Agric Res J ***62*** *(3): 345-352, June 2025*
DOI: 10.5958/2395-146X.2025.00041.0

INFLUENCE OF PREVAILING WEATHER VARIABLES ON KARNAL BUNT DYNAMICS IN WHEAT

Shubham Anand[1], Sarabjot Kaur Sandhu[1] and Parminder Singh Tak[2]
[1]*Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana-141 004, Punjab, India*
[2]*Department of Plant Pathology, Punjab Agricultural University, Ludhiana-141 004, Punjab, India*

ABSTRACT

Field experiments were conducted with three wheat varieties *viz*. PBW 725, HD 2967 and HD 3086 sown on three different dates (14-15th October, 8-9th November and 3rd-4th December) with two microclimate modification levels with four replications at the Research Farm, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana (Ldh), India and Regional Research Station, Gurdaspur (Gsp) during *rabi* season of 2021-22 and 2022-23. The main objective of study was to investigate the effect of prevailing weather conditions and microclimatic modification on Karnal bunt incidence of wheat under two agroclimatic zones of Punjab. Karnal bunt incidence was highest in PBW 725 (17.1–12.4% at Ludhiana, 20.3–15.4% at Gurdaspur), followed by HD 2967 (16.1–11.4% at Ludhiana, 19.3–13.9% at Gurdaspur) and HD 3086 (15.5–10.6% at Ludhiana, 17.9–12.9% at Gurdaspur). November sowing (D_2) and additional water sprays (M_2) significantly increased Karnal bunt incidence. The highest incidence was observed in D_2M_2 (17.6–12.4% at Ludhiana, 20.4–15.4% at Gurdaspur), while the lowest was in D_3M_1 (15.1–10.5% at Ludhiana, 18.1–12.9% at Gurdaspur). Higher Karnal bunt incidence during 2021-22 than 2022-23 can be primarily attributed to lower maximum and minimum temperature and higher morning and evening relative humidity during 2021-22 than 2022-23. In 2021-22, the maximum amount of rainfall was received between the 1st and 5th SMW [149.3 mm (Ldh) and 235 mm (Gsp)] which had positive influence on disease incidence, while in 2022-23, it was concentrated between the 11th and 14th SMW [77.2 mm (Ldh) and 78 mm (Gsp)] at both locations. The booting stage of wheat sown in November coinciding with low temperature, high humidity and rainy days are crucial parameters for Karnal bunt development.

Keywords: Karnal bunt, Microclimate modification, Weather variables, Wheat

Crop diseases are profoundly influenced by prevailing weather conditions. The disease triangle, a conceptual framework, elucidates the fundamental elements contributing to disease occurrence. It suggests that diseases manifest when a potent pathogen interacts with a susceptible host organism in favourable environmental conditions. Newbery *et al.* (2016) have facilitated a more concise comprehension of how climate, crop growth and disease models can be seamlessly integrated to predict crop growth stages and disease incidence/ severity across different climate change scenarios. The issue of effective plant disease protection is closely linked to the challenges of sustainable agriculture and climate change. Climate change can impact pathogen development stages and rates, as well as alter host plant resistance, resulting in physiological changes in the interactions between hosts and pathogens. These changes can have significant implications for the occurrence and management of plant diseases (Garret *et al*., 2006).

Smiley (1996) highlighted the importance of specific climatic elements, particularly adequate rainfall and associated humidity levels, influencing crucial stages of the teliospore lifecycle-germination, secondary sporidial multiplication, penetration, and infection. These events must align with the susceptible period, typically spanning 3 to 4 weeks leading up to wheat anthesis. The specified favourable rain and humidity events involve quantifiable rainfall (> 3 mm) occurring on two or more consecutive days, with at least 10 mm within a 2-day interval, and an average daily relative humidity exceeding 70% on both rainy days. In essence, the weather conditions conducive to the survival, establishment, and spread of *Tilletia indica* sporidia during the susceptible period before wheat anthesis encompass maximum temperature ranging from 16 to 23°C, minimum temperature ranging from 7 to 11°C, average daily humidity (>70%), or relative humidity surpassing 48% at

*Corresponding author: skchahal@pau.edu
Date of receipt: 16.05.2024, Date of acceptance: 10.06.2025

3 pm, along with measurable rainfall on multiple consecutive days (Smiley and Patterson, 1996).

