Plant Protection, 07 (02) 2023. 135-151 DOI: 10.33804/pp.007.02.4588

Available Online at EScience Press
Plant Protection
ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

ASSESSMENT OF WHEAT FOLIAR RUST INFESTATIONS IN THE UPPER, MIDDLE, AND LOWER POTHWAR REGIONS OF PUNJAB, PAKISTAN

Summia Sami, Shazia Iram
Department of Environmental Sciences, Fatima Jinnah Women University, The Mall, 46000, Rawalpindi, Pakistan.

ARTICLE INFO

Article history
Received: 29th April, 2023
Revised: 11th June, 2023
Accepted: 17th June, 2023

Keywords
Triticum aestivum
Environmental factors
Disease incidence
Correlation analysis
Yield attributes

ABSTRACT

In the present study, the incidence and severity of yellow rust and brown rust in different regions of Pothwar have been studied. The lower Pothwar region (Jhelum) had the highest incidence of brown rust with a prevalence of 54.3%, while Rawalpindi had the highest incidence of yellow rust in the upper region with a prevalence of 26.8%. In the middle region (Attock), brown rust incidence was the lowest with a prevalence of 4.6%. The severity of both rusts varied among locations, with some locations experiencing severe outbreaks while others had little or no incidence. The highest incidence of both rusts was observed in Harrial for yellow rust (90%) and Balla for brown rust (100%). The severity of rusts ranged from Resistant to Moderately Susceptible. The study examined the yield attributes of wheat crops in the Upper, Middle, and Lower Pothwar regions of Pakistan. The results showed that Rawalpindi district had the highest crop yield, while Jhelum had the lowest. The study also found a correlation between disease incidence and various environmental factors such as temperature, humidity, precipitation, tillers per meter length, tillers per meter square, number of grains per spike, and grain weight. Yellow rust had a strong correlation with humidity, tillers per meter square, and grain weight, while brown rust showed a strong correlation with temperature, precipitation, and humidity. The study highlights the importance of understanding the relationship between environmental factors and crop yield to ensure food security.

Corresponding Author: Shazia Iram
Email: shaziairam@fjwu.edu.pk

INTRODUCTION

Transnationally, wheat (*Triticum aestivum* L.) is a staple food and is considered to be a prime source of vegetable protein in human food, as it has higher protein content than other cereals. However, the negative externality associated with this valued crop is its low production rate due to various biotic and abiotic stresses. Furthermore, it is projected that by 2050, the world's demand for wheat will rise to 37.14 million tons to feed a population of 334.68 million (Scott, 2011).

Pakistan has an agro-based economy with wheat as a major staple crop, and it is considered the most imperative crop of Pakistan, as it is the 9th leading wheat-producing state. Unfortunately, it ranks 44th in terms of productivity. According to the annual report for 2012-2013 from the State Bank of Pakistan, about 24.21 million tons of wheat were produced from an area of 8.66 million hectares in the fiscal year of 2013. In 2012, 23.47 million tons of wheat were produced from 8.65 million hectares, and 25.21 million tons were produced from an area of 8.90 million hectares in 2011 (Zulfiqar and Hussain, 2014). At the provincial level, Punjab, Sindh, Khyber

Pakhtunkhwa, and Baluchistan account for 76%, 16%, 5%, and 3% of the total wheat production of the country, respectively (Abid, 2018). According to a report, wheat constitutes 60% of the daily caloric intake of the average Pakistani, and it is grown over land of 9 million hectares throughout the country (Haider and Zaidi, 2017).

Currently, the population of the country is escalating day by day, and thus, the burden on agriculture to meet food demand is increasing (Iram et al., 2020). Therefore, wheat production is not ample to meet the country's ever-increasing population growth rate of 2.5% per annum. To achieve self-sufficiency, sustainable productivity of wheat is of vital importance in the context of food security, as food security in the country squarely depends on the fortunes of the wheat crop. However, its yield per unit area is low (Afzal et al., 2008). The total area under cultivation of wheat in Pakistan is 9,062 thousand hectares with 23,421 thousand tons production. Its production should increase by 2% annually on the same area to meet the human stipulate, but its production is endangered by a number of biotic and abiotic stresses (human and environmental factors) (Javed et al., 2013).

Different yield attributes, such as the number of tillers per meter length, the number of tillers per meter square, the number of grains per spike, the harvest index, grain yield, and straw yield, determine the production and quality of wheat grains. Production hampering stresses greatly affect these yield parameters (Marasini et al., 2016). The major stress faced by wheat crops nowadays is fungal outbreaks that cause innumerable infections. Among all, the leading categories of wheat maladies include seed-borne diseases, leaf and head blight diseases, crown and root rot diseases, stripe, leaf, and stem rust diseases, and viral diseases. Rust diseases are the most momentous amongst biotic stresses, which have been devastating the crop for a long time (Figueroa et al., 2018). Rust-causing fungi are highly specific obligate parasites that affect wheat in a gene-for-gene relationship. Among all rust syndromes, foliar rust diseases are serious constraints on wheat grains because they adversely affect the growth and yield parameters of wheat plants when heavily infected (Javed et al., 2013). Moreover, wheat rust epidemics occur on a larger scale due to the widely distributed urediniospores (Kolmer, 2005). There are mainly three types of rust infections in wheat crops, and they differ according to their pathogen, appearance, and host, as described in Table 1.

Table 1: Different types of rust fungi and their characteristics.

Disease	Pathogen	Primary Host	Alternate Host	Symptoms
Leaf rust	*Puccinia triticina*	Bread and durum wheat and triticale	*Thalictrum, AnchusaIsopyrum,* and *Clematis*	Tiny oval to circular yellow colored spots on upper surface of leaf. With disease progression, spots expand into orange colored pustules surrounded by a yellow halo.
Stem rust	*Puccinia graminis* f.sp. *tritici*	Bread and durum wheat, barley and triticale	*Berberis vulgaris*	Development of reddish-brown oval to elongate shaped lesions on stem that weakens the stem and results in lodging.
Stripe rust	*Puccinia striiformis* f.sp. *tritici*	Bread and durum wheat, triticale, and a few barley cultivars	Unknown	Development of light yellow colored, straight-sided pustules on heads and leaves. With maturation, yellow to orange spores are produced. The end result is chlorosis of leaves.

Subsequently, the top wheat-producing countries (India, China, and Pakistan) are suffering from the stripe rust syndrome (yellow rust), which affects an area of 24.8 million hectares or approximately 60% of the total 139.3 million hectares under wheat cultivation (Bux et al., 2012). As a result, rust has become a major limitation in wheat production in various parts of Punjab, Baluchistan, and KPK provinces in Pakistan (Bux et al., 2011). In Pakistan, wheat is cultivated on more than eight million hectares, 70% of which are prone to yellow rust (Bahri, 2011). Rust epidemics have occurred in Pakistan in 1947-48, 1953-54, 1958-59, and 1977-78. Mild epidemics of stripe and leaf rusts also occurred in 1972-73 and 1975-76, which resulted in a 10.1% yield loss (Afzal et al., 2008).

In essence, rust is considered the Polio of agriculture. In order to address this devastating situation and the magnitude of rust diseases in the agricultural sector, the

present study was conducted in the upper, middle, and lower Pothwar regions of Pakistan to improve wheat crop yields at the local farmer level in the era of climate change. This was achieved by isolating and identifying rust-causing pathogens from infected plant foliar samples and eliminating these constraints on wheat crops. Additionally, this research helps take defensive measures to avoid rust infections by taking environmental conditions into consideration since rust-causing pathogens are sensitive to temperature and humidity.

