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Disease-driven yield losses in wheat (*Triticum aestivum*) crop under different agroclimatic locations of Punjab

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ABSTRACT

The experiments were conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at Punjab Agricultural University, Ludhiana, Punjab to examine the yield losses due to diseases in wheat (*Triticum aestivum* L.) crop under different agroclimatic locations of Punjab. The experiment was conducted in split-plot design (SPD) having three dates of sowing (14^{th}–15^{th} October, 8^{th}–9^{th} November and 3^{rd}–4^{th} December) in main plots and wheat varieties, viz. PBW 725, HD 2967 and HD 3086 with two microclimate modification levels M_1 (recommended irrigation) and M_2 (additional water sprays) in sub plots, replicated four times. The yellow rust severity was maximum at Ludhiana (56.14%, 57.17%) and Gurdaspur (56.75%, 58.42%) in HD 2967 under early sown conditions in M_2 treatment during 2021–22 and 2022–33, respectively. The Karnal bunt incidence was comparatively higher at Ludhiana (18.5% and 13.4%) and Gurdaspur (21.4% and 16.7%) in variety PBW 725 under normal sowing condition in M_2 than other treatments during both the years of study, respectively. Grain yield during 2021–22 and 2022–23 was more in early sowing at Ludhiana (43.3 q/ha, 48.1 q/ha) and Gurdaspur (44.5 q/ha, 50.8 q/ha) than other dates of sowing. In variety × microclimate modification levels treatments, grain yield was maximum at Ludhiana (43.1 q/ha, 47.2 q/ha) and Gurdaspur (44.0 q/ha, 50.2 q/ha) in variety PBW 725 under M_1 than other treatments during both the years of study. Early date of sowing recorded more yield losses followed by late and normal sowing and losses were more at Gurdaspur as compared to Ludhiana. Average yield losses during 2022–23 were higher i.e. 5.6% and 7.1% as compared to 1.6% and 2.3% during 2021–22 at Ludhiana and Gurdaspur, respectively.

Keywords: Date of sowing, Karnal bunt, Microclimate modification, Yellow rust, Yield losses

The tremendous population growth and random climatic changes pose major challenges to the farming sector in terms of food availability, productivity and sustainability. Climate change is a prevailing concern for country's food security and its consequences have been seen in the form of extreme weather events. The increase in temperature by 1.0–2.5°C may have significant implications on crop yield (Bhanumathi *et al.* 2019). Biotic stresses like diseases are the main factors limiting wheat (*Triticum aestivum* L.) yield. By reducing the quality and quantity of grains, diseases like rusts, smuts, bunts, leaf spots or blights and powdery mildews cause significant losses (Duveiller *et al.* 2005). In sub-mountainous areas of Himachal Pradesh, Jammu and Kashmir, Punjab, Haryana, and Uttarakhand, these diseases frequently occurs in higher proportions. Since 2008, the disease was reported in mild to severe forms and 2009–10 was epidemic year in Punjab and caused yield losses up to 68.8% (Pannu *et al.* 2010) which deciphered to monetary losses of ₹236 crores (Jindal *et al.* 2012). Karnal bunt (*Tilletia indica*) is an important post-harvest disease of wheat showed an increasing trend in severity and prevalence from 2012–13 to 2014–15 in Punjab (Kaur *et al.* 2018). Karnal bunt (KB) was considered as minor disease of wheat, it has shown its recurrence (Sharma *et al.* 2012). It is evident that yellow rust causes quantitative yield losses and Karnal bunt causes qualitative yield losses. Sandhu and Dhaliwal (2017) concluded that yield losses were lowest in HD 2967 and maximum in PBW 343 due to yellow rust. Bala *et al.* (2022) developed model for *Tilletia indica* and observed that almost all wheat varieties grown in Punjab till date are susceptible to disease. The Karnal bunt prevalence was examined by Bala *et al.* (2013) during 2005–2012 in Punjab, 3677 out of 10593 samples that were collected were infected with KB. The Gurdaspur district had the highest rate of infection while Patiala had the lowest disease incidence. So, keeping this in view present study was carried out to estimate the per cent yield losses due to different wheat diseases.

