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Research Article

Optimum Limits of Temperature, and Sunshine Hours for High Rice Yield in Punjab, India

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ABSTRACT

Rice is a *kharif* season crop and is highly susceptible to abrupt increase/ decrease in weather parameters. Therefore, a study was conducted to compute the critical limits of temperature andsunshine hours by analyzing meteorological and crop data (2000-2019) for three locations (Ludhiana, Patiala and Amritsar) in Punjab. Amongst the 20 years, high yield years for Ludhiana (Yield >4601 kg/ha: 2004, 2009, 2016, 2017 and 2019), Patiala (Yield >4201 kg/ha: 2007, 2008, 2009, 2016 and 2017) and Amritsar (Yield >3001 kg/ha: 2000, 2001, 2004, 2006, 2007, 2016, 2017 and 2019) were identified. Then meteorological data for main crop growth stages, i.e, sowing (20-22 Standard Meteorological Week (SMW), transplanting (23-26 SMW), tillering (27-30 SMW), heading (31-34 SMW), flowering (35-36 SMW), Grain filling (37-39 SMW) and physiological maturity (40-41 SMW) were tabulated. The week wise deviations of maximum/ minimum temperature and sunshine hours from normal data of those 20 years under study were computed to derive their critical limits. Then these stage wise critical limits were validated using the actual yields achieved during crop years 2020 and 2021 and the reasons for high yields obtained at three locations during 2021 and two locations during 2020 and medium yield at one location during 2020 were fully accounted for by these ranges. Hence it may be concluded that to get higher rice productivity the maximum/ minimum temperature ranges during vegetative growth should be 34-40/ 23-28°C, during flowering should be 33-35/ 25-27°C and during grain filling should be 32-35 / 20-25°C. Similarly the sunshine hour's ranges during vegetative phase should be 7-11 hours, flowering should be 6-10 hours and during grain development should be 7-10 hours. The results of the study can play a guiding role for the scientists while optimising the growing window for the rice cultivars in the state. The information is also helpful for the agricultural scientists while preparing the estimates of the projected yield of rice during the growing period of crop and prior to its harvesting.

Key words: Rice, Optimum limits, Temperature, Sunshine hour, Yield, Punjab

Introduction

World's half population depends on rice crop as a staple food. During 2021-22, in India rice production of 130.29 million tonnes was achieved from 46.37 million hectares of cultivated area (Anonymous, 2020). While in Punjab state during 2021-22, rice was cultivated over 31.45 thousand hectares of area with total production and productivity of 203.71 thousand tonnes and 64.78 q/ha (Anonymous, 2023).

Every crop thrives best under an optimum combination of weather variables. Rice grows best under flooded conditions and requires warm and humid weather with ample of sunshine duration. Krishnan *et al.* (2011) reported that rice requires a mean temperature>20°C during the entire growing

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period. The tillering period in rice gets shortened with daily mean temperature >26°C (Lalitha *et al.*, 1999). While the higher temperatures during flowering and grain-filling stage shorten the grain-filling duration and enhances the spikelet sterility thereby reducing the yield of rice (Tian *et al.*, 2007; Xie *et al.*, 2009). Ziska *et al.* (1997) found that during the growing season an elevation in temperature by 4°C resulted in earlier maturation of the crop by five and six days for wet and dry seasons, respectively. Under Punjab conditions, Hundal and Kaur (2007) reported that with an elevation of temperature by 1°C, the yield of rice was reduced by 3%. Similarly, during vegetative stage a decrease in the temperature can cause slow growth and reduce seedling vigour (Ali *et al.*, 2006). Samui (1999) reported that rainfall in the range of 100 to 115 cm with temperatures in the range of 29 to 32°C are conducive for higher productivity of rice in India.

In Punjab state, the rice is ideally recommended for cultivation during *kharif* season (Anonymous, 2022). Sandhu *et al.* (2013) reported that in Punjab cumulative sunshine >1010 hours during rice growing period combined with well distributed rainfall are the favourable weather conditions for getting high rice yields.In another study by Mahajan *et al.* (2009) observed that if rice crop receives more sunshine hours during the tillering stage, then it will have more number of panicles per unit area and hence higher grain yield. During the vegetative stage of rice a combination of adequate sunshine hours and well-distributed rainfall increase the yield potential of rice cultivars (Prabhjyot-Kaur *et al.*, 2021).