MATERIALS AND METHODS

Study area

The study area was selected in collaboration with the Department of Agriculture Extension in four districts of the rain-fed Pothwar region of Punjab province, Pakistan. These four districts are Rawalpindi and Chakwal (upper Pothwar region), Attock (middle Pothwar region), and Jhelum (lower Pothwar region). The reason behind selecting Punjab province is its significant share in the agricultural sector, particularly as it produces 75% of Pakistan's total wheat crop (Ahmad et al., 2018). Additionally, weather variations have caused major constraints to the wheat crop in this region. Furthermore, the study area is regarded as a sub-tropical and sub-humid region, with a mean annual rainfall of 737 mm, a mean minimum temperature of 0-1°C in winter, and a mean maximum temperature of 38.5°C in summer. Therefore, to carry out the epidemiological study, different locations were identified as representative sampling sites for the respective districts where foliar rust diseases of the wheat crop were reported in the last two to three years (2012-2014). A total of 70 wheat-growing fields were selected from the sampling sites.

Survey and assessment of foliar rust of wheat growing fields

To conduct an epidemiological survey of foliar rust diseases in rain-fed wheat fields in the upper, middle, and lower regions of Pothwar, the fields were scrutinized at different stages of plant growth. For this purpose, foliar rust pathogens were identified on the wheat crop and collected by detaching infected leaves from the plants. The infected leaves were then placed in folded newspapers and labeled properly. These samples were brought to the Environmental Mycology and Eco-toxicology laboratory in the Department of Environmental Sciences at Fatima Jinnah Women University, The Mall Rawalpindi, and preserved at -5°C. To avoid contamination, each yellow and brown rust sample was preserved separately (Atiq-ur-Rehman et al., 2010). In the fields, the incidence and severity of foliar rust infections were noted on infected wheat crops. A diagrammatic scale (Roelfs et al., 1992) with a percentage of infection was used to assess the intensity of rust (Figure 1 and Table 2).

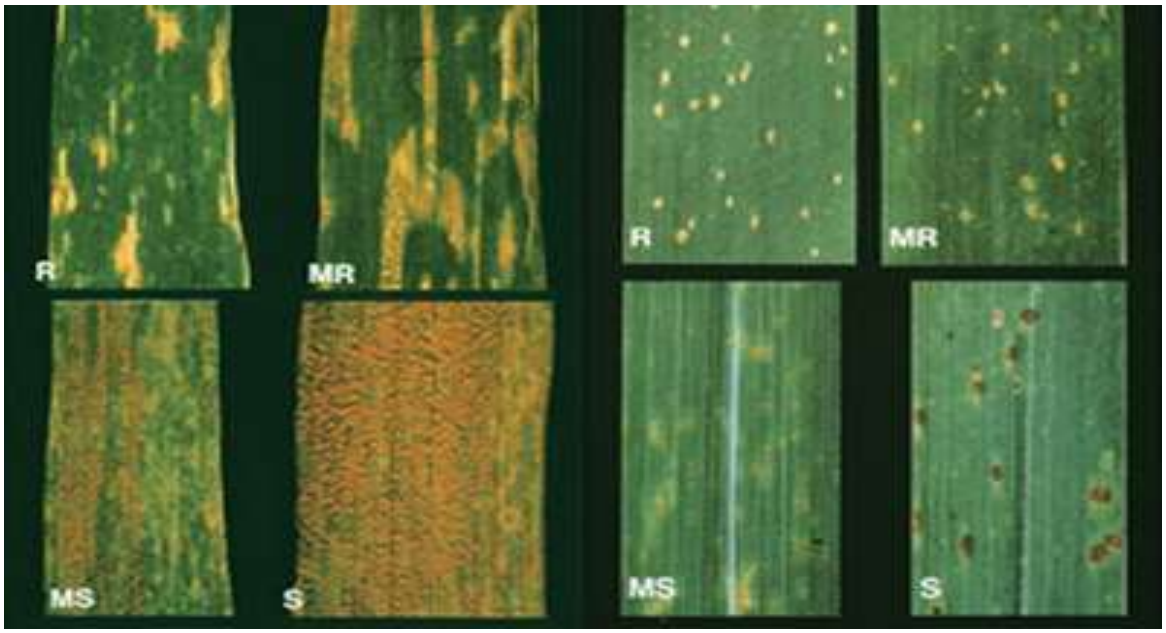

Figure 1: Relative resistances of wheat to stripe (left) and leaf rust (right): R = resistant, MR = moderately resistant, MS = moderately susceptible, and S = susceptible.

Table 2: Disease severity index.

Visual rating of severity	Symptoms	Levels of severity scale
0	No symptoms	Highly Resistant (HR)
1	Few lesions on an area <50% of leaves	Resistant (R)
2	5-20% lesions on an area <50% of leaves	Moderately Resistant (MR)
3	5-20% lesions on an area >50% of leaves	Moderately Susceptible (MS)
4	20-50% lesions on an area <50% leaves	Susceptible (S)
5	>50% lesions on an area > 50% leaves	Highly Susceptible (HS)

Collection of yield attributes

All selected wheat fields were observed following a diagonal pattern protocol. Yield attributes were collected by measuring the number of productive tillers per meter length and per meter area. About 80-100 plants were selected to count the number of grains per spike, and mean values were calculated for the entire fields. Grains were collected from each field, and 1000 grains were weighed to assess the productivity of the wheat crop. Grain yields and straw yields were estimated to measure the harvest index (Anneke and Benson, 2011).

Collection of weather data

Weather is considered a major factor behind rust development. To relate disease incidence with weather patterns, weather data for the study area, including three components: temperature, rainfall, and humidity, was collected from Pakistan Meteorological Department, Islamabad, for the studied months (November 2014 to May 2015). The obtained data were presented in tabular form to show variations.

Statistical analysis

A comparison of disease incidence and yield attributes was done among all scrutinized districts to get a better overview of the prevalence of diseases. Regression analysis (correlation coefficient) was applied to assess the relationship between foliar rust disease incidence (yellow rust and brown rust) and average yield attributes and average precipitation, humidity, and temperatures (for the period ranging from November 2014 to May 2015) of Jhelum, Chakwal, Rawalpindi, and Attock districts. The analysis was done by applying formulae to two variables at a time. Results were interpreted based on the value of R obtained.

RESULTS

Incidence and severity of rust in the Pothwar region

The overall prevalence of yellow rust and brown rust, in the upper, middle and lower Pothwar region has been shown in Figure 2. It is clear from the figure that the lower Pothwar region (Jhelum) had the highest incidence of brown rust with an incidence of 54.3%. In the upper Pothwar region, Rawalpindi had the highest incidence of yellow rust with a prevalence of 26.8% and Chakwal had the lowest incidence of yellow rust with a prevalence of 17.9%. On the other hand, in the middle Pothtwar region (district Attock), the incidence of brown rust was the lowest with a prevalence of only 4.6%. The individual incidences of yellow and brown rusts in the upper, middle and lower regions of Pothwar are given in Figure 2.

