maximum during 1st SMW with a probability of 4.2%.

The rise in temperature during the reproductive stages of wheat is very serious and there are many reports which highlight its importance, like in wheat the grain yield decreases significantly when the temperature alleviates above 24 °C during the reproductive stage (Prasad and Djanaguiraman, 2014). The high temperatures during February and March contributes to reductions in grain size, total biomass, the proportion of grain to total biomass and overall yield (Moshatati *et al*., 2017). Bala *et al*., (2014) reported that terminal heat stress reduced the thousand grain weight by 24.0 and 31.0 per cent and grain yield by 26.0 and 54.2 per cent in tolerant (C 273) and susceptible (PBW 343) cultivars, respectively. Sandhu *et al*., (2016) also reported that increase in temperature by 1.0 °C during the 16–31 January, 1–15 February, 16–28 February and 1–15 March decreased the wheat productivity by 1.6, 2.1, 2.6 and 2.6 per cent, respectively, while temperature increase of 2.0 °C during same period decreased the wheat productivity by 3.0, 4.0 4.9 and 2.7 per cent, respectively and when increased by 3.0 °C decrease was 2.1, 3.8, 4.8 and 5.0 per cent, respectively. Singh *et al*., (2017) conducted a polyhouse experiment to study the response of artificial heat stress of 1.9 to 3.4 °C higher than control on three wheat varieties (HD 2967, WR 544 and HD 2985) and reported a substantial decrease in 1000 grain weight, grain yield and straw yield as compared to the ambient temperature. Mamrutha *et al*., (2020) reported that in wheat, among different stages, grain filling stage was most susceptible to high night temperature (5 °C higher than ambient). Kaur *et al*., (2021) reported from Ludhiana, Punjab that heat stress (average maximum temperature higher than ambient by 6.8 and 4.6 °C during 2016–2017 and 2017–2018, respectively) during 91-105 DAS caused highest reduction in grain yield by 22.1% and 18.8% in

Table 3: Mean, standard deviation (SD), upper limit of statistical range and probability at Bathinda

SMW	Temperature (°C)		Mean+0.5*SD		Mean+SD		Mean+1.5*SD		Mean+2*SD	
	Mean	SD	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)	Temp (°C)	Probability (%)
Maximum temperature (Tmax)										
1st	18.1	3.8	20.0	36.2	21.9	14.3	23.8	5.5	25.6	0.6
2nd	18.4	3.4	20.1	35.0	21.8	14.3	23.5	3.9	25.2	0.9
3rd	18.2	3.3	19.9	38.6	21.5	13.1	23.2	4.5	24.8	1.2
4th	19.6	3.0	21.1	31.0	22.6	15.8	24.1	4.9	25.6	1.2
5th	20.5	2.8	21.9	35.3	23.2	16.1	24.6	5.5	26.0	0.6
6th	21.2	3.1	22.7	27.3	24.3	13.1	25.8	5.2	27.4	1.5
7th	22.3	2.9	23.7	34.0	25.2	17.0	26.6	5.8	28.0	0.3
8th	23.3	3.2	25.0	34.9	26.6	17.3	28.2	4.2	29.8	0.9
9th	24.4	3.8	26.3	33.7	28.1	14.9	30.0	2.4	31.9	0.6
10th	26.4	3.1	28.0	36.2	29.6	16.4	31.1	5.8	32.7	0.6
11th	27.5	3.3	29.2	36.2	30.9	17.9	32.5	5.5	34.2	1.5
12th	29.1	3.3	30.8	31.6	32.4	16.4	34.1	6.7	35.7	3.0
13th	30.9	3.5	32.6	34.0	34.4	19.7	36.2	5.2	37.9	0.6
Minimum temperature (Tmin)										
1st	4.7	3.0	6.1	27.3	7.6	15.8	9.1	10.3	10.6	4.2
2nd	4.7	2.9	6.2	30.7	7.6	14.6	9.1	8.2	10.6	3.9
3rd	4.9	2.9	6.4	30.7	7.9	18.5	9.4	10.0	10.8	3.9
4th	5.4	3.2	7.0	29.5	8.6	18.5	10.2	7.9	11.8	3.9
5th	5.7	2.9	7.1	28.9	8.5	17.6	9.9	9.4	11.4	3.9
6th	6.7	5.2	9.3	19.8	11.9	6.4	14.6	0.6	17.2	0.3
7th	8.0	2.8	9.4	33.1	10.8	17.9	12.2	7.6	13.7	3.9
8th	8.6	2.9	10.1	33.7	11.5	18.2	13.0	6.4	14.4	1.5
9th	9.5	2.8	10.9	31.0	12.3	17.9	13.7	6.7	15.1	1.8
10th	10.5	2.7	11.8	32.5	13.2	17.9	14.5	6.4	15.9	3.6
11th	12.0	2.7	13.4	34.3	14.8	19.4	16.1	7.6	17.5	1.8
12th	13.3	2.8	14.7	34.0	16.1	17.9	17.5	6.4	18.9	1.8
13th	14.8	2.5	16.1	29.5	17.3	14.6	18.6	6.7	19.9	2.1

2016–2017 and 2017–2018, respectively. All these studies highlight the importance of high temperature during the reproductive stages of wheat. The optimum temperature for wheat during different SMWs in Punjab is determined by Sandhu *et al.,* (2018) and cand serve as a benchmark for comparing with the prevailing temperature. This comparison along with information on probability of occurrence of higher temperatures of different severity levels (highest severity is in case of temperatures above mean+2.0 SD) will be important in designing new strategies, such as optimizing planting dates, irrigation scheduling, application of chemicals like KNO_3 and salicylic acid, etc. to mitigate the impact of heat stress.