MATERIALS AND METHODS

The experiments were conducted during winter (*rabi*) seasons of 2021–22 and 2022–23 at Punjab Agricultural University, Ludhiana, Punjab. The experiment was

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conducted in split-plot design (SPD) having three dates of sowing [14^{th}–15^{th} October (D_1); 8^{th}–9^{th} November (D_2); and 3^{rd}–4^{th} December (D_3)] in main plots and wheat varieties, viz. PBW 725, HD 2967 and HD 3086 with two microclimate modification levels M_1 (recommended irrigation) and M_2 (additional water sprays) in sub plots, replicated four times. Power knapsack sprayer was used 10 days and 25 days after disease initiation in case of yellow rust and after disease inoculation in case of Karnal bunt to give water sprays in M_2. Water sprays were given using cut nozzle to imitate rainfall effect. The selected plots were sprayed 9 times at 1 h interval spanning one full day. Daily data of different meteorological parameters were collected from the Agrometeorological Observatory of Ludhiana and Gurdaspur.

For yellow rust, crop was inoculated artificially by spraying with a uredosporidial suspension of *Puccinia striiformis* during first week of January. For Karnal Bunt, crop was inoculated artificially at booting stage (February). A standard method described by Aujla *et al.* (1982) to inoculate the plants by spraying with a sporidial suspension of *Tilletia indica* was used. Around 100 wheat plants in each of the 72 plots were artificially inoculated, while another 72 plots were maintained as controls without any artificial inoculation. The Modified Mannar's scale (Peterson *et al.* 1948) was used for recording yellow rust severity (Table 1) from mid-January after appearance of rust symptoms.

Table 1 Rating scale for yellow rust disease of wheat

Code	Scale for severity of infection
5	Up to 5% leaf area infected
10	Up to 10% leaf area infected
20	Up to 20% leaf area infected
50	Up to 50% leaf area infected
75	Up to 75% leaf area infected
100	Up to 100% leaf area infected

Disease severity was calculated as:

$$\text{Disease severity (\%)} = \frac{\sum \text{Number of infected leaves} \times \text{Scale}}{\text{Total number of leaves} \times \text{Maximum grade}} \times 100$$

The following formula was used to compute the per cent disease incidence of Karnal bunt at harvest:

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

To compare yield losses same experiment was conducted under controlled conditions where plants were not artificially inoculated and when natural rust incidence was observed, Tilt 25 EC @200 ml/acre in 200 litres of water was sprayed to control yellow rust disease effectively. The grain yield losses were calculated as:

$$\text{Grain yield loss (\%)} = \frac{GY_{Control} - GY_{Diseased\ plot}}{GY_{Control}} \times 100$$

where $GY_{Control}$, Grain yield of control plots; $GY_{Diseased\ plot}$, Grain yield of diseased plots.

RESULTS AND DISCUSSION

Disease observations: The yellow rust severity was not considerable in variety PBW 725 at both locations under study. Among different sowing dates, the disease severity was highest in case of early sowing (15^{th} October) which was 56.14% as compared to normal (38.33%) and late (24.68%) dates of sowing during 2021–22 (Fig. 1) under M_2 microclimate modification level in HD 2967. Singh (2019) also reported that HD 2967 is susceptible to yellow rust under early sown conditions. Following similar trends in 2022–23, the early sown HD 2967 recorded highest rust severity (57.17%) as compared to normal (43.81%) and late (27.65%) sown under M_2 microclimate modification level. The maximum rust severity (56.75%) was observed in varieties sown on October 14^{th}, than in November 8^{th}