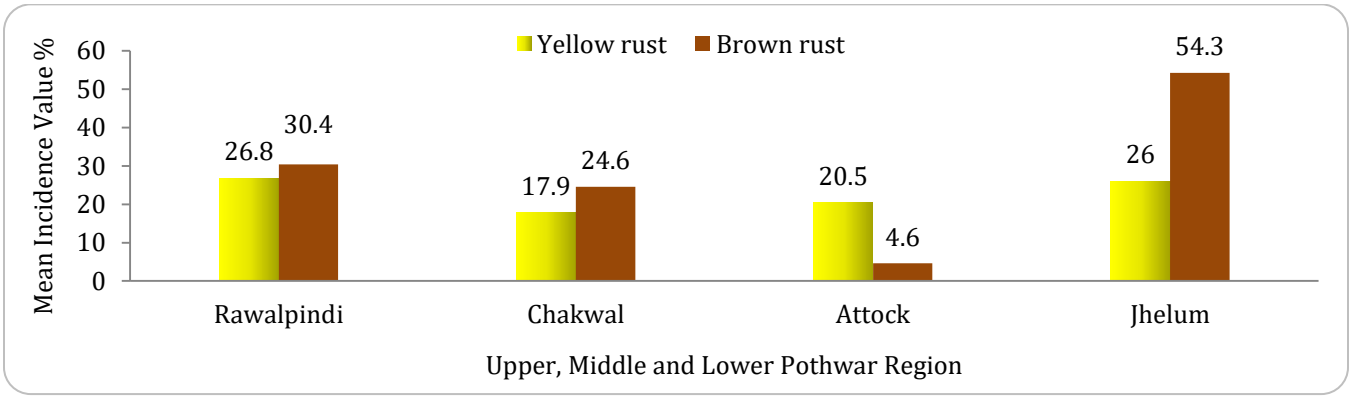

Figure 2: Comparison of disease incidence in the upper (Rawalpindi and Chakwal), middle (Attock) and lower (Jhelum) Pothwar regions.

Incidence and severity of rust in the upper Pothwar region

In district Rawalpindi

The incidence and severity of yellow and brown rusts in different locations of district Rawalpindi in the upper Pothwar region is given in Table 3. The results showed that both yellow rust and brown rust are prevalent in the study area, with an average incidence of 26.8% and 30.4%, respectively. The highest incidence of 100% of yellow rust was observed in Kutbal followed by 80% in Dhokmukadam while it was the minimum (5%) in Kuliam Sharif, Faisal colony and Salri Mor. Similarly, the highest incidence of 85% of brown rust was found in Gujar Khan followed by 80% in Bucha and was the minimum (5%) in Kutbal. The severity of both the rusts ranged between R to MS (Table 3).

Table 3: Incidence and severity of yellow and brown rusts in district Rawalpindi of the upper Pothwar region.

S #	Location	Yellow Rust		Brown Rust	
		Incidence %	Severity [a]	Incidence %	Severity [b]
1	Kallarsyedan	10	MS	20	MS
2	Mohradarogha	40	MS	50	MS
3	Salri Mor	5	S	15	S
4	Dhokmukadam	80	S	10	MS
5	Mishranmor	0	R	30	S
6	Faisal colony	5	MR	10	MS
7	Bucha	20	S	80	MS
8	Gujar Khan	25	MS	85	MS
9	Sanghori	20	MR	30	MS
10	Kuliam Sharif	5	MR	20	MS
11	Duma	25	MS	50	MS
12	Dhoknamkeen	20	MR	0	R
13	Kutbal	100	S	5	MS
14	Hattar	20	MS	20	MS
	Mean incidence %	26.8		30.4	

In district Chakwal

The incidence and severity of yellow and brown rusts in the surveyed locations of district Chakwal of the upper Pothwar region is presented in Table 4. The mean incidence percentages for yellow and brown rusts are 17.9% and 24.6%, respectively, indicating that both types of rusts are present in the area, but brown rust appears to be more prevalent. The incidence of rusts also vary widely, with some locations showing high incidences, such as Sutwal and Shah Syed Gullu for brown rust (90%) and Chattal for yellow rust (80%). No incidence of both the rusts was observed in Dub, Janga, Dhok Hajri, and Khewal, which were all classified as resistant for both types of rust (Table 4).

Incidence and severity of rust in the middle Pothwar region (Attock)

The incidence and severity of yellow and brown rusts in different locations of district Attock in the middle Pothwar region is shown in Table 5. The results showed that yellow rust was more prevalent than brown rust in the district. Yellow rust incidence ranged from 0 to 70%, with a mean incidence of 20.5%. The highest incidence was observed in Dhok Chajja and Thatta (70%), followed by Gaggan (60%), and no incidence was observed in Kot Mor, Dhok Kirchiyal, Sakki, Dhok Momin, and Bajual. The severity of yellow rust ranged MR to S.

Likewise, brown rust incidence ranged from 0 to 20%, with a mean incidence of 4.6%. The highest incidence was observed in Dhok Itbar, Thatta, and Gaggan (20%), followed by Bhatiyot Syedan (10%). On the other hand no incidence was observed in Kot Mor, Dhok Kirchiyal, Sakki, Dhok Momin, Bajual, and Bangesh Abad. The severity of brown rust was within a range of R to MR.

Incidence and severity of rust in the lower Pothwar region (Jhelum)

Overall, brown rust was more prevalent and severe in the district than yellow rust, with a mean incidence of 54.3% compared to 26% for yellow rust. The severity of both rusts varied among locations, with some locations experiencing severe outbreaks while others had little or no incidence.

Table 4: Incidence and severity of yellow and brown rusts in district Chakwal of the upper Pothwar region.

S #	Location	Yellow Rust		Brown Rust	
		Incidence %	Severity [a]	Incidence %	Severity [b]
1	Khanpur	10	MS	25	S
2	Seghalabad	40	S	0	R
3	Seghalabad	40	S	20	S
4	Chattal	80	S	5	MS
5	Dub	0	R	0	R
6	Sutwal	0	R	90	S
7	Chach	5	MR	70	MS
8	Janga	0	R	0	R
9	Dhok Talian	5	MR	5	MR
10	Dhok Hajri	0	R	0	R
11	Jhatla	0	R	10	MS
12	Ijazabad	70	MS	0	R
13	Shah Syed Gullu	0	R	90	S
14	Ahmedabad	0	R	30	MR
15	Tharpal	5	MR	15	MS
16	Mohra Qazi	0	R	80	MR
17	Khewal	0	R	0	R
18	Kajli	10	MR	40	S
19	Mulhal Mughlan	70	MS	0	R
	Mean incidence %	17.9		24.6	

Table 5: Incidence and severity of yellow and brown rusts in district Attock of the middle Pothwar region.

S #	Location	Yellow Rust		Brown Rust	
		Incidence %	Severity [a]	Incidence %	Severity [b]
1	Dhok Malal	10	MS	0	R
2	Burj	5	MR	0	R
3	Dhok Itbar	5	MR	20	S
4	Jaffar	20	MS	0	R
5	Gulial	10	MS	0	R
6	Kot Mor	0	R	0	R
7	Dhok Chajja	70	MS	7	MR
8	Khunda	5	MS	5	MS
9	Dhok Kirchiyal	0	R	0	R
10	Basal	20	MS	5	MS
11	Thatta	70	S	20	MS
12	Mthial	45	S	0	R
13	Dhok Markli	5	MR	0	R
14	Talhi Adda	45	MS	5	MS
15	Bajual	0	R	0	R
16	Bhatiyot Syedan	10	MS	10	MS
17	Sakki	0	R	0	R
18	Dhok Momin	0	R	0	R
19	Gaggan	60	MS	20	MS
20	Bangesh Abad	30	MS	0	R
	Mean incidence %	20.5		4.6	

Table 6 provides data on the incidence and severity of yellow rust and brown rust in different locations of district Jhelum in the lower Pothohar region. Yellow rust incidence was the highest in Harrial (90%) followed by Bhatiyan (80%). Boora Jungle and Shamspur locations had moderate incidence (70% and 50%, respectively). The rest of the locations had low or no incidence of yellow rust. On the other hand, brown rust incidence was the highest (100%) in Balla and Sukha locations followed by Shamspur, Gujran Malot and Khanewal having incidences of 90 and 80% respectively. The rest of the locations had low or no incidence of brown rust (Table 6).

Table 6: Incidence and severity of yellow and brown rusts in district Jhelum of the lower Pothwar region.