In Punjab state, the rice crop is cultivated under assured irrigation conditions with optimum crop management practices. But still inter seasonal fluctuations in yield of rice are common mainly due to prevailing weather conditions.A recent study by Prabhjyot-Kaur and Sandhu (2021) have reported that in Punjab during crop year 2019 (44.53 q/ha) the rice yield was reduced from that of crop years 2017 (48.15 q/ha) and 2018 (47.43 q/ha). It was concluded that this reduction in yield was due to higher (>3-4°C) maximum temperature during transplanting and tillering stage and higher (>3-4°C) minimum temperature during flowering stage rice. So the present study was conducted to determine the optimum limits of the meteorological parameters for acquiring high yield of rice crop in Punjab.

Materials and Methods

Data sets used for the study

The data for phenology of rice were collected from field experiments conducted under "*All India Co-ordinated Research Project on Agrometeorology*" in the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana. The stages of rice were categorized into nursery sowing (20-22 Standard Meteorological Week (SMW)), transplanting (23-26 SMW), tillering (27-30 SMW), heading (31-34 SMW), flowering (35-36 SMW), grain filling (37-39 SMW) and physiological maturity (40-41 SMW) by taking in consideration the early, normal and late sowingconditions for rice in the state.

The daily weather data i.e., maximum and minimum temperature and sunshine hours for three major rice growing districts (Fig. 1) falling in the central irrigated plains (Ludhiana, Patiala and Amritsar) of Punjab from 2000-2019 were collected from meteorological observatories to compute the weekly and crop stage wise normals. The historical data on yield of rice for the three districts were

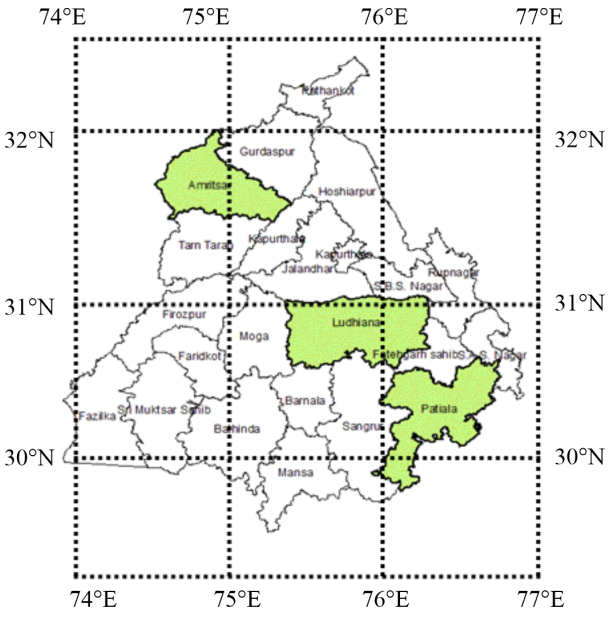


Fig. 1. Map of the state with three districts under study

Table 1. Location-wise yield (kg/ha) of rice crop from 2000-2019

Station	High yield year	Medium yield year	Low yield year
Ludhiana	Yield >4601 kg/ha	Yield 4401-4600 kg/ha	Yield <4400 kg/ha
	2004, 2009, 2016, 2017 and 2019	2005, 2007, 2008, 2010, 2012, 2013, 2015 and 2018	2000, 2001, 2002, 2003, 2006, 2011 and 2014
Patiala	Yield >4201 kg/ha	Yield 3901-4200 kg/ha	Yield <3900 kg/ha
	2007, 2008, 2009, 2016 and 2017	2005, 2006, 2012, 2013, 2014, 2015, 2018 and 2019	2000, 2001, 2002, 2003, 2004, 2010 and 2011
Amritsar	Yield >3001 kg/ha	Yield 2801-3000 kg/ha	Yield <2800 kg/ha
	2000, 2001, 2004, 2006, 2007, 2016, 2017 and 2019	2002, 2005, 2008, 2012, 2013, 2015, 2018	2003, 2009, 2010, 2011, 2014

collected from Statistical Abstracts, Punjab from 2000-2019. The rice yield during these 20 years was categories into high, medium and low yield (Table 1).