Employing epidemiology as a key tool becomes crucial for assessing disease incidence, evaluating crops in fields and model farms and inspecting storage facilities to ascertain the status of grain lots for national consumption. Karnal bunt incidence is also influenced significantly by microclimatic conditions and prevailing weather conditions. Attri *et al.* (2021) found that relative humidity inside crop canopy and canopy temperature showed 71 and 65 per cent variability in Karnal bunt incidence and additional leaf wetness caused higher disease incidence. Comprehending the relationships between meteorological parameters, microclimatic conditions, disease incidence and development is crucial for effective disease management. With this perspective in mind, study was designed to investigate how agronomic practices influence Karnal bunt incidence in wheat across two agroclimatic regions and identify meteorological parameters that impact Karnal bunt in wheat crop.

MATERIALS AND METHODS

The field experiments were conducted with three wheat varieties *viz.,* PBW 725, HD 2967 and HD 3086 sown on three different dates at Gurdaspur (14th October, 8th November and 3rd December) and at Ludhiana (15th October, 9th November and and 4th December) with two microclimate modification levels with four replications during 2021-22 and 2022-23. The experiment was laid out in Split Plot Design with varieties in main plot and dates of sowing x microclimate modification levels as sub plots. The two microclimate modifications were M_1 (Recommended irrigations) and M_2 (Recommended irrigations + 2 additional water sprays). Power sprayer with cut nozzle was used 10 days and 25 days after disease inoculation to give water sprays in M_2 to imitate rainfall effect. The selected plots were sprayed nine times at 30 minutes interval starting from 10 am spanning one full day. Daily data of different meteorological parameters were collected from the Agrometeorological Observatory of Ludhiana and Gurdaspur.

Agronomic practices

To prepare the field, plank levelling was done and then the field was ploughed thrice using a tractor-drawn disc harrow. In both experiments, wheat was sown by using seed @ 40 kg/acre using the *kera* method on a flat surface at a depth of 4 to 6 cm and with a row spacing of 22.5 cm. The fertilizers were applied in accordance with the recommendations suggested in PAU's Package of Practices for *rabi* crops in Punjab. Nitrogen, Phosphorus and Potassium were applied at rate of 110 kg N/acre, 55 kg P_2O_5/acre and 20 kg K_2O/acre, respectively. At the time of sowing, the full doses of P and K as well as half of the nitrogen dose were applied. After first irrigation, the remaining half nitrogen dose was applied. In order to promote good seed germination, the crop was provided irrigation prior to sowing. Four irrigations were then given to the crop over the growing season, depending on the crop's needs and the weather. During 2021-22, a special irrigation was provided during March month to save crop from heat stress at both locations after following the agro advisory issued for both locations. To control the weeds, one litre of pendimethalin (Stomp 30 EC) was used per acre as a pre-emergence herbicide. After the first irrigation, two manual hoeings were also done to control weeds in addition to herbicide spray. Actara 25WG (thiamethoxam) was sprayed on the crop @ 20g per acre in 100 litres of water to manage wheat aphid, while to manage yellow rust, brown rust at the time of disease appearance and for Karnal bunt management at ear emergence stage Tilt 25 EC (propiconazole) was used @ 200 ml per acre in 200 litres of water in control experiments conducted at both locations. For termite protection, 20 kg of moist sand was combined with 1.2 litres of Dursban 20 EC (chloropyriphos) per acre.

Artificial inoculation

For inducing Karnal bunt, crop was inoculated artificially at booting stage with a sporidial suspension of *Tilletia indica.* Aujla *et al.* (1982) developed a mist spray technique for artificial inoculation of wheat with *Tilletia indica*. Teliospores of *Tilletia indica* were collected from infected wheat grains. The teliospores were surface sterilized and placed on 2% water agar for germination. After germination, secondary sporidia (allantoid or curved type) were harvested from the agar plates. The sporidial suspension was prepared by suspending these secondary sporidia in sterile distilled water. The concentration of the suspension was adjusted to 5×10^4 to 1×10^5 sporidia/ml for effective infection. Wheat plants at the booting stage (Zadoks Scale 45-49) were selected for inoculation. The ear heads were exposed from the boot leaf before anthesis. A fine mist spray of the sporidial suspension was applied using an hand sprayer. The spray was directed at the emerging wheat spikes, ensuring full coverage. Each earhead was sprayed twice at 12-hour intervals to increase the chances of infection. Healthy and uniform plants were chosen to ensure consistent results. Plastic polythenes were used to cover the inoculated plants after sprinkling water around the boots to maintain humidity. Around 100 boots in each of the 72 plots were artificially inoculated. The disease incidence was recorded from 100 plants of each plot which were artificially inoculated at the boot leaf stage. The following formula was used to compute the per cent disease incidence of Karnal bunt at harvest:

$$\text{Disease incidence (\%)} = \frac{\text{No. of infected grains}}{\text{Total no. of grains examined}} \times 100$$