S #	Location	Yellow Rust		Brown Rust	
		Incidence %	Severity [a]	Incidence %	Severity [b]
1	Boora Jungle	70	S	60	S
2	Harrial	90	S	70	S
3	Balla	0	R	100	S
4	Bhatiyan	80	MS	0	R
5	Sukha	0	R	100	S
6	Shamspur	30	MR	90	S
7	Kala dev	50	S	0	R
8	Chontra	0	R	0	R
9	Gujran Malot	0	R	80	S
10	Mong	0	R	15	S
11	Khanewal	0	R	80	S
12	Dina	60	MS	60	MS
13	Khalowal	0	R	100	S
14	Sohawa	5	MR	60	S
15	MissaKiswal	5	MR	0	R
	Mean incidence %	26		54.3	

Yield attributes of wheat in the upper Pothwar region

In district Rawalpindi

Yield attributes are traits that contribute to crop yields and define the economic value of crop outcomes. Table 7 presents the different yield attributes of wheat crops in the Rawalpindi District. The results revealed that the number of tillers per meter length varied from 21 to 40 at Sanghori and Mishran Mor fields in Rawalpindi district, while the highest count of grains per spike was recorded in the fields of Faisal colony, with 72 wheat grains per spike. Kutbal, Gujar Khan, and Kallar Syedan had significantly less grain weight compared to other fields in Rawalpindi.

In district Chakwal

In the same way, Table 8 demonstrated the yield attributes of wheat crops in the Chakwal district, and it concludes that Jhatla, Tharpal, and Kajli had more than 30 tillers/meter length. Kajli had the highest number of tillers/square meter among the total of 19 fields, where the number of tillers/meter length and per square meter is comparatively lower. Overall, the grain health is good, with an average weight of 1000 grains recorded as 47.40 g.

Yield attributes of wheat in the middle Pothwar region (Attock)

After analyzing samples from district Attock, the results on yield attributes of rain-fed wheat fields in the middle Pothohar region revealed that the number of productive tillers ranged between 28-40 tillers/meter length for numerous fields. The maximum number of tillers was observed at Sakki and Basal fields, followed by Bangesh Abad and Thatta. Moreover, the wheat growing fields of Kot Mor and Bangesh Abad exhibited the maximum number of tillers/meter square, as shown in Table 9.

Similarly, there was significant variation in the number of grains, ranging from 30 to a maximum of 62 grains per spike. The mean grain weight of 1000 grains was also found to be in a wide range of 30-55 grams, compared to other districts. Only one out of the 20 observed fields in district Attock was free of weeds, while the other 19 fields showed the growth of various weeds along with the crop.

Table 7: Yield attributes of rain fed wheat growing fields of upper Pothwar region (Rawalpindi district).

Location	Wheat Variety	Tillers/ meter	Tillers/m^2	No. of grains/spike	1000 Grain weight (g)	Weeds
Kallarsyedan	Sahar	24	220	58	26.88	Layli, Athubathu, Poli, Jangli jai
Mohradarogha	Sahar	38	224	42	41.22	Poli, Layli, Bhang, Jangli jai
SalriMor	Sahar	26	210	54	46.00	Jangli jai, Bhang
Dhokmukadam	Sahar	37	221	42	50.12	Poli, Jangli jai, Layli
Mishranmor	Chakwal 50	40	213	42	43.20	Jangli jai, Poli, Jountri
Faisal colony	Chakwal 50	35	218	72	37.65	No weeds
Bucha	Chakwal 50	36	239	48	60.23	Athubathu, Bhang
Gujar khan	Sahar	27	228	48	27.44	Dudhpatar, Athubathu
Sanghori	Sahar	21	200	54	67.56	Jountri, Poli,
Kuliam Sharif	Punjab 2011	25	246	60	57.87	Dumbiciti, Jangli jai, Layli, Poli
Duma	Sahar	23	240	42	40.87	Athubathu, Jangli jai
Dhoknamkeen	Inqilab	27	238	54	41.34	Athubathu, Jangli jai, Poli
Kutbal	Inqilab	26	210	36	27.49	Jangli jai, Bhang, Poli
Hattar	Chakwal 50	25	209	54	40.07	Poli, Bhang, Jangli jai
	Mean values	29.2	222.6	49.6	43.4	

Table 8: Yield attributes of rain fed wheat growing fields of upper Pothwar region (Chakwal district).

Location	Wheat Variety	Tiller/ meter	Tillers/m^2	Grains/spike	1000Grain weight (g)	Weeds
Khanpur	Inqilab	19	226	51	52.30	Kandiari
Seghalabad	Nayyab	20	210	52	48.35	No weeds
Seghalabad	Chakwal-Nayyab	25	206	63	55.48	Dumbiciti
Chattal	Zero-Pachas	24	212	42	49.46	Layi, Jangli jai
Dub	Punjab-2011	26	220	60	54.48	Athubathu, Jangli jai, Layli
Sutwal	Sahar	32	208	42	45.67	Athubathu, Poli
Chach	Nayyab	25	212	39	38.05	No weeds
Janga	Punjab-2011	28	198	40	35.50	No weeds
Dhok Talian	Zero-Pachas	30	244	26	30.68	Poli
Dhok Hajri	Chakwal-Nayyab	28	188	60	58.42	Jangli jai, Dumbiciti,
Jhatla	Watan	38	210	60	53.52	Jangli jai
Ijazabad	Aas	15	230	60	48.51	No weeds
Shah Syed Gullu	Punjab-2011	36	215	54	60.30	Safaidsaag, Jangli jai, Bughat
Ahmedabad	Chakwal-Pachas	36	220	39	39.25	Palakpatar, Poli, Sonchal
Tharpal	Chakwal-Pachas	37	212	40	35.34	Jangli jai, Sonchal, Bughat
Mohra Qazi	Inqilab	26	218	39	45.30	Jangli jai, Palak Kanda
Khewal	Aas	34	230	60	58.73	Jangli jai, Poli, Bughat
Kajli	Sahar	37	248	43	49.30	Bathu
Mulhal Mughlan	Chakwal-Pachas	27	195	46	50.36	Choi moi, Jangli jai, Layli
	Mean values	28.6	217.0	48.2	47.7	

Table 9: Data of epidemiological survey for foliar rust diseases in middle Pothwar region (Attock district).

Location	Wheat Variety	Tillers/ meter	Tillers /m^2	Grains/ spike	1000 Grain weight (g)	Weeds
Dhok Malal	Sahar	32	216	36	53.35	layli, Athubathu, Jangli jai, Poli
Burj	Sahar	28	208	34	48.23	layli, Poli, Athubathu
Dhok Itbar	Faisalabad-2008	37	220	54	55.42	Jangli jai, Layli, Dodhpatar
Jaffar	Sahar	36	210	57	45.30	Jangli jai, Layli
Gulial	Bhakar	34	215	30	42.05	Jangli jai, Poli
Kot Mor	Bhakar	35	244	42	58.35	Jangli jai
Dhok Chajja	Bhakar	36	215	54	49.37	Jangli jai, Poli, Layli
Khunda	Faisalabad-2008	35	230	48	48.60	Jangli jai
Dhok Kirchiyal	Inqilab	30	153	60	53.20	layli, Jangli jai
Basal	Faisalabad-2008	40	240	54	40.52	Poli, Layli
Thatta	Inqilab	38	230	57	50.46	Layli
Mthial	Inqilab	28	153	60	48.27	layli, Jangli jai
Dhok Markli	Faisalabad-2008	32	206	38	35.40	Jangli jai
Talhi Adda	Faisalabad-2008	32	220	35	32.40	No weeds
Bajual	Faisalabad-2008	37	215	38	34.28	Layli
Bhatiyot Syedan	Sahar	34	185	50	38.67	Jangli jai, poli
Sakki	Chakwal-50	40	237	42	30.53	Poli
Dhok Momin	Chakwal-50	35	172	32	42.48	No weeds
Gaggan	Inqilab	28	168	48	50.26	Athubathu, Jangli jai
Bangesh Abad	Inqilab	38	244	62	55.05	Jangli jai, Poli
Mean values		34.3	209	46.5	45.6	

Yield attributes of wheat in the lower Pothwar region (Jhelum)

The data presented in Table 10 illustrates the status of different yield attributes in Jhelum District. The findings suggest a decline in the number of productive tillers per meter length, with Bhatiyan recording the lowest count of tillers (28), while Misa Kiswal had the highest count of tillers (43). The number of tillers per square meter varied between 198 and 242. Furthermore, the presence of weeds was observed in all the fields, indicating that weed proliferation was at its peak in Jhelum district.

