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A study on the effects of environmental factors on the development and progression of wheat stripe rust under field conditions

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Abstract

Stripe rust of wheat, caused by *Puccinia striiformis* f. sp. tritici, is a major constraint to wheat production worldwide. The present investigation was conducted to study the relationship between the development and progression of stripe rust and various weather parameters during the crop seasons 2020-21 and 2021-22. The first appearance of the disease was observed at the end of the first standard week of January in 2020-21, with a disease index of 0.15 percent. In contrast, during 2021-22, the disease first appeared in the second standard week of January, with a disease index of 0.10 percent. Disease progression varied significantly between the two cropping years. The highest disease progression was recorded during 2020-21, with a maximum disease index of 42.5 percent and an AUDPC (Area Under Disease Progress Curve) value of 1263.25. In comparison, during 2021-22, the maximum disease index was 37.5 percent, with an AUDPC value of 1154.3. Correlation analysis indicated that maximum and minimum temperatures, morning and evening relative humidity, rainfall, and sunshine hours significantly influenced disease development and progression.

Keywords: Wheat, stripe rust, weather parameters, temperature, diseases severity, relative humidity, rainfall and sunshine hours

Introduction

Stripe or yellow rust of wheat, caused by *Puccinia striiformis* Westend. f. sp. tritici Ericks., is one of the most important diseases, causing significant economic yield losses in most wheat-growing regions of the world (Chen *et al.*, 2014) [2]. The disease appears as yellow stripes on leaves and leads to substantial yield losses by damaging the photosynthetic system, ultimately reducing grain weight and affecting grain quality (Line, 2002; Chen, 2005) [8, 3]. Stripe rust can cause up to 100 percent yield losses in susceptible cultivars if infection occurs early and the disease continues to develop throughout the growing season (Afzal *et al.*, 2007) [1]. Chen (2005) [3] reported that, depending on cultivar susceptibility, the timing of initial infection, the rate of disease development, and disease duration, yield losses may range from 10 to 70 percent. Therefore, effective disease management practices are essential to minimize these losses.

Wheat is a staple food for more than 40 percent of the global population. In India, it is the second most important food crop and is extensively cultivated in the northwestern and central zones. It is also the most important cereal crop in Uttar Pradesh. However, wheat is affected by numerous diseases that often occur in epidemic form, resulting in significant yield losses and deterioration in grain quality. Plant diseases affect approximately 55 percent of the global wheat-growing area, causing an estimated annual loss of 20 million tonnes of wheat (Kosina *et al.*, 2007) [7].

In the northwestern plains of India, wheat rusts, particularly stripe or yellow rust (*Puccinia striiformis* f. sp. tritici), are of major concern. Severe outbreaks of yellow rust have been reported in the plains of Jammu and Kashmir, the foothills of Punjab and Himachal Pradesh, parts of Haryana, and the tarai region of Uttarakhand during 2008-09, 2009-10, and 2010-11 (Pannu *et al.*, 2010) [10]. The increased severity of stripe rust in recent decades (1994-2004) has been attributed to the emergence of new physiological races capable of overcoming widely used resistance sources in wheat (Prasher *et al.*, 2007) [11]. The disease has occurred in severe forms in several

parts of North India, including Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, and sub-mountainous regions of Punjab, causing substantial yield losses in recent years. Since 2008, stripe rust has continued to occur at moderate to severe levels, resulting in estimated losses of about Rs 236 crores in Punjab alone (Jindal *et al.*, 2012) [5].

Weather factors such as temperature, relative humidity, rainfall, and sunshine hours play a crucial role in the occurrence, development, spread, and progression of stripe rust. Therefore, understanding the relationship between environmental factors and disease development is essential for predicting disease outbreaks and developing effective management strategies. The present study was undertaken to investigate the influence of weather parameters on different components of stripe rust development under both natural and artificially inoculated field conditions.