RESULTS AND DISCUSSION

Disease observations

The Karnal bunt incidence across different wheat varieties, sowing dates, and microclimate modifications was calculated for two locations (Ludhiana and Gurdaspur) over two consecutive years (2021-22 and 2022-23). Among the three wheat varieties tested, PBW 725 (V_1) exhibited the highest Karnal bunt incidence across all locations and years (Fig. 1). At Ludhiana, Karnal bunt incidence in PBW 725 was recorded as 17.1% in 2021-22 and 12.4% in 2022-23, whereas at Gurdaspur, it was 20.3% in 2021-22 and 15.4% in 2022-23. The variety HD 2967 (V_2) followed a similar trend but with slightly lower Karnal bunt incidence *i.e.* 16.1% and 11.4% at Ludhiana and 19.3% and 13.9% at Gurdaspur during the respective years (Fig. 2). HD 3086 (V_3) consistently showed the least Karnal bunt incidence, with values of 15.5% and 10.6% at Ludhiana and 17.9% and 12.9% at Gurdaspur in 2021-22 and 2022-23, respectively (Fig. 3). The Karnal bunt incidence among wheat varieties is statistically different in all cases (Table 1). Similar results for different varieties were observed by Attri (2021). He also observed that Karnal bunt incidence was maximum in PBW 725 as compared to HD 2967 and PBW 677. Similarly, Kaur *et al.* (2002) reported higher Karnal bunt infection in varieties PBW 725 and HD 2967 from different blocks of Tarn Taran district of Punjab. Bala *et al.* (2022) found that almost all wheat varieties grown in Punjab till date are susceptible to Karnal bunt. The analysis by Bala *et al.* (2013) revealed that during the years 2005 to 2012, Gurdaspur district had highest Karnal bunt incidence (60.46%), followed by the Muktsar (50.38%) and Moga (49.91%) districts, while Patiala had the lowest Karnal bunt incidence (14.96%). The interaction of sowing date and microclimate modification significantly influenced Karnal bunt incidence across both locations and years. At Ludhiana (2021-22), the highest Karnal bunt

Table 1. Analysis of variance (ANOVA) of Karnal bunt incidence during *rabi* season of 2021-22 and 2022-23 at Ludhiana and Gurdaspur

Location		Ludhiana		Gurdaspur	
Treatments		**2021-22**	**2022-23**	**2021-22**	**2022-23**
Varieties					
PBW 725 (V_1)		17.1	12.4	20.3	15.4
HD 2967 (V_2)		16.1	11.4	19.3	13.9
HD 3086 (V_3)		15.5	10.6	17.9	12.9
CD (p = 0.05)		*0.2*	*0.3*	*0.4*	*0.5*
Dates of sowing x microclimate modification					
14-15th October (D_1)	**Recommended irrigations (M_1)**	15.6	11.0	18.6	13.5
8-9th November (D_2)		16.9	11.3	19.7	14.5
3rd-4th December (D_3)		15.1	10.5	18.1	12.9
14-15th October (D_1)	**Recommended irrigations + 2 additional water sprays (M_2)**	16.3	12.1	19.4	14.4
8-9th November (D_2)		17.6	12.4	20.4	15.4
3rd-4th December (D_3)		15.8	11.6	18.7	13.8
CD (p = 0.05)		*0.4*	*0.3*	*0.5*	*0.4*

incidence (17.6%) was recorded for D_2M_2 (November 8-9th sowing with recommended irrigation and two additional water sprays), followed by D_2M_1 (16.9%), while the lowest incidence (15.1%) was observed in D_3M_1 (December 3rd-4th sowing with recommended irrigation). A similar trend was observed in 2022-23, where D_2M_2 had the highest Karnal bunt incidence (12.4%), followed by D_2M_1 (11.3%), while the lowest

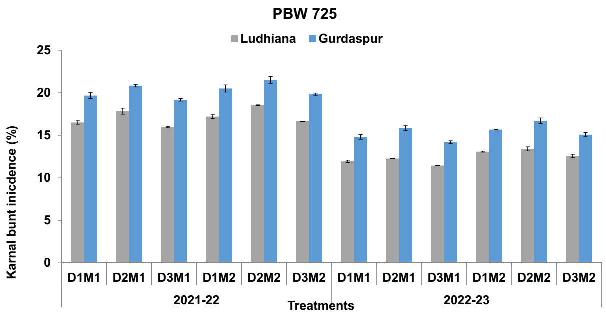

Fig. 1. Karnal bunt incidence in different dates of sowing and microclimate modification levels in variety PBW 725 during *rabi* season of 2021-22 and 2022-23 at Ludhiana and Gurdaspur