Comparison of yield attributes in the upper, middle and lower Pothwar regions

The comparison of yield attributes in the lower, middle, and upper Pothwar regions revealed that Rawalpindi district had the highest crop yield (344.8) in terms of tillers per meter length, tillers per square meter, number of grains per spike, and grain weight of 1000 grains. The second highest crop yield (343.6) was observed in Jhelum district, followed by Chakwal (341.5) and Attock (335.4), respectively (Figure 3).

Analysis of Weather Conditions of Pothwar region

Weather Conditions in the upper Pothwar region

Rawalpindi

Table 11 illustrates the weather patterns of Rawalpindi district, which is a crucial factor when conducting surveys. The predominant weather conditions in this region were found to be warm and humid. The lowest precipitation was recorded during November, with an average of 0.66 mm, while the highest was in April, with a maximum value of 10.66 mm. High humidity levels were observed from November 2014 to May 2015, with maximum mean values during the wheat ripening stages. The temperature remained relatively stable, ranging from 11^{o}C to 23^{o}C. The humidity was elevated in March, followed by February and April, respectively.

Chakwal

Similarly, in the Chakwal district, the highest precipitation was recorded during January, February, and March. Higher humidity levels prevailed from November until March, as shown in Table 12. Temperature also varied from 23.9-34^{o}C throughout the

growing season of wheat crops. As the region has rain-fed wheat fields, there is no need for an irrigation system, and rainfall is sufficient to meet the crop's water requirements. However, it is worth noting that the minimum rainfall has been observed during November, when wheat sowing is underway.

Table 10: Yield attributes of rain fed wheat growing fields of lower Pothwar region (Jhelum district).

Location	Wheat Variety	Tillers /meter	Tillers /m^2	Grains /spike	1000 Grain weight (g)	Weeds
Boora Jungle	Punjab-2011	34	196	60	35.20	Jangli Jai
Harrial	Faisalabad-2008	34	210	52	40.57	Jangli Jai, Layli, Bughat
Balla	Inqilab	33	208	33	50.20	Jangli Jai, Bughat, Bhang,
Bhatiyan	Aas	28	220	38	35.28	Poli, Bughat, Bhatiyan, Jangli jai
Sukha	Punjab-2011	40	228	60	45.42	Bhang, Poli, Jangli jai
Shamspur	Sahar	38	232	52	42.85	Bhang, Poli, Layli
Kala Dev	Aas	37	242	45	32.59	Jangli jai, bhang, Poli
Chontra	Aas	36	203	42	30.59	Dumbiciti, Jangli jai, Bughat
Gujran Malot	Inquilab	34	214	46	37.16	Athubathu, Bhang
Mong	Faisalabad-2008	42	209	43	50.22	Dumbiciti, Jangli jai
Khanewal	Inqilab	40	245	42	40.50	Athubathu, Safaid sag
Dina	Punjab-95	36	235	43	42.53	Dumbiciti, Jangli jai
Khalowal	Sahar	38	228	42	28.40	Athu bath, Jangli jai, Dumbiciti
Sohawa	Punjab-2011	39	200	66	44.73	Bhang, Athubathu, Dumbiciti
Missa Kiswal	Chakwal-50	43	242	42	29.74	Dumbiciti
Mean values		36.8	220.8	47.0	39.0	

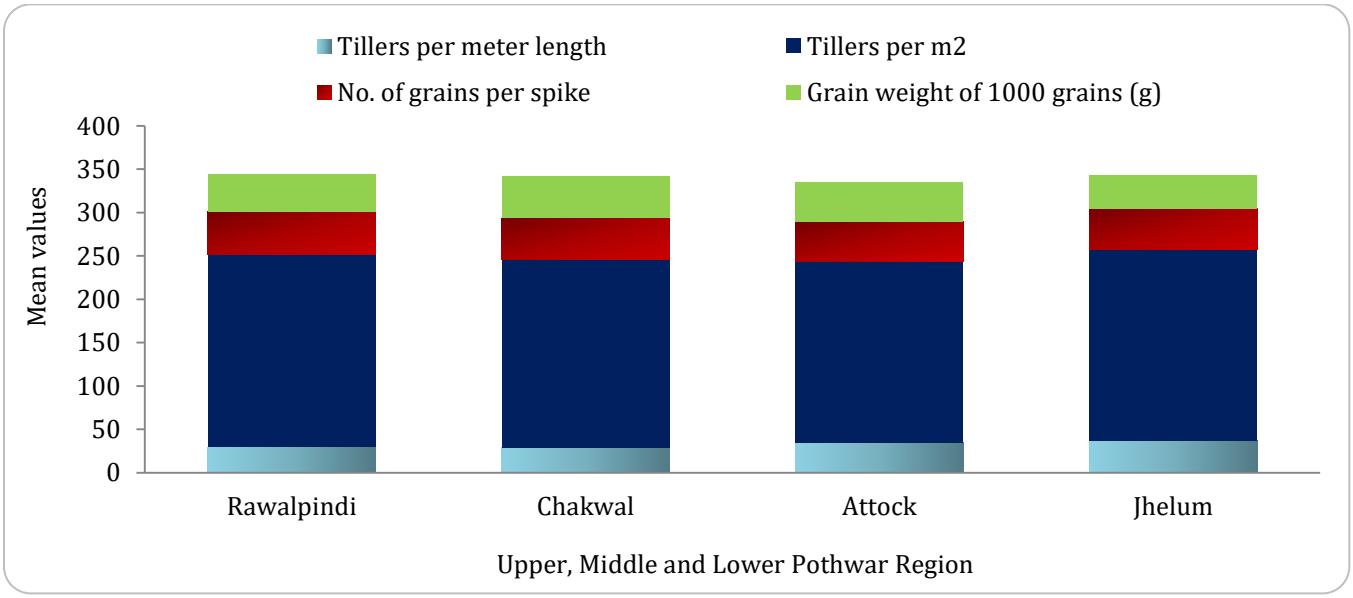

Figure 3: Comparison of yield attributes in the upper, middle and lower Pothwar region.

Weather Conditions in the middle Pothwar region

Table 13 shows that the Attock district experienced moderate temperature ranges and low levels of precipitation. The highest recorded precipitation was a mere 6.5 mm in April 2015. Throughout the wheat growing season, the temperature fluctuated between 5°C and 18°C.

Table 11: Average precipitation, humidity and temperature of Rawalpindi.

Months	Temperature (˚C)	Humidity (g/m3)	Precipitation (mm)
November 2014	17	62	0.16
December 2014	13	64	0.0
January 2015	11	56	01
February 2015	20	66	03
March 2015	17	68	9.2
April 2015	23	60	10.66
May 2015	28	43	8.5
Mean values	18.4	59.9	4.6

Table 12: Average precipitation, humidity and temperature of Chakwal.

Months	Temperature (˚C)	Humidity (g/m3)	Precipitation (mm)
November 2014	23.9	75	0.6
December 2014	19.4	73	0.0
January 2015	18	49	29.4
February 2015	20.1	66	30.8
March 2015	25	54	31.2
April 2015	29.1	45	20.1
May 2015	34	33	14.4
Mean values	24.2	56.4	18.0

Table 13: Average precipitation, humidity and temperature of Attock.