Materials and Methods

Wheat (*Triticum aestivum* L.) variety PBW 343, with a crop duration of 130-135 days and susceptible to yellow rust, was selected for this study. In this experiment, seeds were sown in 4 × 3 m² plots with three replications in the field, maintaining a plant-to-plant and row-to-row spacing of 15 × 25 cm at the Agricultural Farm, Chirodi, SVPUA&T, on the same dates during two cropping seasons, viz., rabi 2020-21 and 2021-22, by following standard agronomical practices. For this study, no chemicals or botanicals of any kind were used so as to facilitate the uninterrupted occurrence of yellow rust of wheat under natural conditions in relation to weather factors. The severity of yellow rust of wheat was recorded at different crop growth stages, starting from the jointing stage to maturity, at weekly intervals by randomly selecting 20 plants from each plot replicate. Weekly meteorological data were collected throughout the crop season from the meteorological observatory, Department of Soil Science and Agricultural Chemistry, SVPUAT, Meerut. The severity of the disease was recorded according to the Modified Cobb or Peterson scales at 5-day intervals, starting from the initial infection of the disease until terminal disease severity. After scoring the percent severity of yellow rust of wheat, the percent disease index (PDI) was calculated using the following formula: Percent disease index (PDI) = (Total grade points / Number of leaves observed) × (100 / Maximum grade observed). The weekly percent disease index (PDI) was recorded and correlated with mean weekly meteorological parameters such as maximum and minimum temperatures (°C) (T-max; T-min), morning and evening relative humidity (percentage) (m-RH; a-RH), bright sunshine hours (BSS), and total rainfall (RF) (mm), which were collected from the agro-meteorological observatory, SVPUAT, for the entire period of experimentation. The area under the disease progress curve (AUDPC), which gives a quantitative measure of disease development and disease intensity, was estimated using the following formula:

$$\text{AUDPC} = \frac{N_1(X_1+X_2)}{2} + \frac{N_2(X_2+X_3)}{2}$$

This formula was given by Milus and Line (1986) [8], where X₁, X₂, and X₃ represent disease severity recorded on the first, second, and third scoring dates, respectively; N₁ is the interval between X₁ and X₂, and N₂ is the interval between X₂ and X₃. The effect of crop growth stages and different meteorological parameters on disease severity was determined by correlation analysis.

Statistical analysis

The recorded data were subjected to statistical analysis using

analysis of variance (ANOVA) for a randomized block design (RBD). The standard error of the mean (SEm) for each treatment and the critical difference (CD) for significant cases were computed at the 5% level of probability. Treatment means were compared using the least significant difference (LSD) test wherever applicable. Correlation analysis was also performed to determine the relationship between disease severity and meteorological parameters.

Results and Discussion

1. Crop growth stages and disease progression

From the findings of the present investigation, it was observed that disease initiation first occurred at the vegetative stage of crop growth and reached peak levels at the maturity stage, with a sharp increase from the reproductive to the ripening phase. The first appearance of the disease was recorded at the end of the first standard week of January during 2020-2021 (Table 1), with a disease index of 0.15 percent. In contrast, during 2021-2022, the first appearance of the disease was observed in the second standard week of January, with a disease index of 0.10 percent. Disease progression varied significantly between the two cropping years. The highest disease progression was observed during 2020-2021, with a maximum disease index of 42.5 percent and an AUDPC (Area Under Disease Progress Curve) value of 1263.25. In comparison, during 2021-2022, the maximum disease index recorded was 37.5 percent, with an AUDPC value of 1154.3. These results are in agreement with the findings of Gupta *et al.* (2017) [4], who reported an initial disease severity of 1 percent at the jointing stage (73 days after sowing), followed by a gradual increase in disease progression toward maturity, ultimately resulting in maximum disease severity. The development of yellow rust in wheat increased as the crop progressed from the vegetative to the ripening stage, particularly during the period from January to March under prevailing relative humidity conditions, when the crop tends to become more susceptible to the disease (Sandhu *et al.*, 2017; Kashyap *et al.*, 2018) [14, 6]. The higher severity of yellow rust observed as the crop approaches maturity may be attributed to physiological exhaustion, as a major portion of the plant's energy is diverted toward reproductive development. Consequently, less energy remains available for defense against disease, which may be a key factor contributing to increased disease severity at later growth stages.