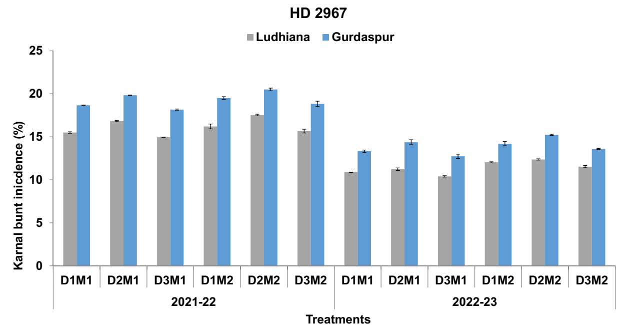

Fig. 2. Karnal bunt incidence in different dates of sowing and microclimate modification levels in variety HD 2967 during *rabi* season of 2021-22 and 2022-23 at Ludhiana and Gurdaspur

Table 2. Descriptive statistics of meteorological parameters and Karnal bunt incidence during *rabi* season of 2021-22 and 2022-23 at Ludhiana and Gurdaspur

Location	Ludhiana				Gurdaspur			
Meteorological parameter	Maximum	Minimum	Mean	Standard Deviation	Maximum	Minimum	Mean	Standard Deviation
***Rabi* 2021-22**								
Maximum temperature (°C)	39.9	13.5	25.6	7.3	39.3	13.6	25.8	7.3
Minimum temperature (°C)	24.4	5.0	12.3	5.5	21.7	3.9	12.2	5.5
Morning relative humidity (%)	97.0	61.0	88.8	7.9	96.7	57.0	84.7	10.7
Evening relative humidity (%)	83.0	13.0	45.6	17.5	83.1	38.4	61.0	11.8
Rainfall (mm)	51.6	0.0	7.0	14.7	88.1	0.0	10.5	23.2
Sunshine hours	10.7	0.1	6.7	2.7	7.9	0.0	5.0	2.0
Karnal bunt incidence (%)*			15.5-20.5%				15.5-22.5%	
***Rabi* 2022-23**								
Maximum temperature (°C)	36.1	13.3	25.1	5.7	35.7	11.1	24.8	6.4
Minimum temperature (°C)	22.9	4.3	12.1	4.8	22.4	3.6	11.6	5.3
Morning relative humidity (%)	95.0	75.0	88.9	4.7	97.7	74.2	87.8	6.5
Evening relative humidity (%)	72.0	19.0	45.2	13.1	88.1	33.7	58.7	13.2
Rainfall (mm)	33.0	0.0	4.2	8.2	36.4	0.0	4.9	8.3
Sunshine hours (hours)	11.1	1.4	6.7	2.8	8.6	0.6	4.8	1.9
Karnal bunt incidence (%)*			9.5-15.1%				10.5-17.8%	

* Karnal bunt incidence range in PBW 725, HD 2967 and HD 3086

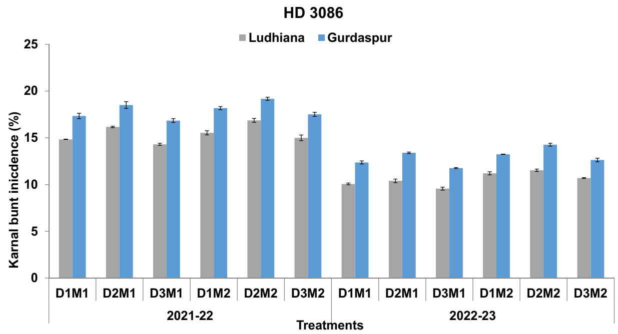

Fig. 3. Karnal bunt incidence in different dates of sowing and microclimate modification levels in variety HD 3086 during *rabi* season of 2021-22 and 2022-23 at Ludhiana and Gurdaspur