Months	Temperature (˚C)	Humidity (g/m3)	Precipitation (mm)
November 2014	12	32	0.6
December 2014	07	28	0.0
January 2015	05	45	1.2
February 2015	06	54	05
March 2015	09	54	06
April 2015	14	55	6.5
May 2015	18	38	02
Mean values	10.1	43.7	3.0

Weather Conditions in the lower Pothwar region

According to the Table 14, Jhelum district experienced higher levels of precipitation and humidity as compared to all the other districts in the current study. The range of precipitation recorded was between 0 mm to 31.8 mm, with the highest levels occurring in the months of January, February, March, and April. These elevated levels of precipitation also lead to increased humidity, reaching a peak value of 88 in Jhelum district.

Table 14: Average precipitation, humidity and temperature of Jhelum.

Months	Temperature (˚C)	Humidity (g/m3)	Precipitation (mm)
November 2014	27.1	83	1.5
December 2014	20.6	88	0.0
January 2015	18.8	68	33.8
February 2015	22.9	60	50
March 2015	25.3	54	60.5
April 2015	31.3	48	36.6
May 2015	34	44	31.8
Mean values	25.7	63.6	30.6

Correlation between disease incidence and environmental factors

The results of correlation between disease incidence and various factors such as average yield attributes, precipitation, humidity, and temperatures for the districts of Rawalpindi, Chakwal, Attock, and Jhelum are presented in Table 15.

The findings showed that all the variables studied were related to each other. None of the variables had a correlation coefficient (r) value of zero, indicating that they were all interconnected. For yellow rust, the correlation coefficients for temperature, humidity, precipitation, tillers per meter length, tillers per meter square, number of grains per spike, and grain weight were 0.15, 0.59, 0.13, 0.30, 0.68, 0.32, and -0.84, respectively. A positive sign indicated a direct relationship between the variables, implying that an increase in environmental factors and yield attributes would lead to an increase in disease incidence and vice versa. In contrast, a negative sign suggested an inverse relationship between grain weight and disease incidence, which meant that an increase in disease incidence would lead to a decrease in grain weight. Brown rust also exhibited direct relations with weather parameters (temperature, precipitation, and humidity) while showing an inverse relation with grain weight.

The correlation analysis revealed that yellow rust had a weak correlation with temperature, precipitation, tillers per meter length, and numbers of grains per spike as the r values were far from 1. However, humidity, tillers per meter square, and grain weight had a strong correlation with yellow rust as the r values were closer to 1. Similarly, temperature, humidity, precipitation, tillers per meter square, and grain weight were strongly correlated with brown rust, except for tillers per meter length and number of grains per spike, which showed a weak correlation with brown rust.

DISCUSSION

Epidemiological assessment is helpful in evaluating the intensity of disease occurrence, or in other words, the rate of disease appearance. An epidemiological survey of four districts in the Punjab region, which come under the Pothwar region, was carried out to understand the status of foliar rust disease in various rain-fed wheat-growing fields.

According to the data collected from the surveys, Rawalpindi district showed exceptionally high levels of yellow rust infections, with the highest mean disease incidence of 27% among all the districts studied. The wheat-growing fields of Kutbal had the maximum disease incidence of 100%, followed by Dhok Mukadam, with 80% disease incidence and full severity of S on the severity scale in both villages. Stem rust was totally absent, whereas brown rust displayed the second highest disease incidence percentage of 30% compared to other districts. The highest incidence for brown rust was in the Gujar Khan field, with 85% disease incidence and MS disease severity. Crop health conditions were relatively better in the Chakwal district, with the lowest incidence of 17% for yellow rust and an overall lower percentage of leaf rust as well. The survey clearly implies that none of the fields were fully infected with any of the foliar diseases, and the highest severity value was found only in a few fields.

District Attock also experienced moderate attacks of yellow rust, but with the least impact of leaf rust, having a minimal mean disease incidence of 4.6%. As a result, the crop yield output from Attock District is generally estimated to be greater, as yield losses due to foliar diseases are insignificant. Among all the Pothwar regions, Jhelum district had the greatest incidence of leaf rust epidemic, with a remarkably high percentage of 54% disease incidence, and standing at second in terms of mean yellow rust incidence with 26%. Kalowal, Sukha, and Balla fields predominantly showed a 100% spread of leaf rust, with the highest severity of 5 in most of the fields. None of the fields were free of foliar diseases.

A similar study was conducted by Batool et al. (2014) to estimate the epidemiology of foliar rust diseases of wheat in rain-fed areas of Punjab, Pakistan. This study indicated the absence of brown rust and the highest prevalence of yellow rust in Jhelum district in 2014, while Attock fields were highly infected with both diseases. Another study conducted by Neelam et al. (2015) revealed that brown rust was more prevalent in Jhelum district compared to yellow rust, which is consistent with the present study. A research conducted in Punjab, Pakistan, regarding foliar rust diseases revealed that the incidence, prevalence, and disease index of yellow rust were higher than brown rust and powdery mildew. This finding contrasts with the present study (Atiq-ur-Rehman et al., 2011).

Yield attributes are the most significant tool to judge the economic value associated with a crop.

Table 15: Correlation of disease incidence with average yield attributes and average precipitation, humidity and temperatures of Rawalpindi, Chakwal, Attock and Jhelum districts.

Foliar diseases	Disease incidence (%)	Correlation Coefficient						
		Temperature (˚C)	Humidity (g/m3)	Precipitation (mm)	Tillers per meter length	Tillers per m^2	No. of grains per spike	1000 Grain weight (g)
Rawalpindi		18.4	59.9	4.6	29.2	222.6	49.6	43.4
Yellow rust	26.8	0.15[b]	0.59[a]	0.13[b]	0.30[b]	0.68[a]	0.32[b]	-0.84[a]
Brown rust	30.4	0.84[a]	0.94[a]	0.83[a]	0.31[b]	0.81[a]	0.14[b]	-0.80[a]
Chakwal		24.2	56.4	18.0	28.6	217.0	48.2	47.7
Yellow rust	17.9	0.15[b]	0.59[a]	0.13[b]	0.30[b]	0.68[a]	0.32[b]	-0.84[a]
Brown rust	24.6	0.84[a]	0.94[a]	0.83[a]	0.31[b]	0.81[a]	0.14[b]	-0.80[a]
Attock		10.1	43.7	3.0	34.3	209.0	46.5	45.6
Yellow rust	20.5	0.15[b]	0.59[a]	0.13[b]	0.30[b]	0.68[a]	0.32[b]	-0.84[a]
Brown rust	4.6	0.84[a]	0.94[a]	0.83[a]	0.31[b]	0.81[a]	0.14[b]	-0.80[a]
Jhelum		25.7	63.6	30.6	36.8	220.8	47.0	39.0
Yellow rust	26	0.15[b]	0.59[a]	0.13[b]	0.30[b]	0.68[a]	0.32[b]	-0.84[a]
Brown rust	54.3	0.84[a]	0.94[a]	0.83[a]	0.31[b]	0.81[a]	0.14[b]	-0.80[a]

A disease attack directly affects yield attributes in a negative manner, thus deteriorating the crop's health and nutritional value. Great variation in the number of tillers per meter length and the number of tillers per square meter is particularly characterized by the area under cultivation and the sowing patterns that farmers are following. Information from surveys implies that wheat crop varieties with the trait of a dense and spread canopy are more preferably cultivated at reasonable distances between tillers. On the other hand, crops are more preferably cultivated at a reasonable distance between tillers. Crops with a highly degree of overlapping were also observed during surveys, which might be one of the farmer's strategies to get higher yields from a smaller area. However, disease dispersal in a crop with a close canopy is at its peak because of additional means of spore diffusion by contact (Batool et al., 2014).