2. Correlation of disease progress with temperature and relative humidity

From the findings of the present investigation, it was observed that an increase in PDI (percent disease index) occurred during the mid and end of the cropping season, with a corresponding decrease in weekly maximum temperature (T-max) during both consecutive years. This relationship showed significant positive correlation (SPC) coefficients (r) of 0.915** and 0.950** during 2020-2021 and 2021-2022, respectively. Similarly, a highly significant positive correlation was observed between weekly PDI and weekly minimum temperature (T-min), with correlation coefficients (r) of 0.978** and 0.905** during 2020-2021 and 2021-2022, respectively (Table 2). From these findings, it is evident that an increase in both T-max and T-min toward the end of the cropping season may be unfavorable for the progression of yellow rust disease in wheat during both years. Mateen and Khan (2014) also reported a positive linear relationship between temperature and disease severity.

The experimental results further indicated that higher weekly morning relative humidity (m-RH) was observed throughout the

cropping period during 2020-2021 (>94.86 percent), in contrast to lower weekly m-RH values recorded during 2021-2022 (<28.4 percent). On the other hand, afternoon relative humidity (a-RH) exhibited a significant negative correlation with weekly PDI toward the end of the cropping season during 2020-2021 ($r = -0.830^{**}$). Similarly, a highly significant negative correlation ($r = -0.629^{**}$) between a-RH and weekly PDI was observed toward the end of the season during 2021-2022, indicating a greater decline in a-RH at the end of the crop season. These results suggest that prolonged higher levels of weekly m-RH and a-RH, along with increased T-max and T-min toward the end of the crop season in 2020-2021, were responsible for greater disease progression and higher PDI compared to 2021-2022, where lower m-RH and a-RH were recorded. These findings are in agreement with Gupta *et al.* (2017) [4] and Mateen and Khan (2014), who reported that PBW 343 exhibited a disease severity of 1.0 percent at the jointing stage (73 days after sowing), with corresponding weather parameters (one week prior) of maximum temperature 17.5 °C, minimum temperature 5 °C, maximum relative humidity 92.5 percent, and minimum relative humidity 59 percent.

3. Correlation of disease progress with rainfall and bright sunshine hours

From the experimental data, a positive and significant correlation was observed between rainfall and the percent disease index (PDI) of stripe rust during both years, 2020-2021 and 2021-2022. However, continuous intermittent drizzles, especially from the vegetative stage to the early reproductive stage during 2020-2021, may have contributed to greater spore dispersal (high inoculum pressure), resulting in higher PDI in that year. In contrast, during 2021-2022, no precipitation occurred at these stages, which may explain the comparatively lower disease intensity. Mateen and Khan (2014) reported similar findings, indicating that environmental factors have a significant effect on the progression of stripe rust in wheat. A positive linear relationship between temperature (maximum and minimum) and disease severity showed that stripe rust was most prevalent at maximum temperatures of 28-32°C and minimum temperatures of 14-18°C. Other environmental factors, such as relative humidity, rainfall, and wind speed, also showed positive correlations with disease severity. From the present findings, a non-significant negative correlation was observed between the percent disease index (PDI) and bright sunshine hours (BSS) during both cropping seasons, 2020-2021 and 2021-2022. Similar findings were also reported by Kashyap *et al.* (2018) [6] and Sandhu *et al.* (2017) [14].

Conclusion

The present investigation established that wheat stripe rust development and progression under field conditions are closely associated with crop growth stage and prevailing environmental factors. The disease appeared in early January and progressed steadily with crop advancement, reaching maximum severity at the maturity stage. Comparatively higher disease intensity and AUDPC values during 2020-21 indicated that this season provided more favorable conditions for stripe rust development than 2021-22. Among the weather variables studied, temperature, relative humidity, rainfall, and bright sunshine hours significantly influenced disease progression. Higher humidity and intermittent rainfall during the vegetative to reproductive phases appeared to promote disease buildup, while temperature and sunshine hours also contributed to variation in disease severity between seasons. These findings highlight the importance of understanding weather-disease relationships for forecasting stripe rust occurrence in wheat. Such information can be effectively utilized

for early warning, timely disease management, and the development of predictive models to minimize yield losses under field conditions.