Computation of crop growth stage wise "critical limits" of the meteorological parameters

The stage wise actual ranges of meteorological parameters for rice crop at three different districts/ locations were computed from the meteorological data from 2000-2019. Then the deviations of weekly meteorological parameters for rice crop were computed for high, medium and low yield years from the weekly normals. Later the *"Critical limits"* of various meteorological parameters were iteratively calculated by comparing the ranges of respective parameters observed during the high yield years for each district/location. Finally by computing the mean and standard deviation for each stage wise meteorological parameters their respective lower and upper ranges for nursery sowing (20-22 SMW), transplanting (23-26 SMW), tillering (27-30 SMW), heading (31-34 SMW), flowering (35-36 SMW), grain filling (37-39 SMW) and physiological maturity (40-41 SMW) were derived for obtaining high yield of rice in Punjab state.

Validation of the critical limits

The actual yield of rice for the three districts/ locations obtained during crop year 2020 and 2021 were evaluated within the lower and upper limit of maximum (Tmax) and minimum (Tmin) temperature and sunshine hours (SSh).

Results and Discussion

Weekly average range of meteorological parameters during rice crop season

The daily meteorological data were analysed and cloned into their weekly averages which were categorized into rice crop growth stages, i.e, nursery sowing, transplanting, tillering, heading, flowering, grain filling and physiological maturity stage for Ludhiana, Patiala and Amritsar (Table 2). The perusal of the data revealed that the weekly maximum / minimum temperature at Ludhiana, Patiala and Amritsar ranged between 32.7-39.7/19.3-27.2°C, 32.8-39.9/19.3-27.3°C and 32.8-40.3/18.1-25.9°C, respectively. Similarly, the weekly sunshine hours ranged between 5.5-9.7 hours at Ludhiana.

Comparison of the range of normal and optimum meteorological parameters during rice crop season

The normal weekly meteorological data for Ludhiana, Patiala and Amritsar was then compared with the respective weeks (20-41 SMW) data and their deviations from normal were calculated for each category (high, medium and low) of rice yield over the 20 years time period. Then the range of optimum meteorological parameters for each stage of rice crop were derived from the actual data observed during the high yield years at the respective location (Table 3 and 4). The perusal of the data revealed that at Ludhiana, Patiala and Amritsar the optimum weekly maximum / minimum temperature ranged between 34.4-43.7/ 22.1-26.8°C, 29.9-42.3/ 21.2-27.2°C and 37.9-44.2/ 20.0-25.1°C, respectively for nursery

Table 2. Weekly average meteorological parameters for rice crop during *kharif* season (2000-2019)

Growth stage	Week Number (#)	Ludhiana			Patiala		Amritsar	
		Temperature (°C)		Sunshine hours (#)	Temperature (°C)		Temperature (°C)	
		Maximum	Minimum		Maximum	Minimum	Maximum	Minimum
Nursery sowing	20	39.4	24.5	9.1	39.8	25.2	40.1	23.0
	21	39.7	24.6	9.2	39.9	25.2	40.2	23.3
	22	39.5	25.2	9.7	39.8	25.7	40.3	23.6
Transplanting	23	39.3	26.2	9.4	39.0	26.0	40.3	24.6
	24	37.7	26.2	7.8	38.0	26.5	38.4	24.3
	25	37.3	26.8	8.4	37.4	26.8	38.1	25.7
	26	35.6	27.0	6.8	36.2	26.8	36.6	25.4
Tillering	27	35.0	27.2	6.7	35.5	27.2	36.2	25.8
	28	34.2	26.9	6.3	34.3	26.8	34.9	25.4
	29	34.0	27.1	6.1	34.3	27.3	34.8	25.8
	30	33.8	27.2	5.5	34.2	27.0	34.4	25.9
Heading	31	33.6	26.8	6.0	33.8	26.7	34.1	25.6
	32	33.7	27.0	5.8	33.9	26.6	34.1	25.7
	33	33.4	26.3	6.3	33.4	26.4	34.0	25.4
	34	33.6	26.2	7.5	33.3	26.2	34.4	25.3
Flowering	35	33.5	26.0	7.0	33.9	25.9	33.9	24.6
	36	33.3	25.0	7.8	33.5	25.0	33.9	23.7
Grain filling	37	32.9	24.4	7.5	33.2	24.5	33.5	23.1
	38	32.9	23.5	7.8	32.8	23.4	33.6	22.1
	39	32.9	22.0	8.7	33.2	22.1	33.3	20.9
Physiological maturity	40	33.4	21.3	8.1	33.7	21.7	33.8	20.3
	41	32.7	19.3	7.9	33.1	19.3	32.8	18.1