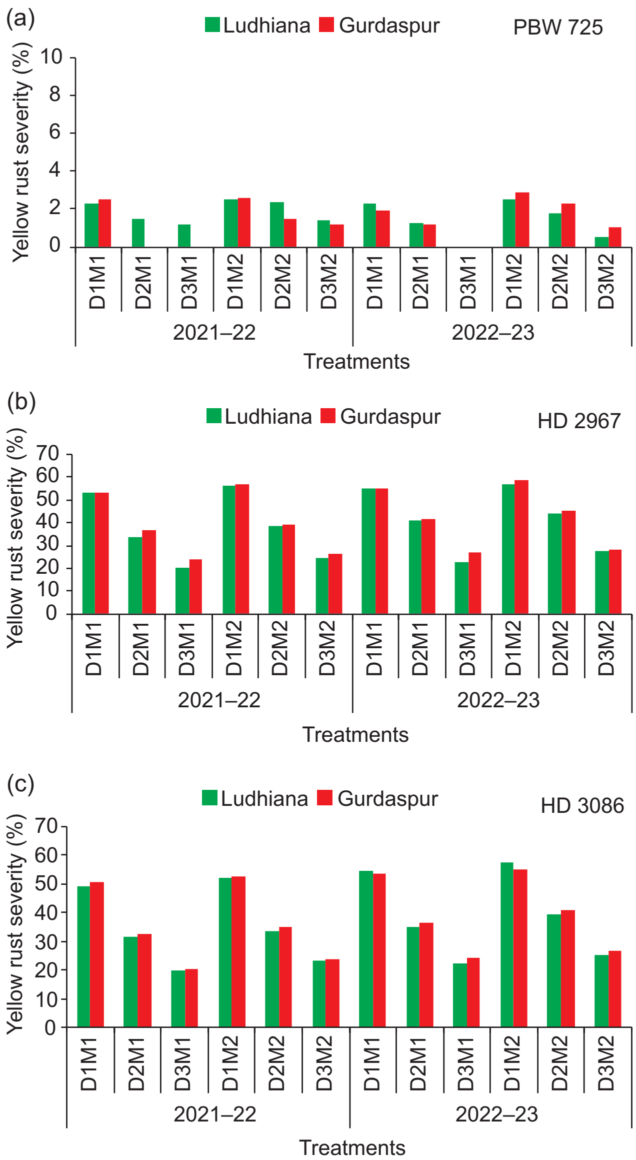

Fig. 1 (a–c) Yellow rust severity under different treatments at Ludhiana and Gurdaspur.
Treatment details are given under Materials and Methods.

(39.09%). In contrast, least rust severity under late sown conditions (3rd December) was observed as 26.57% during 2021–22 at Gurdaspur. During 2022–23, early sowing (October 14th) recorded higher rust severity (58.42%) compared to normal (45.56%) and late (28.13%) sowing dates. Microclimate plays a vital role in disease progress and proliferation. As microclimatic parameters, viz. canopy temperature and relative humidity within crop canopy showed significant variability in yellow rust severity in wheat crop (Sandhu *et al.* 2017).

The karnal bunt incidence under different date of sowing was recorded and disease incidence was found to be relatively higher under normal sowing (9th November), during both the years of study (18.5% and 13.4%) than the early and late sowing of wheat (Fig. 2). Among varieties,