CONCLUSIONS

The effect of heat stress on wheat can be profound so, it is important to understand temperature variability for agricultural planning and management. This study examined historical temperature data during reproductive phase of wheat in three regions of Punjab for probability analysis of temperature events higher than range. It was found that Ludhiana exhibited maximum probability of occurrence of Tmax and Tmin higher than range. During the reproductive phase of wheat in northeastern and southwestern regions of Punjab the probability of having Tmax and Tmin above range was maximum during 12th-13th and 9th-11th SMW, respectively, while in central region it was maximum during 9th and 4th SMW, respectively.

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REFERENCES

Anonymous. (2015). Statistics of Punjab Agriculture. Punjab Agricultural University, Ludhiana.

Bala, S., Asthir, B. and Bains, N.S. (2014). Effect of terminal heat stress on yield and yield attributes of wheat. *Indian J. Appl. Res*., 4: 1-2.

Dhaliwal, L.K., Kaur, J. and Singh, J. (2022). Weather variability during wheat growing season in central plain region of Punjab. *Inter. J. Plant Soil Sci*., 34: 34-48.

Dubey, R., Pathak, H., Singh, S., Chakravarti, B., Thakur, A.K. and Fagodia, R.K. (2019). Impact of sowing dates on terminal heat tolerance of different wheat (*Triticum aestivum* L.) cultivars. *Natl. Acad. Sci. Lett*., 42: 445-449.

IPCC (2007). Global Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

Kaur, N. and Prabhjyot-Kaur (2016). Projected climate change under different scenarios in central region of Punjab, India. *J. Agrometeorol.*, 18(1): 88-92. https://doi.org/10.54386/jam.v18i1.907

Kaur, J., Sandhu, S.S. and Sharma, S. (2021). Yield response of wheat grown under periodic heat stress imposed by using mini heat tents. *J. Agron. Crop. Sci*., 207: 285-303.

Mamrutha, H.M., Rinki, K., Venkatesh, K., Gopalareddy, K., Khan, H., Mishra, C.N., Kumar, S., Kumar, Y., Singh, G. and Singh, G.P. (2020). Impact of high night temperature stress on different growth stages of wheat. *Plant Physiol. Rep*., 25: 707-15.

Moshatati, A., Siadat, S.A., Alami-Saeid, K., Bakhshandeh, A.M. and Jalal-Kamali, M.R. (2017). The impact of terminal heat stress on yield and heat tolerance of bread wheat. *Int. J. Plant Prod*., 11(4): 549-560.

Prabhjyot-Kaur, Singh, H., Rao, V.U.M., Hundal, S.S., Sandhu, S.S., Nayyar, S., Rao, B.B. and Kaur, A. (2015). Agrometeorology of wheat in Punjab state of India. Punjab Agricultural University, 1-85.

Prasad, P.V. and Djanaguiraman, M. (2014). Response of floret fertility and individual grain weight of wheat to high temperature stress: sensitive stages and thresholds for temperature and duration. *Funct. Plant Biol*., 41: 1261-69.

Rao, B.B., Chowdary, P.S., Sandeep, V.M., Pramod, V.P. and Rao, V.U. (2015). Spatial analysis of the sensitivity of wheat yields to temperature in India. *Agric. Forest Met.*, 200: 192-202.

Sandhu, S.S., Prabhjyot-Kaur, Tripathi, P., Patel, S.R., Prasad, R., Solanki, N.S., Kumar, R., Singh, C.B., Dubey, A.P. and Rao, V.U.M. (2016). Effect of rise in intra-seasonal temperature at major wheat growing location in India: A study using CERES-Wheat model. *J. Agrometeorol.,* 18(2): 222-233. https://doi.org/10.54386/jam.v18i2.939

Sandhu, S.S., Prabhjyot-Kaur, Gill, K.K. and Singh, P. (2018). Weekly temperature ranges for higher wheat productivity in central Punjab. *J. Agrometeorol.,* 20 (Special issue): 23-30.

Singh, H.V., Kumar, S.N., Ramawat, N. and Harit, R.C. (2017). Response of wheat varieties to heat stress under elevated temperature environments. *J. Agrometeorol.,* 19(1): 17-22. https://doi.org/10.54386 jam.v19i1.750

Slafer, G.A. and Satorre, E.H. (1999). Wheat: Ecology and Physiology of Yield Determination. Haworth Press Technology and Industrial, New York.

Wollenweber, B., Porter, J.R. and Schellberg, J. (2003). Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. *J. Agron. Crop Sci*., 189(3): 142-150