Table 1: Weekly PDI in relation with different crop stages of wheat and total AUDPC (area under disease progress curve) during the year 2020-2021 and 2021-2022

2020-2021			2021-2022		
Crop stage	Standard week	PDI	Crop stage	Standard week	PDI
Vegetative stage	49	0	Vegetative stage	49	0
	50	0		50	0
	51	0		51	0
	52	0		52	0
	1	0.15		1	0
Late Vegetative stage	2	0.28	Late Vegetative stage	2	0.10
	3	0.80		3	0.70
	4	2.15		4	1.9
Reproductive stage	5	4.10	Reproductive stage	5	3.7
	6	6.45		6	5.2
	7	11.73		7	9.8
	8	16.45		8	15.4
	9	21.63		9	20.3
Ripening stage	10	26.96	Ripening stage	10	25.7
	11	31.37		11	29.3
	12	37.15		12	34.1
	13	42.5		13	37.4
	Total AUDPC	1263.25		Total AUDPC	1154.3

Table 2: Weekly meteorological parameters correlated with weekly PDI during the cropping season 2020-2021

Standard week	PDI	T max	T min	m-RH	a-RH	BSS	Rainfall
49	0	26.3	7.9	85	45	6.1	0
50	0	22.9	6.4	85.6	49.9	4.8	5.9
51	0	20.3	6	87.4	51.3	5.8	0
52	0	18.7	4.9	92.1	54.4	5.2	0.2
1	0.15	19.01	6.17	94.14	66.14	2.79	24
2	0.28	18.84	5.7	94.86	63.57	3.86	0
3	0.80	18.13	7.2	93.29	62.29	3.23	0
4	2.15	18.8	6.46	90	57.29	4.76	0
5	4.10	21.61	7.13	85.71	56	6.21	1.1
6	6.45	23.94	7.73	86	55.29	7.43	5.6
7	11.73	26.56	9.8	84.29	43	5.91	0
8	16.45	29.44	12.04	83.29	40.43	7.77	0
9	21.63	30.47	14.11	76.57	41.29	9.23	0.1
10	26.96	32.26	14.54	72.57	35.43	8.74	0
11	31.37	34.01	15.74	71	32.86	6.6	0
12	37.15	35.09	16.63	75.57	38	6.57	0
13	42.5	38.26	16.86	71.86	35.14	8.83	0

PDI-Percent disease index; Tmax- Maximum temperature; Tmin- Minimum temperature; m-RH- morning relative humidity; a-RH- Afternoon relative humidity; BSS- Bright sunshine hours; RF-Rainfall.

Table 3: Weekly meteorological parameters correlated with weekly PDI during the cropping season 2021-2022

Correlation coefficients (r)	
Max temp	0.915**
Min temp	0.978**
m-RH	-0.906**
a-RH	-0.830**
BSS	0.704**
Rainfall	-0.279 ^{NS}

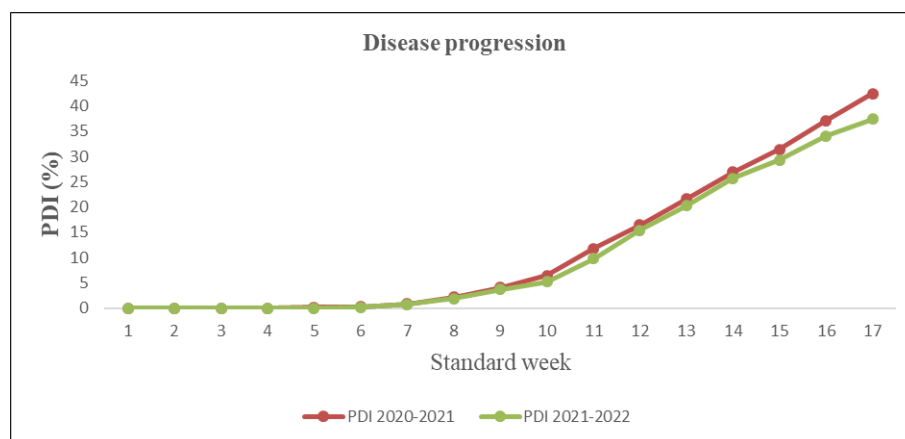
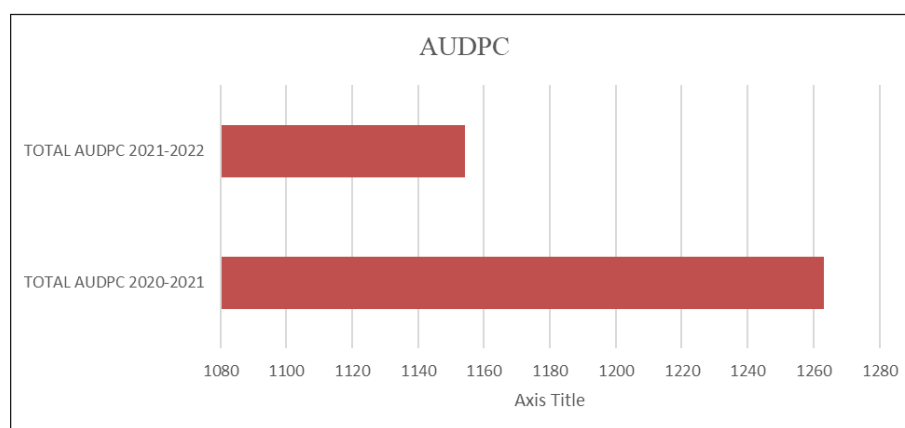
Table 4: Weekly meteorological parameters in relation to percent disease index (PDI) during the cropping season 2021-2022.