Karnal bunt incidence (10.5%) was recorded in D_3M_1. At Gurdaspur (2021-22), the highest Karnal bunt incidence (20.4%) was observed for D_2M_2, followed by D_2M_1 (19.7%), whereas the lowest incidence (18.1%) was recorded for D_3M_1. In 2022-23, D_2M_2 exhibited the highest Karnal bunt incidence (15.4%), followed by D_2M_1 (14.5%), while the lowest Karnal bunt incidence (12.9%) was recorded in D_3M_1. November sowing (D_2) resulted in significantly higher Karnal bunt incidence than December sowing (D_3). Additional water sprays (M_2) significantly increased Karnal bunt incidence compared to recommended irrigation (M_1). D_2M_2 and D_3M_1 consistently showed significant differences, indicating that delayed sowing and avoiding excessive irrigation can effectively reduce Karnal bunt incidence. Similarly, Attri *et al.* (2021) observed that increased leaf wetness led to a higher disease incidence (26.99%) as compared to recommended irrigation condition (11.56%). They also reported that relative humidity and canopy temperature had a strong influence on Karnal bunt development. The variation in disease incidence among different varieties across years may be attributed to prevailing weather conditions during the critical growth stages (booting/earing) as well as the morphological traits and inherent tolerance or escape mechanisms of specific varieties.

Meteorological observations

The descriptive statistics of studied factors *viz.* meteorological parameters during 2021-22 and 2022-23 at Ludhiana and Gurdaspur are presented in Table 2. At Ludhiana, during 2021-22, the range of various meteorological parameters *viz.* maximum temperature (13.5-39.9°C), minimum temperature (5.0-24.4°C), morning relative humidity (61-97%), evening relative humidity (13-83%), sunshine hours (0.1-10.7 hrs/day) and rainfall (0.0-51.6 mm) were recorded. The maximum temperature ranged between 13.3°C and 36.1°C, while the minimum temperature ranged from 4.3°C to 22.9°C during 2022-23 at Ludhiana. Jhorar *et al.* (1992) reported that minimum temperature between 7-11ºC from booting to anthesis is favourable for Karnal bunt diseases. Sharma and Sharma (2015) found that the sporidia remained viable for 21 days in January, 18 days in February and only 9 days in March at monthly average temperature of 11.8°C, 15.2°C and 19.5°C in 2006-07, respectively and of 11.5°C, 13.3°C and 22.2°C in 2007-08, respectively. Morning relative humidity was observed in range of 75%-95% and evening relative humidity ranged from 19%-72%. Increasing relative humidity (RH) has beneficial effect on the survival of teliospores. With increase in RH from 55-100 per cent, the per cent germination of sporidia also increased (Kaur *et al.*, 2002). Sunshine hours spanned from 1.4 to 11.1 hours per day and rainfall varied from 0 to 33 mm. The cumulative sunshine hours during 2021-22 were 1204.8 hours and 1211.5 hours in 2022-23. Mavi *et al.* (1992) reported that sunshine hours from 9th to 11th SMW have negative impact on disease intensity. Biswas *et al.* (2013) concluded that Karnal bunt of wheat is influenced by meteorological parameters. Day temperature between 25-30°C and night time temperature between 10-15°C showed higher probability density asserting good association with sporidial showering. However, separately, relative humidity (RH) of morning or evening did not show such good association. But the diurnal range was important as RH morning > 90 per cent and RH evening between 40 and 60 per cent gave the maximum combined probability density with daily sporidial showering. A predictive regression model for inoculum load was constituted with an adjusted R^2 value of 0.89 and could explain maximum variance in the response variable. During 2021-22 and 2022-23, the total recorded rainfall at Ludhiana varied, with 195.3 mm in 2021-22 surpassing the 118.1 mm in 2022-23 (Fig.4.). The distribution of rainfall was uneven across the seasons; in 2021-22, it was concentrated between the 1st and 5th standard meteorological weeks (SMWs), while in 2022-23, it occurred predominantly between the 11th and 14th SMWs. Specifically, Ludhiana received higher amount of rainfall (113.4 mm) in January 2022, contrasting with 18.1 mm in January 2023. Above-normal rainfall of 55.0 mm occurred in March during 2023, whereas a negligible amount of rainfall (0.8 mm) was recorded in 2022. Singh *et al.* (2013) predicted