Studies reveal that damage caused to the crop by disease attack is characterized by the growing stage at which the disease attacks. A research study was conducted to estimate the percentage losses of yield due to different leaf rust severities at all growing stages of wheat. The results reported the highest yield losses when the disease attacks at flowering stages ranging between 25-100% in extreme cases, whereas damage is minimal at the milk stage of wheat development. The ripening stage of the crop then indicated the disease attack in the form of ripened teliospores of the fungus (Gill et al., 2019; Channa et al., 2022).

Rawalpindi and Jhelum districts represented exceptionally low grain weight of 1000 grains, which is attributed to the highest incidence of yellow rust there. Devadas et al. (2014) carried out an experimental work to find out the effect of stripe rust on the yield of the crop by reducing the uptake of nitrogen by the plant at the grain filling stage, thus resulting in reduced average grain protein. Ultimately, the stripe rust epidemic is affecting the economics by increasing the demand for nitrogen fertilization to enhance the protein content (Devadas et al., 2014). The correlation statistics of the present study regarding grain weight and disease incidence (yellow and brown rust) are also justified by Salman et al. (2006) and Devadas et al. (2014). The findings indicate that with an increase in yellow and brown rust, the weight of the grain gets reduced (Salman et al., 2006).

Traditional crop management activities based on indigenous knowledge of natives were mostly preferred by the farmers from various fields of the study area. During the survey, it was found that few of the farmers had little awareness regarding the effects of foliar diseases on crop productivity. Thus, the seed selection criteria were solely based on high-yielding varieties without any consideration regarding disease-resistant cultivars. Inqilab and Sahar crop varieties have been declared as susceptible to disease, but the survey reported that these varieties are still among the most commonly used varieties in Jhelum district, which might be the leading cause behind the problem. Most of the farmers avoided introducing new varieties and used previously stored seeds for sowing due to the unavailability and higher prices of seeds. Stored seeds might be containing the fungal inoculum, thereby destroying the crop. In the upper Pothwar region, several other varieties were also reported, consequently showing better yield attributes. A research conducted in 2013 on the beneficial agro-economic effects of the wheat and canola intercropping system concluded that it reduces the crop damage by diseases, by pest and weeds, thus improving the production of both crops concurrently (Naeem et al., 2013).

In complex farming systems, time conflicts are major constraints for wheat management. Harvesting of the previous crop and wheat sowing, use of fertilizers, seed rate, and land preparation are determinants of yield-contributing traits (Iqbal et al., 2001). A survey sorted out a large number of fields where farmers reported late sowing. Research found a 27% loss in grain yield by practicing one month delayed sowing, as it shrinks the development stages and productivity in return (Wellings et al., 2004).

Jhelum fields were full of a diverse range of weeds such as Dumbi citii, Athu bathu, Bhang, Poli, Layli, etc., whereas Chakwal fields showed less infestation. These weeds provide serious competition for nutrition to the crop and are disadvantageous as they are susceptible to several pathogens. Timely weeding was not practiced in most of the fields, except for a few fields in Rawalpindi and Chakwal. Manual tilling should be practiced to make the fields free of weeds and to increase the plant biomass with elevated yields. Weed proliferation deprives the crop of light, moisture, space, and CO_2. A study reported annual losses of 28 billion to the wheat crop in Pakistan. Due to laborious mechanical control, chemical control of weeds is mostly favored (Marwat et al., 2006).

The most important features of weather, temperature, moisture, and precipitation, play a significant role in disease incidence. Moisture helps in spore germination while temperature keeps the spore alive (Bux et al., 2012). Shifts in climatic patterns lead to variations in the status of various foliar rust diseases in study areas. Results show variation in average precipitation, humidity, and temperatures of four districts compared to the previous year. Studies report that the ideal conditions for the pathogen to germinate and cause infection in wheat canopy include warmer days (15-26^{o}C) along with moderate night temperatures that are conducive to creating longer dew periods (Salgado et al., 2016). The highest severity and incidence of the disease in Jhelum district is justified by mean temperatures of 26^{o}C along with higher humidity that rapidly builds up an epidemic in wheat fields. Much-reduced rainfall has been observed in Chakwal district, which becomes a leading reason for lesser infections and better crops. Apart from climatic conditions, several other biotic and abiotic factors govern the attack of the disease and level of infections. With the passage of time, formerly resistant wheat varieties get susceptible to the disease due to the rapidly changing nature of rust fungus.

Global climate change reduces the effectiveness of disease management practices by affecting both disease and host life cycles, and by changing the geographical patterns of plant disease spread (Chakraborty et al., 2000). Unfavorable weather conditions are the main contributing factor to the reduced incidences of foliar disease in Attock. Research shows that a pathogen requires suitable environmental conditions, the presence of fungal inoculum, and a susceptible host to cause disease. Any of these factors can become the leading source of a disease epidemic. The presence of resistant cultivars, significantly lowered precipitation and humidity, and higher mean temperatures help crops to flourish without rust epidemics in Attock (Wellings et al., 2000; Afzal et al., 2022).

A broad study was carried out in 2008 to assess the risk of rust epidemics and the influence of meteorology. This study found that fungal spores are discharged from diseased fields, with the majority of them landing back in the same field canopy or at ground level within the canopy. In contrast, rust spores dispersed by higher wind speeds manage to cover longer distances and

become a source of fungal inoculum across various locations. Weather conditions play a vital role as they affect disease development by both providing suitable conditions for disease development and affecting the survival of fungal spores through environmental variables such as temperature, ultraviolet radiation, solar radiation, and humidity. Higher daytime temperatures are disadvantageous for spore dispersal (Del Ponte et al., 2008). The correlation statistics of this study between disease incidence and weather parameters are also in line with those of Del Ponte et al. (2008) and Salgado et al. (2016).

CONCLUSIONS

A survey conducted in the Pothwar region has highlighted several factors, including rainfall, temperature, and humidity, that act as key regulators of disease dispersal and fungal spore germination, thereby limiting the yield and quality of wheat. The present study concludes that disease incidence and severity were maximum in Jhelum district due to higher mean precipitation, humidity, and temperature, which are conducive to prolonged dew episodes. With time, the fungus rapidly changes its properties, rendering previously resistant wheat cultivars susceptible to diseases. Disease attacks are also dependent on sowing dates, with late seeding leading to a reduction in developmental stages. Maximum yield losses were recorded when foliar diseases attacked the flowering stage of the wheat crop. Weed infestation is a significant threat to wheat crops, providing serious competition for crop nutrients, moisture, and space, thus reducing the yield. Farmers lack access to and awareness of modern crop management practices, and therefore do not consider disease resistance abilities when choosing a cultivar.

Hence, the present study's evaluation of wheat susceptibility to new races of rust fungi will provide insight into retrieving the health of wheat crop fields and improving the economic condition of the country. Therefore, there is an urgent need to expand farmers' access to information about newly introduced farming practices that are less laborious and time-consuming.

ACKNOWLEDGMENTS

We thank Fatima Jinnah Women University, Rawalpindi, Pakistan who provided us alleyway to execute this exquisite research.

AUTHORS' CONTRIBUTION

SI conceived and designed the study; SS conducted surveys and collected the data; SI analyzed the data; SS wrote the manuscript; SI supervised the work and proofread the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abid, S., Masood, M.A., Anwar, M.Z., Zahid, S., Raza, I., 2018. Trends and variability of wheat crop in Pakistan. Asian Journal of Agriculture and Rural Development 8, 153-159.

Afzal, S.N., Haque, M.I., Ahmedani, M.S., Rauf, A., Munir, M., Firdous, S.S., Ahmad, I., 2008. Impact of stripe rust on kernel weight of wheat varieties sown in rainfed areas of Pakistan. Pakistan Journal of Botany 40, 923-929.