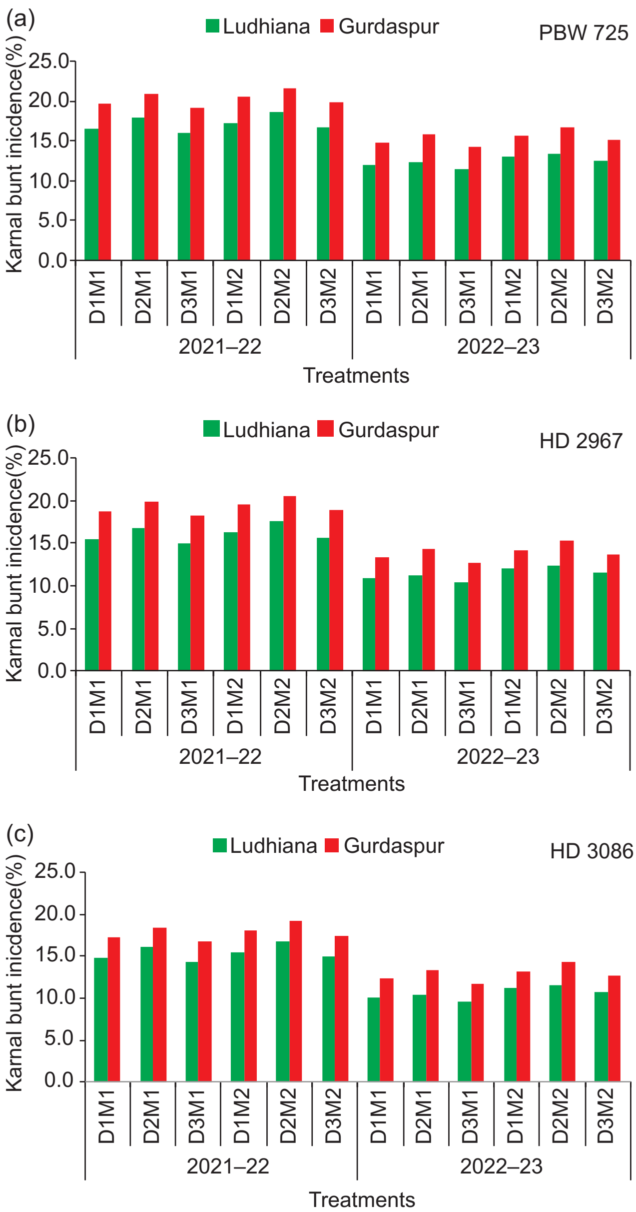

Fig. 2 (a–c) Karnal bunt incidence under different treatments at Ludhiana and Gurdaspur.
Treatment details are given under Materials and Methods.

Karnal bunt incidence was highest in PBW 725 followed by HD 2967 and HD 3086. Attri (2021) also observed that Karnal bunt incidence was maximum in PBW 725 as compared to HD 2967 and PBW 677. Similarly, Kaur *et al.* (2018) reported the higher Karnal bunt infection in varieties PBW 725 and HD 2967 from different blocks of Tarn Taran district of Punjab. Minimum or no disease infection was reported in variety Unnat PBW 343. Similarly, at Gurdaspur, in crop sown on November 9th, disease incidence decreased from 21.5–15.7% between the two years. Moreover, for crop sown on December 4th, the incidence declined from 16.7–12% in the same time frame. During 2021–22, karnal bunt incidence was 17.8% in M_1, which decreased to 12.3% in following year. Attri (2021) also observed that additional leaf wetness resulted in more Karnal bunt incidence (26.99%) as compared to recommended irrigation (11.56%). Relative humidity inside crop canopy and canopy temperature exhibited 71% and 65% variability in disease incidence, respectively.

Ear length, biological yield attributes and grain yield: In wheat crop sown on 15th October significantly higher (10.0, 11.2) ear length was recorded followed by 9th November (8.9 cm, 9.8 cm) and 4th December (8 cm, 8.7 cm) sowing during both the study years at Ludhiana (Table 2). In diseased plots, the ear length reduced in each date of sowing and remained significantly different from each other. More ear length was observed in case of 15th October (9.9 cm, 10.8 cm) sowing followed by 9th November (8.8 cm, 9.2 cm) and 4th December (7.9 cm, 8.3 cm) during both the years under study (Table 2). Among different sowing dates, more ear length was observed in 15th October sowing followed by 9th November and 4th December which were significantly different from each other during both the study years (Table 3) at Gurdaspur. In diseased plots, the ear length reduced in each date of sowing and remained significantly different from each other.

Among different dates of sowing, highest biological yield was observed at Ludhiana in case of 15th October (135.4 q/ha, 142.1 q/ha) sowing followed by 9th November (130.7 q/ha, 137.1 q/ha) and 4th December (122.1 q/ha, 128.3 q/ha), which were significantly different from each other during both the study years (Table 2). In diseased plots, the biological yield reduced in each date of sowing and was at par with each other but D_1 remained significantly different from D_3. In diseased plots, maximum biological yield was observed in case of 15th October (134.2 q/ha, 132.0 q/ha) sowing followed by 9th November (130.1 q/ha, 129.3 q/ha) and 4th December (120.4 q/ha, 120.3 q/ha) during both the years under study (Table 2). Dubey *et al.* (2019) reported that the decrease in biomass yield can be accredited to heat stress at reproductive stages under 15th December sowing which ensued overall decrease in grain weight and eventually yield. Lagheri *et al.* (2012) also concluded that biological yield was reduced by 42.4% due to delayed sowing. Sial *et al.* (2005) stated that delayed sowing in wheat caused yield reduction by 55 to 70% among the wheat varieties. Among the varieties, highest biological yield was observed in PBW