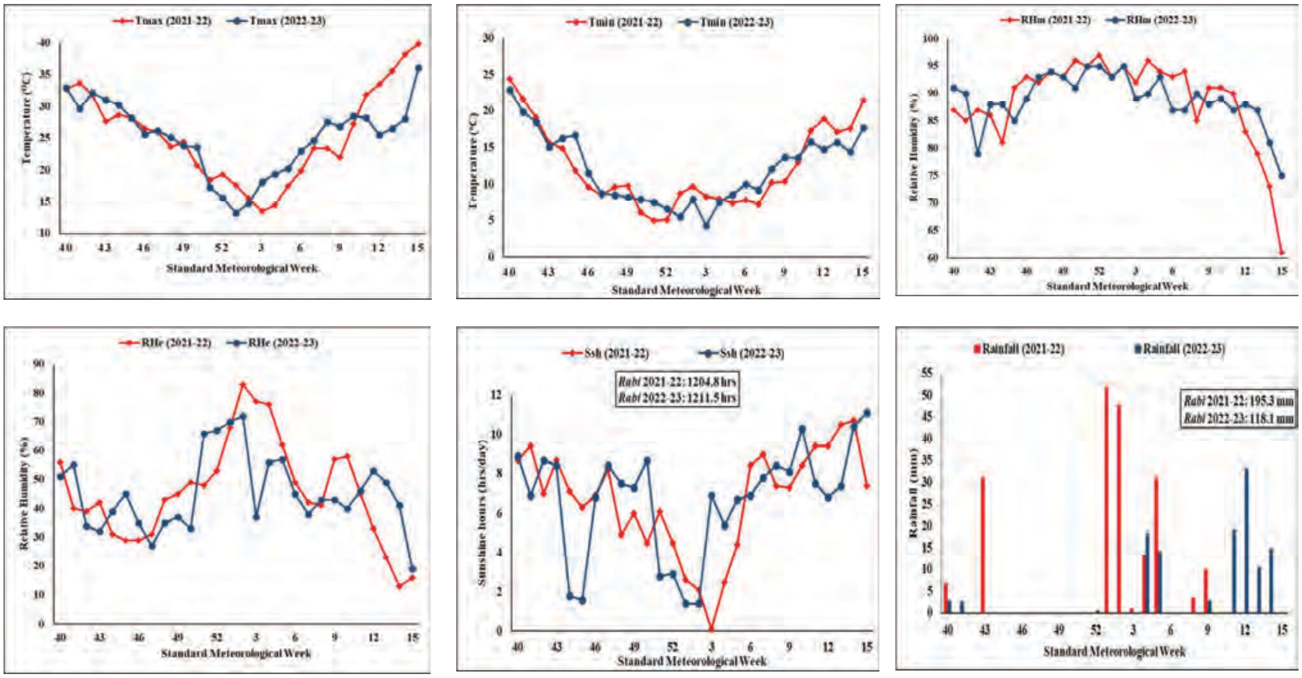

Fig. 4. Weekly meteorological parameters during crop duration in *rabi* season of 2021-22 and 2022-23 at Ludhiana

the occurrence of Karnal bunt of wheat on the basis of meteorological parameters in Karnal. They found that rainfall and number of rainy days during the 6th SMW were the most important weather parameters indicating a favourable role in the development of Karnal bunt. Wind speed was also important during this week for the transfer of primary sporidia from soil to leaf. Rainfall, number of rainy days have favourable role in further multiplication of secondary sporidia during the week following inoculations. The maximum temperature during 9th SMW, minimum temperature during 8th SMW and rainy days during 6th, 11th and 12th SMW were identified as most contributing to disease incidence in the region. Singh *et al.* (2010) studied the effect of weather parameters from 1st January to 25th March on Karnal bunt disease in wheat in Karnal region of Haryana. They found that when the maximum temperature exceeded normal along with little or poor rainfall during 6th to 8th SMW, the disease intensity was low. But when there was no rainfall during 6th and 7th SMW, there was no disease occurrence during that year. Rainfall during the 3rd week of January showed strong relationship indicating favourable role in formation and further multiplication of secondary sporidia. Maximum temperature, relative humidity, rainfall, sunshine duration during 9th SMW showed high correlation. Five weather parameters *viz*. rainfall, maximum temperature, evening relative humidity and number of rainy days caused 84 per cent occurrence of Karnal bunt in Karnal during 6th to 12th SMW.

At Gurdaspur, the maximum temperature was in range of 13.6°C to 39.3°C, while the minimum temperature ranged from 3.9°C to 21.7°C during 2021-22. Morning and evening relative humidity ranged from 57%-96.7% and 38.4%-83.1%, respectively. Khan *et al.* (2010) concluded that if the average minimum temperature ranged between 11 to 16°C and maximum temperature between 27.5 to 31.1°C in the month of February and March in Pakistan, then the incidence of Karnal bunt will be higher. They found that rainfall of 1.10 mm, relative humidity of 49 per cent, low minimum temperature of 14.8°C and low maximum temperature of 27.8°C during the year 2007 caused more disease incidence as compared to year 2006. Sunshine hours spanned from 0.0 to 7.9 hours per day and rainfall varied from 0.0 to 88.1 mm during 2021-22. During 2022-23, the range of various meteorological parameters *viz.,* maximum temperature (11.1-35.7°C), minimum temperature (3.6-22.4°C), morning relative humidity (74.2-97.7%), evening relative humidity (33.7-88.1%), sunshine hours (0.6-8.6hrs/day) and rainfall (0.0-36.4 mm) were recorded. Higher evening relative humidity was observed during most of the cropping season in 2021-22 as compared to 2022-23. The cumulative sunshine hours for 2021-22 were 967.8 hours, exceeding the 926.2 hours recorded in 2022-