Afzal, A., Riaz, A., Ashraf, S., Iqbal, J., Ijaz, M., Naz, F., Shah, S.K., 2022. Identification of durable resistance against yellow rust. International Journal of Phytopathology 11, 97-113.

Ahmad, D., Afzal, M., Rauf, A., 2019. Analysis of wheat farmers' risk perceptions and attitudes: evidence from Punjab, Pakistan. Natural Hazards 95, 845-861.

Atiq-ur-Rehman, R., Shahzad, A., Muhammad, F., Muhammad, Z., Shamim, I., Yasmin, A., 2011. Status of foliar diseases of wheat in Punjab, Pakistan. Mycopath 9, 39-42.

Bahri, B., Shah, S.J.A., Hussain, S., Leconte, M., Enjalbert, J., de Vallavieille-Pope, C., 2011. Genetic diversity of the wheat yellow rust population in Pakistan and its relationship with host resistance. Plant Pathology 60,649-660.

Batool, S.Q., Iftikhar, S., Ahmed, S.S., 2014. Epidemiological Estimation of Foliar Rust Diseases of Wheat and Pathological Assessment of Different Rust Pathogens Isolated from Rainfed Areas of Punjab, Pakistan. International Journal of Scientific and Engineering Research. 5.

Bux, H., Ashraf, M., Chen, X., Mumtaz, S., 2011. Effective genes for resistance to stripe rust and virulence of *Puccinia striiformis* f. sp. *tritici* in Pakistan. African Journal of Biotechnology 10, 5489-5495.

Bux, H., Rasheed, A., Siyal, M.A., Kazi, A.G., Napar, A.A.,

Mujeeb-Kazi, A., 2012. An overview of stripe rust of wheat (*Puccinia striiformis* f. sp. *tritici*) in Pakistan. Archives of Phytopathology and Plant Protection 45, 2278-2289.

Chakraborty, S., Tiedemann, A.V., Teng, P.S., 2000. Climate change: potential impact on plant diseases. Environmental Pollution 108, 317-326.

Channa, A.W., Bux, H., Jatoi, G.H., Sial, M.A., Shah, S.M., Figari, I.M., Koondhar, N., 2022. Evaluation of seedling resistance and marker assisted selection for leaf rust (*Puccinia triticina*) resistance in Pakistani wheat landraces, cultivars and advanced Lines. International Journal of Phytopathology 11, 155-169.

Del Ponte, E.M., Esker, P.D., 2008. Meteorological factors and Asian soybean rust epidemics: a systems approach and implications for risk assessment. Scientia Agricola 65, 88-97.

Devadas, R., Simpfendorfer, S., Backhouse, D., Lamb, D.W., 2014. Effect of stripe rust on the yield response of wheat to nitrogen. The Crop Journal 2, 201-206.

Fermont, A., Benson, T., 2011. Estimating yield of food crops grown by smallholder farmers. International Food Policy Research Institute, Washington DC 1, 1- 68.

Figueroa, M., Hammond-Kosack, K.E., Solomon, P.S., 2018. A review of wheat diseases - a field perspective. Molecular Plant Pathology 19,1523-1536.

Gill, H.S., Li, C., Sidhu, J.S., Liu, W., Wilson, D., Bai, G., Sehgal, S.K., 2019. Fine mapping of the wheat leaf rust resistance gene Lr42. International Journal of Molecular Sciences 20, 2445.

Haider, A., Zaidi, M., 2017. Food Consumption Patterns and Nutrition Disparity in Pakistan. pp. 833-893.

Iftikhar, S., Asad, S., Rattu, A., Fayyaz, M., Khanzada, K., 2010. Spot blotch of wheat in different agroecological zones of Pakistan. Pakistan Journal of Botany 42, 2139-2144.

Iqbal, M., Khan, M.A., Ahmad, M., Ahmad, B., 2001. Determinants of higher wheat productivity in irrigated Pakistan. The Pakistan Development Review 753-766.

Iram, S., Ahmad, I., 2005. Prevalence and disease incidence of foliar blight of wheat in rice wheat cropping system of Punjab. Pakistan Journal of Botany 37,973.

Iram, S., Iqbal, A., Ahmad, K.S., Jaffri, S.B., 2020. Congruously designed eco-curative integrated farming model designing and employment for sustainable encompassments. Environmental Science and Pollution Research 27, 19543-19560.

Javed, N., Atiq, M., Ahmed, S., Raza, S.M., Nawaz, A., Bashir, N., Ahmad, I., 2013. Adult plant resistance evaluation against leaf rust of wheat in Pakistan. Pakistan Journal of Phytopathology 25, 127-132.

Kolmer, J.A., 2005. Tracking wheat rust on a continental scale. Current Opinion in Plant Biology 8, 441-449.

Marasini, D., Marahatta, S., Dhungana, S.M., Acharya, R., 2016. Effect of date of sowing on yield and yield attributes of different wheat varieties under conventional tillage in Sub-Humid condition of Chitwan district of Nepal. International Journal of Applied Sciences and Biotechnology 4, 27-31.

Marwat, K.B., Zahid, H., Bakhtiar, G., Muhammad, S., 2006. Survey on weed problems in wheat crop in district Mardan. Pakistan Journal of Weed Science Research 12, 353-358.

Naeem, M., Cheema, Z.A., Ahmad, A.U.H., Wahid, A., Farooq, O., Saeed-ur-Rehman, H., 2013. Agro-economic assessment of wheat (*Triticum aestivum*) canola (*Brassica napus*) intercropping systems under different spatial patterns. International Journal of Agriculture and Biology15, 1325-1330.

Nebraska-Lincoln, U., 2014. Leaf Rust: Institute of Agriculture and Natural Resources; https://cropwatch.unl.edu/plantdisease/wheat/leaf-rust.

Neelam, M., Iftikhar, S., Ahmad, S.S., 2015. Study of foliar rust diseases of wheat crop in Chakwal district using GIS tools. In 2015 Fourth International Conference on Aerospace Science and Engineering (ICASE) (pp. 1-6). IEEE.

Roelfs, A.P., Singh, R.P., Saari, E.E., 1992. Rust Diseases of Wheat Concepts and Methods of Disease Management.CIMMYT, Mexico, D.F.

Salgado, J.D., Roche, E., Paul, P.A., 2016. Rust Diseases of Wheat: Ohioline, Ohio State University Extension, Department of Palnt Pathology; https://ohioline.osu.edu/factsheet/plpath-cer-12.

Salman, A., Khan, M.A., Hussain, M., 2006. Prediction of yield losses in wheat varieties/lines due to leaf rust in Faisalabad. Pakistan Journal of

Phytopathology 18, 178-182.

Scott, A., 2011. Global food security: could wheat feed the world? Support The Guardian; https://www.theguardian.com/global-developmentprofessionalsnetwork/2014/apr/01/international-wheat-yield-partnership-food-security (acessed 16 May 2014).

Wellings, C., Bariana, H., 2004. Assessment scale for recording stripe rust responses in field trials, Cereal Rust Report Season 2004. Plant Breeding Institute-Cereal Rust Laboratory, University of Sydney 2, 1-2.

Wellings, C.R., Singh, R.P., McIntosh, R.A., Yahyaoui, A., 2000. The assessment and significance of pathogenic variability in *Puccinia striiformis* in breeding for resistance to stripe (yellow) rust: Australian and International studies. In The Eleventh Regional Wheat Workshop for Eastern, Central, and Southern Africa. Addis Ababa, Ethiopia. (pp. 134-143).

Zulfiqar, F., Hussain, A., 2014. Forecasting wheat production gaps to assess the state of future food security in Pakistan. Journal of Food and Nutritional Disorders 3, 1-6.