Table 2 Yield and per cent yield losses in different treatments during winter (*rabi*) 2021–22 and 2022–23 at Ludhiana

Year	2021–22							2022–23						
Treatment	Diseased			Control			Grain yield losses (%)	Diseased			Control			Grain yield losses (%)
	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)		Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	
14th-15th October	9.9	134.2	42.6	10.0	135.4	43.3	1.6	10.8	132.0	44.9	11.2	142.1	48.1	6.7
8th- 9th November	8.8	130.1	39.8	8.9	130.7	40.2	1.0	9.2	129.3	42.7	9.8	137.1	44.5	4.0
3rd- 4th December	7.9	120.4	35.7	8.0	122.1	36.5	2.2	8.3	120.3	37.6	8.7	128.3	40.2	6.5
CD (*P*=0.05)	0.4	3.6	1.7	0.5	5.6	2.7	--	0.3	5.8	3.1	0.5	5.5	2.8	--
PBW 725 + RI*	9.4	140.0	42.6	9.5	141.0	43.1	1.2	10.6	139.0	46.1	10.7	144.0	47.2	2.3
PBW 725 + RI + 2 AWS**	9.2	135.8	41.2	9.2	137.1	41.8	1.4	10.3	135.5	44.8	10.4	141.0	46.3	3.2
HD 2967 + RI	8.6	119.7	37.6	8.6	121.1	38.3	1.8	9.3	118.4	39.4	9.8	129.2	42.4	7.1
HD 2967 + RI + 2 AWS	8.4	116.2	36.1	8.4	117.8	36.9	2.2	8.5	114.7	38.0	9.1	125.8	41.1	7.5
HD 3086 + RI	8.7	130.1	40.1	9.1	131.5	40.8	1.7	9.4	129.5	41.6	9.9	139.1	44.7	6.9
HD 3086 + RI + 2 AWS	8.6	127.6	38.4	8.9	128.1	39.2	2.0	8.6	126.1	40.6	9.3	135.6	43.8	7.3
CD (*P*=0.05)	0.5	7.5	3.0	0.6	9.8	3.2	--	0.5	4.6	3.2	0.5	7.9	3.5	--

*RI, Recommended irrigations; **AWS, Additional water sprays.

Table 3 Yield and per cent yield losses in different treatments during winter (*rabi*) 2021–22 and 2022–23 at Gurdaspur

Year	2021–22							2022–23						
Treatment	Diseased			Control			Grain yield losses (%)	Diseased			Control			Grain yield losses (%)
	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)		Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	Ear length (cm)	Biological yield (q/ha)	Grain yield (q/ha)	
14th–15th October	10.0	136.9	43.3	10.9	138.8	44.5	2.7	11.1	138.2	46.8	11.1	150.2	50.8	7.9
8th–9th November	9.1	131.9	40.7	9.2	132.6	41.2	1.2	10.0	134.8	45.3	10.0	144.2	47.9	5.5
3rd– 4th December	7.5	122.3	36.9	8.4	125.7	37.8	2.4	8.8	124.1	39.2	8.8	133.3	42.5	7.7
CD (*P*=0.05)	1.0	5.6	2.6	0.7	4.9	3.0	--	0.4	4.7	3.3	0.5	4.7	2.7	--
PBW 725 + RI*	9.8	139.7	43.6	10.2	141.3	44.0	0.9	10.8	143.8	48.5	10.8	150.0	50.2	3.4
PBW 725 + RI + 2 AWS**	9.3	136.6	42.6	10.0	138.3	43.1	1.2	9.9	139.8	46.3	9.9	146.3	48.5	4.4
HD 2967 + RI	8.4	124.6	39.0	9.2	126.6	39.7	1.8	9.8	125.3	41.7	9.9	137.9	45.4	8.2
HD 2967 + RI + 2 AWS	8.2	120.0	36.3	8.9	122.9	37.9	4.2	9.2	120.9	39.6	9.2	134.5	43.8	9.6
HD 3086 + RI	8.9	133.3	41.0	9.6	135.4	41.9	2.1	10.4	134.5	44.6	10.4	145.3	48.3	7.7
HD 3086 + RI + 2 AWS	8.7	128.0	39.3	9.1	129.9	40.4	2.7	9.6	129.8	41.8	9.6	141.4	46.2	9.4
CD (*P*=0.05)	1.4	9.4	4.5	0.8	8.9	3.5	--	0.8	5.0	3.1	0.9	5.6	3.3	--