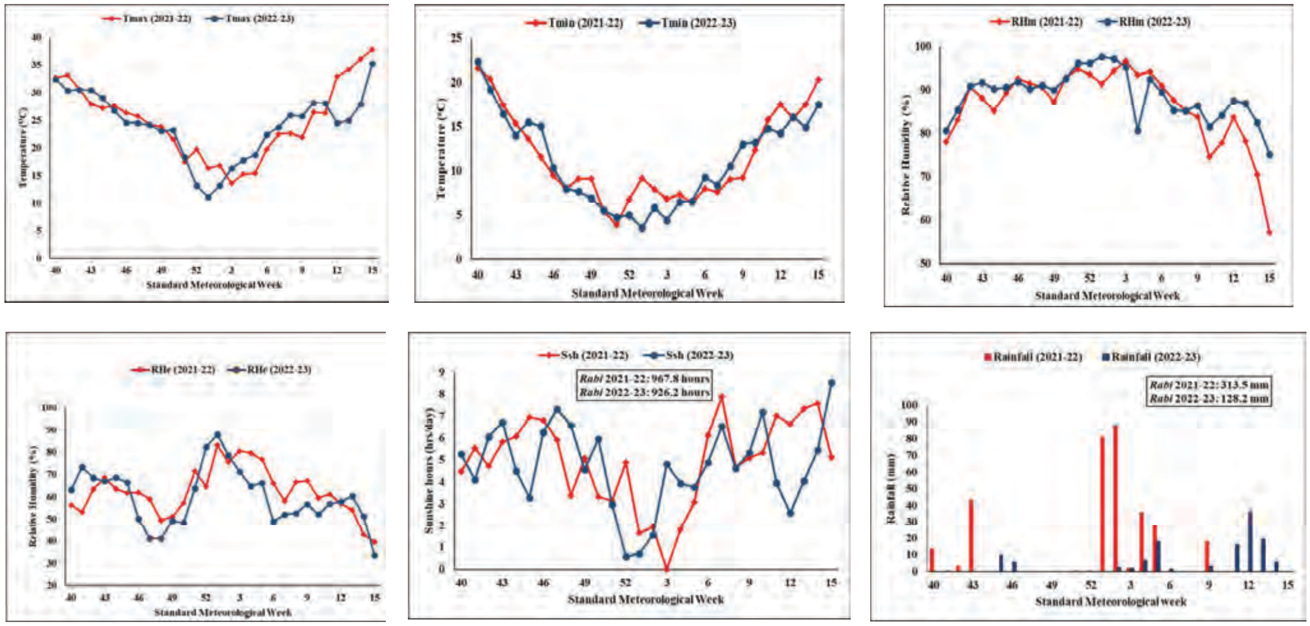

Fig. 5. Weekly meteorological parameters during crop duration in *rabi* season of 2021-22 and 2022-23 at Gurdaspur

23 at Gurdaspur. This district experienced a higher total rainfall of 313.5 mm in 2021-22 compared to 128.2 mm in 2022-23 (Fig. 5.). Similar to Ludhiana, the distribution was uneven, with the majority in 2021-22 between 1st to 5th SMWs and in 2022-23 between 11th to 14th SMWs. During January 2022, Gurdaspur received 207.2 mm rainfall which was significantly higher than the 11.4 mm in January 2023. Singh *et al.* (2018) found that rainfall and number of rainy days along with minimum temperature during the 6th SMW were the most important weather parameters indicating favourable role in the development of Karnal bunt disease. Wind speed was also important during this week for the transfer of primary sporidia from soil to leaf. Rainfall along with morning and evening relative humidity during 9th SMW indicated favourable role in further multiplication of secondary sporidia. Rainfall and rainy days during 10th, 11th and 12th standard meteorological week (SMW) helped in multiplication of Karnal bunt disease in wheat.