Table 3. Stage-wise range of average meteorological parameters for rice crop at Ludhiana during 2000-2019

Crop Growth Stage		Temperature (°C)		Sunshine hours
		Maximum	Minimum	
Nursery sowing	Normal	38.8-39.7	23.1-24.4	9.9-10.3
	Optimum	34.4-43.7	22.1-26.8	7.8-11.5
Transplanting	Normal	36.1-39.6	25.4-26.7	7.7-9.0
	Optimum	33.3-42.7	24.2-29.2	5.0-12.9
Tillering	Normal	33.6-35.3	26.3-26.4	6.2-7.4
	Optimum	31.3-37.7	23.9-28.9	4.0-10.3
Heading	Normal	33.2-33.5	25.6-26.1	6.1-7.9
	Optimum	31.6-36.1	24.6-28.6	4.3-8.9
Flowering	Normal	33.3-33.5	24.3-25.1	7.7-8.1
	Optimum	31.4-34.9	23.3-27.3	5.3-11.2
Grain filling	Normal	33.2-33.4	21.2-23.5	8.5-9.1
	Optimum	30.3-34.8	20.5-26.9	4.0-9.7
Physiological maturity	Normal	32.8-33.3	18.2-19.7	8.9-9.2
	Optimum	29.1-34.4	11.4-24.8	5.0-9.4

Table 4. Stage-wise range of average meteorological parameters for rice crop at Patiala and Amritsar during 2000-2019

Crop Growth Stage		Patiala		Amritsar	
		Maximum	Minimum	Maximum	Minimum
		Temperature (°C)			
Nursery sowing	Normal	39.0-39.9	23.9-25.2	39.3-40.2	21.8-23.2
	Optimum	29.9-42.3	21.2-27.2	37.9-44.2	20.0-25.1
Transplanting	Normal	36.3-39.5	25.8-26.6	12.7-33.9	24.2-25.6
	Optimum	33.5-42.8	24.6-28.6	34.3-42.9	19.5-31.0
Tillering	Normal	33.8-35.5	26.5-26.7	34.4-36.3	25.4-25.8
	Optimum	33.2-36.2	25.2-28.9	33.0-38.5	25.2-27.7
Heading	Normal	33.2-33.4	25.9-26.3	33.9-34.4	25.1-25.5
	Optimum	32.0-35.3	24.1-28.0	32.5-36.3	24.0-27.9
Flowering	Normal	33.1-33.4	24.8-25.5	34.3-34.4	23.9-24.6
	Optimum	33.0-35.0	23.1-26.0	31.9-36.3	23.9-26.0
Grain filling	Normal	33.0-33.2	22.0-24.3	33.8-34.1	20.7-23.0
	Optimum	29.0-35.0	21.4-25.8	32.9-35.9	19.3-24.6
Physiological maturity	Normal	33.0-33.2	19.2-20.7	33.3-33.8	17.3-19.0
	Optimum	32.0-35.0	15.0-25.2	28.1-34.9	14.7-20.9

sowing stage; between 33.3-42.7/ 24.2-29.2°C, 33.5-42.8/ 24.6-28.6°C and 34.3-42.9/ 19.5-31.0°C respectively for transplanting stage; between 31.3-37.7/ 23.9-28.9°C, 33.2-36.2/ 25.2-28.9°C and 33.0-38.5/ 25.2-27.7°C respectively for tillering stage; between 31.6-36.1/ 24.6-28.6°C, 32.0-35.3/ 24.1-28.0°C and 32.5-36.3/ 24.0-27.9°C respectively for heading stage; between 31.4-34.9/ 23.3-27.3°C and 33.0-35.0/ 23.1-26.0°C and 31.9-36.3/ 23.9-26.0°C respectively for flowering stage; between 30.3-34.8/ 20.5-26.9°C, 29.0-35.0/ 21.4-25.8°C and 32.9-35.9/ 19.3-24.6°C respectively for grain filling stage; between 29.1-34.4/ 11.4-24.8°C, 32.0-35.0/ 15.0-25.2°C and 28.1-34.9/ 14.7-20.9°C respectively for physiological maturity stage.