*RI, Recommended irrigations; **AWS, Additional water sprays.

725 (141.0 q/ha, 144.0 q/ha) followed by HD 3086 (131.5 q/ha, 139.1 q/ha) and HD 2967 (121.1 q/ha,129.2 q/ha) in M_1 at Ludhiana. Biological yield was higher in case of M_1 followed by M_2 in each treatment. But there was no significant difference in each variety. In the diseased plots, biological yield reduced in each variety and microclimate modification levels. Biological yield was highest in PBW 725 (140.0 q/ha, 139.0 q/ha) followed by HD 3086 (130.1 q/ha, 129.5 q/ha) and HD 2967 (119.7 q/ha, 118.4 q/ha) in M_1.

Among different dates of sowing, highest biological yield was observed in case of 15th October (138.8 q/ha, 150.2 q/ha) sowing followed by 9th November (132.6 q/ha, 144.2 q/ha) and 4th December (125.7 q/ha, 133.3 q/ha), which were significantly different from each other during both the study years at Gurdaspur (Table 3). In diseased plots, the biological yield reduced in each date of sowing and was at par with each other but D_1 remained significantly different from D_3. Among the varieties, maximum biological yield was observed in PBW 725 (141.3 q/ha, 150.0 q/ha) followed by HD 3086 (135.4 q/ha, 145.3 q/ha) and HD 2967 (126.6 q/ha,137.9 q/ha) in M_1. Biological yield was higher in case of M_1 followed by M_2 in each treatment. But there was no significant difference in each variety. In the diseased plots, biological yield reduced in each variety and microclimate modification levels. These results are in accordance with Singh (2022).

At Ludhiana, among different dates of sowing, significantly higher grain yield was recorded in case of 15th October (43.3 q/ha, 48.1 q/ha) sowing followed by 9th November (40.2 q/ha, 44.5 q/ha) and 4th December (36.5 q/ha, 40.2 q/ha) under controlled conditions (Table 2). In diseased plots, the grain yield reduced in each date of sowing and was at par with each other but D_1 remained significantly different from D_3. Grain yield was maximum in case of 15th October (42.6 q/ha, 44.9 q/ha) sowing followed by 9th November (39.8 q/ha, 42.7 q/ha) and 4th December (35.7 q/ha, 37.6 q/ha) during both the years under study. Among the varieties, under controlled conditions grain yield was highest in PBW 725 (43.1 q/ha, 47.2 q/ha) followed by HD 3086 (40.8 q/ha, 44.7 q/ha) and HD 2967 (38.3 q/ha, 42.4 q/ha) in M_1. Grain yield was higher in case of M_1 followed by M_2 in each treatment. Yield losses were more under additional leaf wetness due to hydrated condition that led to germination of more sporidia as compared to recommended cultivation (Attri 2021). But there was no significant difference in each variety. In the diseased plots, grain yield reduced in each variety and microclimate modification levels. Grain yield was highest in PBW 725 (42.6 q/ha, 46.1 q/ha) followed by HD 3086 (40.1 q/ha, 41.6 q/ha) and HD 2967 (37.6 q/ha, 39.4 q/ha) in M_1. Similarly, Bisht *et al.* (2019) and Dubey *et al.* (2019) observed highest grain yield in early sowing. Narayanan (2018) concluded that high temperature stress (>35^{o}C maximum temperature and >20^{o}C minimum temperature) from anthesis to physiological maturity lowered the grain number, grain weight and grain yield by 63%, 29% and 78% respectively.