Standard week	PDI	T max	T min	m-RH	a-RH	BSS	Rainfall
49	0	23.07	11.64	84.29	48.14	4.21	0.9
50	0	22.4	9.36	83.43	39.43	5.8	0
51	0	20.74	7.17	82.43	38.43	6.2	0
52	0	20	6.49	88.63	49.5	4.69	2.5
1	0	20.6	7.5	84.6	61.1	4.1	9.9
2	0.10	17.7	5.3	91.9	80.6	1.2	67.5
3	0.70	16.2	4.7	92.6	71.1	1.6	3.7
4	1.9	16.6	5.3	91.6	67.9	3.2	33.9
5	3.7	20.1	6	88.6	67	2.6	18.4
6	5.2	20.5	7.3	85.9	64.1	5.3	4.5
7	9.8	24.3	8.3	82.6	57.4	6.9	0
8	15.4	25.9	9.9	82.7	50.3	7.4	0.7
9	20.3	26	10.5	88.6	53.1	8.3	31.5
10	25.7	30.3	13.4	76	43	8.8	0
11	29.3	34.2	17.1	71.1	39.6	8.5	0
12	34.1	37.5	20.1	67.4	34.3	8.9	0
13	37.4	38.7	20.3	58.9	28.4	9.3	0

PDI-Percent disease index; Tmax- Maximum temperature; Tmin- Minimum temperature; m-RH- morning relative humidity; a-RH-Afternoon relative humidity; BSS- Bright sunshine hours; RF-Rainfall.

Table 5: Correlation coefficients (r) between meteorological parameters and percent disease index (PDI)

	Correlation coefficient (r)
Max temp	0.950**
Min temp	0.905**
m-RH	-0.853**
a-RH	-0.629**
BSS	0.837**
Rainfall	-0.268 ^{NS}

**Fig 1:** Percent disease index (PDI) at different standard week during the years 2020-21 and 2021-22**Fig 2:** Area under disease progress curve (AUDPC) values during the years 2020-21 and 2021-22.

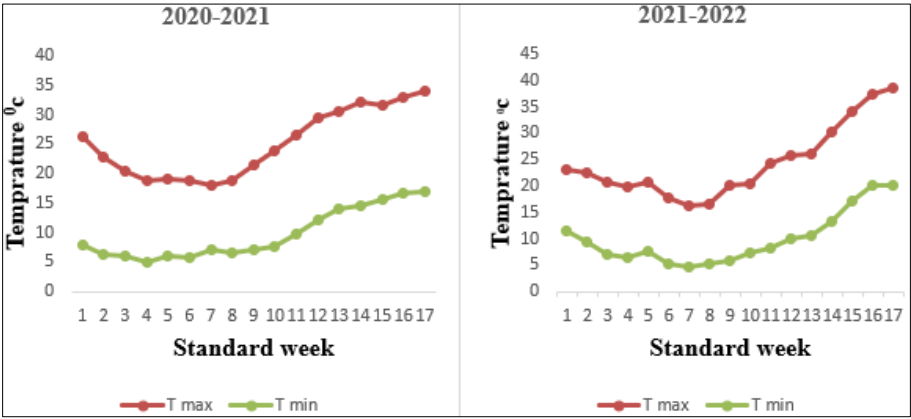


Fig 3: Trend of maximum (Tmax) and minimum (Tmin) temperature of cropping season 2020-20 and 2021-22.