The range of optimum meteorological parameters for three locations during the high yield years were analysed by deriving their mean and standard deviations and then by iterative computations the optimized ranges of each parameter were derived. The data given in Table 5 revealed that in Punjab state for achieving high yield of rice, the maximum / minimum temperature, and sunshine hours respectively should be within the range of 34-40/ 23-28°C and 7-11 hours during vegetative period, 33-35/ 25-27°C and 6-10 hours during flowering growth period and 32-35/ 20-25°C and 7-10 hours during grain development period.

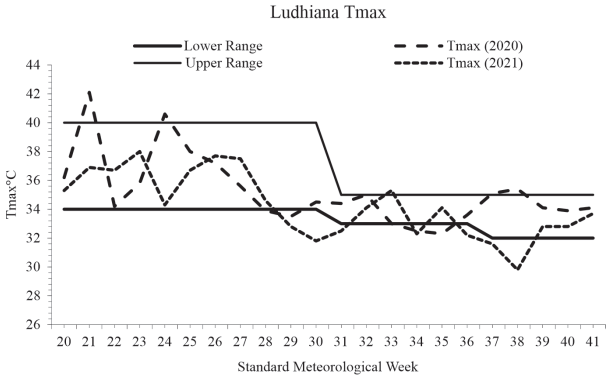
Table 5. Optimum range of weather parameters for higher productivity of rice in Punjab

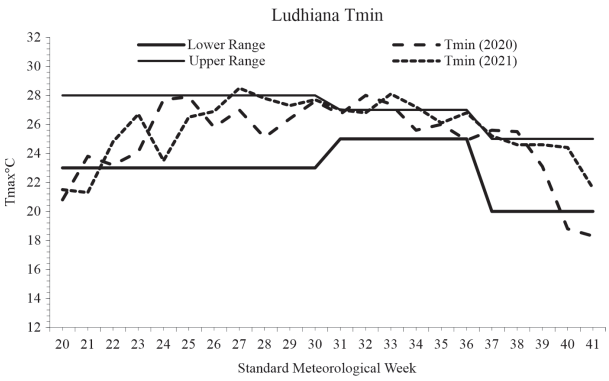
Crop stage	Temperature (°C)		Sunshine hours
	Maximum	Minimum	
Vegetative	34-40	23-28	7-11
Flowering	33-35	25-27	6-10
Grain development	32-35	20-25	7-10

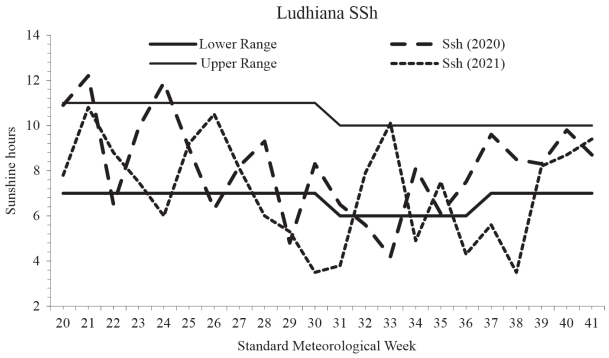
Validation of upper and lower range of meteorological parameters

The actual weekly meteorological data for the three locations during 2020 and 2021 was plotted along with the respective stage wise lower and upper range limits (Fig. 2 to 4). The validation results revealed that high and medium yield of rice achieved at each location could be explained by the outlaying of maximum (Tmax) and minimum (Tmin) temperature, and sunshine hours (SSh) within the lower and upper range of the meteorological parameters.

During the crop year 2020, a high yield (4676 kg/ha) of rice at Ludhiana was achieved as both Tmax







High yield (4676 kg/ha) during 2020

Factors responsible for high yield :

1. Tmax- Remained within optimum ranges

2. Tmin–Remained within optimum ranges and was slightly below the lower range during start and end of season.

3. Sunshine hour–Remained broadly within the optimum range except during end vegetative (1 week) and flowering stage (1 week).