Among different dates of sowing, maximum grain yield was observed in case of 14th October (44.5 q/ha, 50.8 q/ha) sowing followed by 8th November (41.2 q/ha, 47.9 q/ha) and 3rd December (37.8 q/ha, 42.5 q/ha), which were significantly different from each other during both the years under study at Gurdaspur (Table 3). In diseased plots, the grain yield reduced in each date of sowing and was at par with each other but D_1 remained significantly different from D_3. During 2021–22 and 2022–23, maximum grain yield was observed in 15th October (43.3 q/ha, 46.8 q/ha) sowing followed by 9th November (40.7 q/ha, 45.3 q/ha) and 4th December (36.9 q/ha, 39.2 q/ha) sowing, respectively. Among the varieties in control plots, highest grain yield was observed in PBW 725 (44.0 q/ha, 50.2 q/ha) followed by HD 3086 (41.9 q/ha, 48.3 q/ha) and HD 2967 (39.7 q/ha, 45.4 q/ha) in M_1. Grain yield was higher in case of M_1 followed by M_2 in each treatment. But there was no significant difference in each variety. In the diseased plots, grain yield reduced in each variety and microclimate modification levels. Grain yield was maximum in PBW 725 (43.6 q/ha, 48.5 q/ha) followed by HD 3086 (41.0 q/ha, 44.6 q/ha) and HD 2967 (39.0 q/ha, 41.7 q/ha) in M_1. Attri (2021) also found that grain yield in case of high leaf wetness was low due to increase in leaf wetness.

Yield losses: Grain yield reduced drastically in diseased plots as compared to sprayed conditions. Oerke *et al.* (1994) revealed that average actual yield losses caused by wheat diseases in developed and developing countries at global level was about 12.4% on annual basis. At Ludhiana, per cent yield losses were more in case of early sowing (1.6%, 6.7%) as compared to normal (1%, 4.0%) and late sowing (2.2%, 6.5%) during 2021–22 and 2022–23, respectively (Table 2). Among varieties, more yield losses were observed in variety HD 2967 followed by HD 3086 and PBW 725. The yield losses in microclimate modification level M_2 were found to be more than M_1. At Gurdaspur, during both the years under study, it was observed that per cent yield losses were more in early sowing (2.7%,7.9%) as compared to normal (1.2%, 5.5%) and late sowing (2.4%, 7.7%) (Table 3). Among varieties, more yield losses were observed in variety HD 2967 followed by HD 3086 and PBW 725. The yield losses in microclimate modification level M_2 were more in comparison to M_1 at Gurdaspur. Jindal *et al.* (2012) revealed that stripe rust is main and most detrimental disease of wheat which is appearing continuously since 2006–07 in sub-mountainous districts of Punjab and Haryana. The yield losses due to stripe rust varied 4.2–68.8% depending on the resistance of variety. Agra Local an old cultivar, showed highest yield losses (68.3%), followed by HD 2733 (40.6%) and PBW 343 (30.98%). Singh *et al.* (2004) reported that in Asian continent, leaf and stripe rust could affect production on approximately 60 (63%) and 43 (46%) million hectares, respectively, if susceptible cultivars are grown. Early infection on particularly susceptible types might result in a 100% yield losses. In cases of epidemics, yield losses have ranged from 10–70% (Chen 2005). Similarly, Chawla (1996) reported the reduction in 1000-grain weight from 4.5–52.27% with the increased in infection grade from

1–4. He also reported reduction in germination or viability of infected seeds from 61.0–96.3% depending upon the infection. Khanna *et al.* (2005) determined that yield losses due to yellow rust can be considerable, may range from 40% to complete destruction. These losses mainly depend upon the phenological stage of crop at which the disease attack started.

These results accentuate the imperative for a sophisticated and tailored approach for wheat cultivation, where the strategic alignment of sowing time and irrigation practices becomes paramount. The dynamic interaction between microclimate modification and crop response underscores the complexities of optimizing yield outcomes while minimizing disease vulnerabilities. As we navigate the intricacies of agricultural management, these findings underscore the imperative of a adaptable strategy that carefully considers the specificities of wheat varieties and optimal sowing timelines.

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