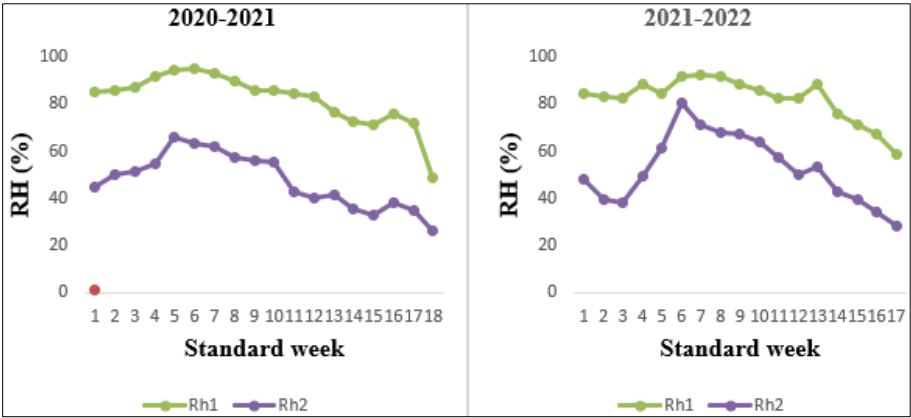


Fig 4: Trend of morning (RH1) and afternoon (RH2) temperature of cropping season 2020-20 and 2021-22

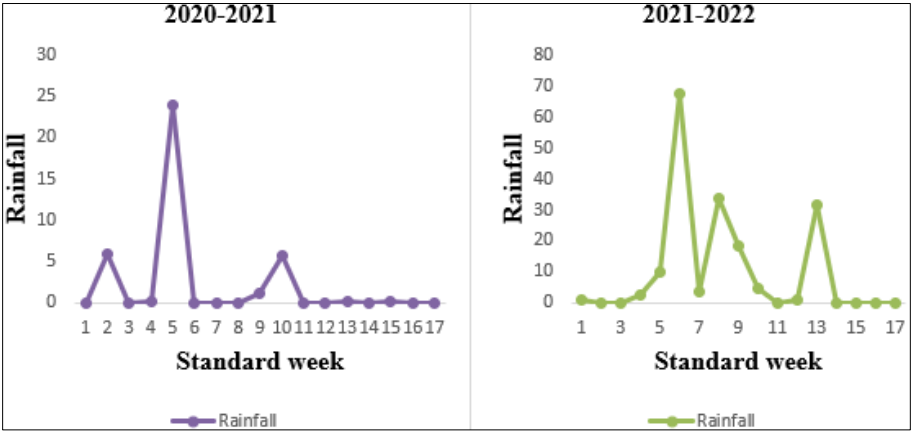


Fig 5: Trend of rainfall of cropping season during rabi season 2020-20 and 2021-22

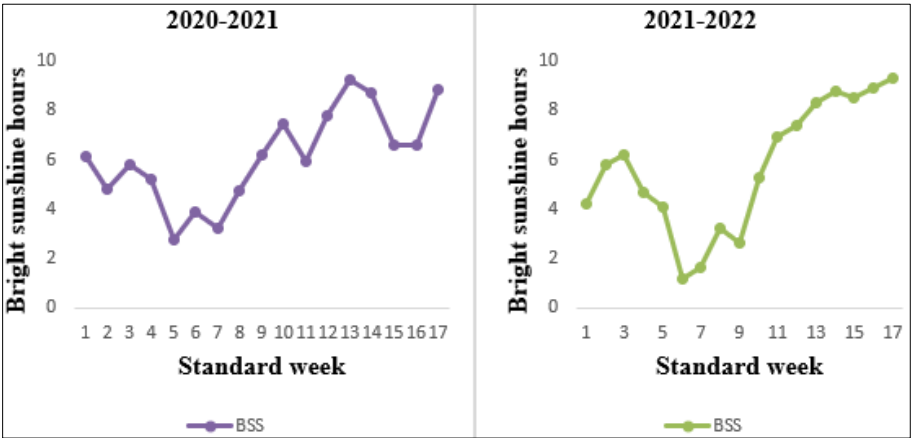


Fig 6: Trend of bright sunshine hours of cropping season during season 2020-20 and 2021-22

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