High yield (4888 kg/ha) during 2021

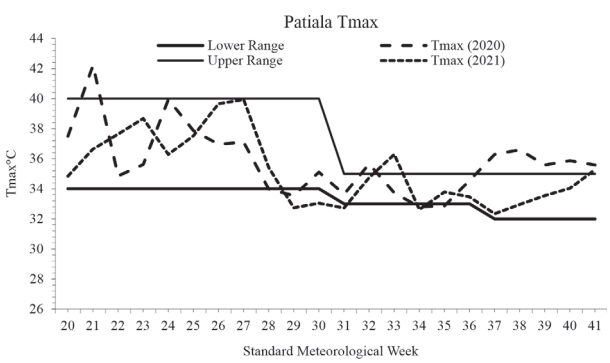
Factors responsible for high yield :

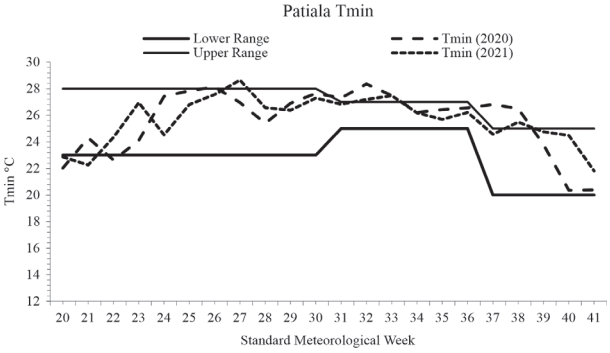
1. Tmax– Mostly remained within optimum ranges and was below range during end of vegetative and start of grain development stage

2. Tmin– Remained within optimum ranges and was slightly below the lower range during start of season.

3. Sunshine hour – Remained within the optimum range.

Fig. 2. Comparison of actual weather data of Ludhiana during 2020 and 2021 for validation of thumb rules for rice crop





Medium yield (3949 kg/ha) during 2020

Factors responsible for medium yield :

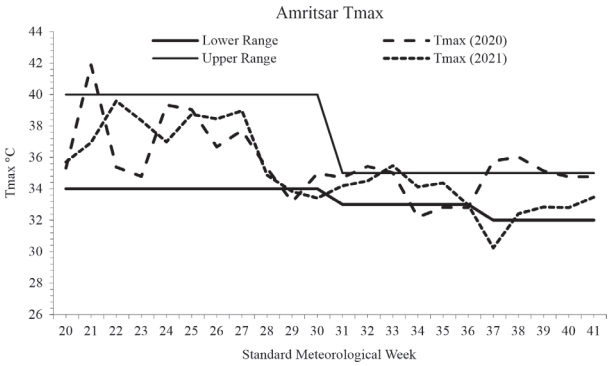
1. Tmax– During the vegetative and flowering remained within optimum range. However, it above the upper range by >1.5°C during the grain development stage of rice.
2. Tmin– During the vegetative and flowering remained within optimum range. However, it above the upper range by 1.5 – 1.8°C during the two weeks of grain development stage of rice.

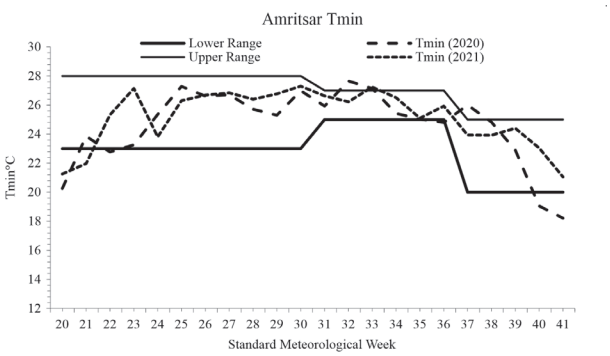
High yield (4472 kg/ha) during 2021

Factors responsible for high yield :

1. Tmax– Mostly remained within optimum ranges and was below range during end of vegetative stage
2. Tmin– Remained within optimum ranges and was slightly below the lower range during start of season.

Fig. 3. Comparison of actual weather data of Amritsar during 2020 and 2021 for validation of thumb rules for rice crop





High yield (3305kg/ha) during 2020

Factors responsible for high yield :

1. Tmax– Mostly remained within optimum ranges and was slightly above the upper range during start of vegetative stage
2. Tmin– Remained within optimum ranges and was slightly below the lower range during start and end of season.