At both locations, during disease development period, the maximum and minimum temperatures were lower while morning and evening relative humidity were higher during 2021-22 than 2022-23. In 2021-22, the maximum amount of rainfall occurred between the 1st and 5th SMW [149.3mm (Ldh) and 235mm (Gsp)] which had positive influence on disease incidence, while in 2022-23, it was concentrated between the 11th and 14th SMW [77.2 mm (Ldh) and 78.0 mm (Gsp)]. Thus, temperature (maximum and minimum), humidity (morning and evening) and rainfall are crucial parameters for Karnal bunt disease development.

CONCLUSION

From the study it can be concluded that none of the tested variety is resistant to Karnal bunt. Microclimate modification through additional water sprays caused higher Karnal bunt incidence. Higher Karnal bunt incidence can be primarily attributed to lower maximum & minimum temperature and higher morning and evening relative humidity during crop season. Rainfall received at booting stage has positive influence on disease incidence. Normal sowing along with recommended irrigation and two additional rainy days aggregate Karnal bunt incidence. The booting stage of wheat sown in November coinciding with low temperature, high humidity and rainy days are crucial parameters for Karnal bunt disease development. So if the weather is favourable for development of Karnal bunt and inoculum is available, disease can occur in severe form. Under such situations, farmers of state should follow PAU recommendation to spray the recommended fungicide(s) at critical crop stage to get Karnal bunt free seed.

LITERATUE CITED

Aujla S S, Grewal A S, Gill K S and Sharma I 1982. New technique of mist spray for Karnal bunt studies. *Indian Phytopathol* **35**: 716-17.

Attri A 2021. *Effect of meteorological parameters on*

Karnal bunt incidence in wheat. M.Sc. Thesis, Punjab Agricultural University, Ludhiana, India.

Attri A, Sandhu S K and Bala R 2021. Effect of microclimate modification on Karnal bunt of wheat under Ludhiana conditions. *Agric Res J* **58**: 1036-41.

Bala R, Kaur D J, Sharma I and Sharma R C 2013. Incidence of Karnal bunt and Ear cockle in Punjab. *Indian Phytopathol* **66**: 313-15.

Bala R, Kaur J, Tak P S, Sandhu S K and Pannu P P S 2022. A model for *Tilletia indica* (Karnal bunt)-*Triticum aestivum* (Wheat) system under changing environmental conditions. *Indian Phytopathol* **75**: 723-30.

Biswas B, Dhaliwal L K, Maan S K, Kaur G and Kashyap P 2013. A model based approach for predicting Karnal Bunt disease of Wheat under Punjab conditions. *J Agrometeorol* **15**: 158-62.

Garret K A, Dendy S P, Frank E E, Rouse M N and Travers S E 2006. Climate change effects on plant disease: Genomes to ecosystems. *Annu Rev Phytopathol* **44**: 489-509.

Jhorar O P, Malvi H S, Sharma I, Mahi G S, Mathauda S S and Singh G 1992. A biometeorological model for forecasting Karnal bunt disease of wheat. *Plant Dis Res* **7**: 204-09.

Kaur S, Singh M and Singh K 2002. Factors affecting telial and sporidial inoculum of *Neovossia indica*. *Indian Phytopathol* **55**: 14-18.

Khan M A, Shakoor M A, Javed N, Arif M J and Hussain M 2010. A disease predictive model for Karnal bunt of wheat based on two years environmental conditions. *Pak J Phytopathol* **22**: 108-12.

Newbery F, Qi A and Fitt B D 2016. Modelling impacts of climate change on arable crop diseases: Progress, challenges and applications. *Curr Opin Plant Biol* **32**: 101-09.

Sharma R C and Sharma I 2015. Role of seed borne inoculum on Karnal bunt infection risks. *J Wheat Res* **7**: 31-38.

Singh R, Karwasra S S, Biswas B and Singh Diwan 2013. Development of predictive model for Karnal bunt of wheat. *J Agrometeorol* **15**(special issue 1): 112-14.

Singh R, Singh R, Karwasra S S, Kumar A and Choudhary D 2018. Climate suitability for Karnal bunt (*Tilletia indica*) disease of wheat crop in Haryana. *J Agrometeorol* **20**(special issue 1): 184-87.

Singh R, Singh R, Singh D, Mani J K, Karwasra S S and Beniwal M S 2010. Effect of weather parameters on Karnal bunt disease in wheat in Karnal region of Haryana. *J Agrometeorol* **20**: 99-101.

Smiley R W and Patterson L M 1996. Pathogenic fungi associated with *Fusarium* foot rot of winter wheat in the semiarid Pacific Northwest. *Plant Dis* **80**: 944-49.