High yield (3343kg/ha) during 2021

Factors responsible for high yield :

1. Tmax– Mostly remained within optimum ranges and was slightly below the lower range during start of grain development stage.
2. Tmin– Remained within optimum ranges and was slightly below the lower range during start of season.

Fig. 4. Comparison of actual weather data of Amritsar during 2020 and 2021 for validation of thumb rules for rice crop

and Tmin remained within optimum range except for two weeks during sowing when Tmax was slightly higher than optimum range and Tmin was slightly below the lower range during start and end of season. Also the SSh remained broadly within the optimum range except during end vegetative (1 week) and flowering stage (1 week). A high yield (4888 kg/ha) of rice at Ludhiana during 2021 was realized as both Tmax and Tmin remained within optimum range except for two weeks when Tmax was below range during end of vegetative and start of grain development stage and Tmin was slightly was slightly below the lower range during start of season. The SSh invariably remained within the optimum range.

At Patiala during 2020a medium yield (3949 kg/ha) of rice was achieved as because Tmax was above optimum by 2°C during the nursery sowing period and by >1.5°C during the grain development stage. The Tmin during the two weeks of grain development stage was above the upper range by 1.5–1.8°C. During crop year 2021 at Patiala a high yield (4472 kg/ha) was obtained as the Tmax remained within optimum range except during end of vegetative stage it was below from lower range. The Tmin remained within optimum range except during start of season when it was below the lower range.

At Amritsar a high yield (3305 kg/ha) of rice during 2020 was obtained as the Tmax remained within optimum range except during start of vegetative stage it was below the lower range. Likewise, the Tmin also remained within the optimum range except during start of season when it was slightly below the lower range. Similarly, during 2021 at Amritsar a high yield (3343 kg/ha) of rice was achieved since the Tmax remained within optimum range except during flowering stage when it was below the lower range. The Tmin too remained within optimum range except during start of season it was slightly below the lower range**.**

Under Indian conditions, earlier study by Lalitha *et al.* (1999) have reported that tiller production in rice is maximum when mean temperature is in the range of 24-27°C under lowland conditions. It has been reported that extremely high temperatures during the reproductive stages of rice significantly decreases the grain yield by more than 50 per cent (Zhang *et al.*, 2018; Fu *et al.*, 2012). Results indicated that temperature above normal in the months of August and September for a continuous period could be harmful as it cause spikelet sterility (Bala and Prabhjyot-Kaur, 2015). In Punjab state, the rice yield during 2019 (44.53 q/ha) was reduced from that of 2017 (48.15 q/ha) and 2018 (47.43 q/ha) as the

maximum temperature was constantlyhigher by >3-4°C during transplanting and tillering stage and the minimum temperature was higher by>3-4°C during flowering stage of rice crop (Prabhjyot-Kaur and Sandhu 2021).

Conclusions

The high yield of a crop can be realized by following the optimized crop management practices in a region (Geerts and Raes, 2009, Bollaveni and Das, 2019). Rice crop is cultivated during the months of May (nursery sowing) to October (harvesting period) by following the recommended package of practice (Kaur *et al.*, 2020). The results of the present study revealed that in Punjab state, for achieving high yield of >4601 kg/ha (in most suitable regions) to >3001 kg/ha (in lesser suitable regions), the maximum / minimum temperature, respectively should be within the range of 34-40/ 23-28°C during vegetative period, 33-35/ 25-27°C during flowering period and 32-35/ 20-25°C during grain development period. The sunshine hours ranging between 6-11 hours/day are optimum for high productivity of rice in the state. This information can act as a guiding tool for the agricultural scientists for optimising the sowing time for the rice crop in Punjab state. The information will be of great help for the policy planners for yield estimation. It can also act as a ready reckoner while preparing the weather based crop insurance schemes.

Acknowledgement

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References

Ali, M.G., Naylor, R.E.L. and Matthews, S. 2006. Distinguishing the effects of genotype and seed physiological age on low temperature tolerance of rice (*Oryza sativa* L.). *Experimental Agriculture* **42**: 337-349.

Anonymous. 2020. *Statistics of Punjab agriculture*. Punjab Agricultural University, Ludhiana 60 p.

Anonymous. 2023. Package of practices for crops of Punjab: *Kharif* crops. Punjab Agricultural University, Ludhiana. pp. 1-25.

Bala, A. and Prabhjyot-Kaur 2015. Weather-based thumb rule models for prediction of rice yield in Punjab. *Journal of Agricultural Physics* **15**(1): 82-87.

Bollaveni, S.K. and Das, J.C. 2019. Influence of weather parameters on water use efficiency and performance of direct-seeded autumn Rice (*Oryza sativa*) under the agro-climatic conditions of Assam. *Journal of Agricultural Physics* **19**(2): 201-209.

Fu, G.F., Song, J., Xiong, J., Liao, X.Y., Zhang, X.F., Wang, X., Le, M.K. and Tao, L.X. 2012. Thermal resistance of common rice maintainer and restorer lines to high temperature during flowering and early grain filling stages. *Rice Sci*. **9**: 309-314.

Geerts, S. and Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management* **96**: 1275-1284.

Hundal, S.S. and Prabhjyot-Kaur. 2007. Climatic variability and its impact on cereal productivity in Indian Punjab. *Current Science* **92**(4): 506-512.

Kaur, J., Saini, K.S., Singh, T. and Manhas, S.S. 2020. Thermal energy utilization pattern and energetics of short duration rice cultivar in relation to age of nursery. *Journal of Agricultural Physics* **20**(1): 48-55.

Krishnan, P., Ramakrishnan, B., Reddy, K.R. and Reddy, V.R. 2011. High temperature effects on rice growth, yield, and grain quality. *Advances in Agronomy* **111**: 87–206.

Lalitha, K., Reddy, D.R. and Rao, S.B.S.N. 1999. Influence of temperature and sunshine hours on tiller production in lowland rice varieties. *Journal of Agrometeorology* **1**: 187–190.

Mahajan, G., Bharaj, T.S. and Timsina, J. 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. *Agricultural Water Management* **96**: 525-532.

Prabhjyot Kaur, Sandhu, S.S., Dhillon B.S. and Singh, H. 2021. Rice yield variability in Punjab: an overview of five decades. *Paddy and Water Environment* **19**: 673-681.

Prabhjyot-Kaur and Sandhu, S.K. 2021. Impact of recent weather variability on rice yield in Ludhiana district of Punjab. *Agricultural Research Journal* **58**(3): 441-445.

Prasada Rao, G.S.L.H.V. 2008. *Agricultural Meteorology*. Prentice Hall of India Pvt Ltd, New Delhi, pp. 185-188.

Sandhu, S.S., Mahal, S.S., Vashist, K.K., Buttar, G.S., Brar, A.S. and Singh, M. 2012. Crop and water productivity of bed transplanted rice as influenced by various levels of nitrogen and irrigation in northwest India. *Agricultural Water Management* **104**: 32-39.

Sandhu, S.S., Prabhjyot-Kaur, Gill, K.K. and Bala, A. 2013. Effect of inter and intra seasonal variability in meteorological parameters on rice productivity in central Punjab. *Journal of Agrometeorology* **15**(2): 147-151.

Samui, R.P. 1999. A note on the weather and rice yield relationship at some stations in India. *Earth and Planetary Science* **108**: 309–371.

Tian, X.H., Matsui, T., Li, S. H. and Lin, J.C. 2007. High temperature stress on rice anthesis: Research progress and prospects. *Chinese Journal of Applied Ecology* **18**: 2632–2636.

Yin, X., Kropff, M.J. and Goudriaan, J. 1996. Differential effects of day and night temperature on development to flowering in rice. *Annals of Botany* **77**(3): 203-213.

Zhang, C.X., Feng, B.H., Chen, T.T., Fu, W.M., Li, H.B., Li, G.Y., Jin, Q.Y., Tao, L.X. and Fu, G.F. 2018. Heat stress-reduced kernel weight in rice at anthesis is associated with impaired sourcesink relationship and sugars allocation. *Environment and Experimental Botany* **155**: 718-733.

Ziska, E. and Fraser, D. *et al.* 1997. Assessing risks of climate variability and climate change for rice. *Science* **240**: 996-1002.

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