International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

EPIDEMIOLOGY AND HOST PLANT RESISTANCE OF WHEAT AGAISNT STRIPE RUST WITH SPECIAL EMPHASIS ON BIOLOGICAL MANAGEMENT

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ABSTRACT

Yellow rust is an important foliar disease of wheat causing a major decline in the food production worldwide. The present investigation was done to evaluate the behavior of the rust causing pathogen *i.e. Puccinia striiformis* f. sp. *tritici* in the agro-climatic zone of Amritsar, during the rabi season 2024-2025. The epidemiological studies showed the significant positive correlation between the minimum and maximum temperature as well as wind speed with the disease severity while the relative humidity and rainfall showed a non-significant correlation with disease severity. A total of thirty-three wheat cultivars were assessed against several parameters of Final Rust Severity, Area Under Rust Progression Curve, Relative Area Under Rust Progression Curve, Coefficient of Infection and infection rate for checking the response of these cultivars out of which six cultivars exhibited a resistant host response. Twenty-six cultivars showed moderate susceptible to moderate resistant response while one cultivar showed highly susceptible response against stripe rust. The dynamic nature of the rust pathogen leads to the emergence of new races of the pathogen that need better control methods for which four biological compounds namely neem leaf extract, fermented buttermilk, garlic clove extract and wood vinegar were assessed for their effectiveness against the rust pathogen. The maximum control was obtained through fermented buttermilk with the minimum control through wood vinegar.

Key words: Area Under Rust Progression Curve, Coefficient of Infection, Final Rust Severity, infection rate, relative Area Under Rust Progression Curve

INTRODUCTION

Wheat (*Triticum aestivum* L.; 2n = 42) is among the world's most significant cereal crops and serves as a primary food source for nearly one-third of the global population. In India, the crop is cultivated across approximately 31.83 million hectares, producing nearly 113.29 million metric tonnes annually. Punjab is one of the leading wheat-growing regions, covering about 3.52 million hectares and contributing an estimated 17.74 million metric tonnes with an average yield of 5045 kg per hectare (Ministry of Agriculture and Farmers Welfare, 2023). Despite its importance, wheat production is frequently constrained by a number of biotic stresses, particularly the rust diseases *i.e.* yellow rust (stripe rust), stem rust, and leaf rust, among which yellow rust remains the most persistent and damaging in northern

India (Rehman et al., 2013). Yellow (Syn: stripe) rust of wheat caused by *Puccinia striiformis* f.sp. *tritici* (Pst) is considered as the most severe biotic threat in the North-Western Plain Zone and the Hill Zone of India. Disease outbreaks can reduce wheat yield by 10–70 per cent escalating to complete crop under conducive weather conditions (Rani *et al.,* 2019). The predominant pathotypes i.e. 46S119 and 78S84 continue to pose a major challenge for wheat cultivation across the northern states of India (Prashar *et al.,* 2015).

The pathogen belongs to the division Basidiomycota, order Uredinales, and family Pucciniaceae. It is an obligate, macrocyclic, heteroecious fungus requiring wheat as its primary host and certain species of *Berberis* and *Mahonia* as alternate hosts to complete its life cycle. Yellow rust development is favoured by cool temperature particularly around 20°C combined with high humidity (Zeng *et al.,* 2022). The urediniospores are highly efficient airborne disseminators capable of travelling long distances. Under high inoculum pressure, the spores can spread hundreds of kilometres from the initial infection site enabling rapid disease expansion across wheat-growing areas (Chen *et al.,* 2014). Infected plants experience significant physiological disruption as the pathogen interferes with water and nutrient transport leading to shrivelled grains, reduced grain weight and substantial yield decline (Rani *et al.*, 2019). Characteristically, yellow rust produces elongated yellow pustules arranged in stripes on the leaf surface which do not merge easily unlike those of other rusts. As the disease progresses, uredinia eventually convert into telia, which form black, elongated structures visible on leaves and sometimes on leaf sheaths. Teliospores possess a smooth, blackish coating appearing mostly beneath the leaf exterior and represent the overwintering stage of the pathogen (Srinivas *et al.*, 2021). It can cause 100 per cent yield loss in case of susceptible cultivars if infection occurs early and the disease continues to develop during the growing season (Afsal *et al.,* 2007).

In 2010-2011, stripe rust occurred in a severe form in plains of Jammu and Kashmir, foothills of Punjab and Himachal Pradesh and Terrai region of Uttarakhand, but timely action on monitoring its spread through fungicide protected the crop. In susceptible varieties, early infection can lead to almost total yield loss particularly when disease onset occurs before or during grain filling stage. The continuous emergence of new virulent pathotypes and changing climatic patterns further complicate disease management. Given these challenges, the present study aims to evaluate how different weather parameters influence the onset, development and severity of yellow rust, with the broader goal of supporting more effective surveillance and management strategies.

MATERIALS AND METHODS

1.1 Epidemiological studies against stripe rust of wheat

The susceptible wheat variety PBW 343 was sown in plots of size 3 X 3meter squares in the month of November. The fresh inoculum of *Puccinia striiformis* f. sp. *tritici* was mixed with talcum powder and was inoculated on the seedlings during the month of December and January to promote infection. The plots were regularly assessed after the appearance of the symptoms and daily observations on maximum temperature, minimum temperature, relative humidity, rainfall and wind speed were taken from the agrometeorological observatory at the P.G. Department of Agriculture, Khalsa college Amritsar. The progress of stripe rust was recorded at a weekly interval in terms of per cent disease severity using the modified cobb's scale (Table 1.1) given by Peterson *et al.* (1948) on a scale of six categories ranging from 0-5 on the basis of per cent area infected. Correlation analysis between the weekly disease severity and various weather parameters was conducted and data obtained was used to explain the results.

Table 1.1 Infection type at APR (Adult Plant Resistance) using Modified Cobb's Scale.

Scale	Reaction type	Description
0	Immune (0)	No visible infection
1	Resistant (R)	1-5% leaf area infected
2	Moderately resistant (MR)	6-10% leaf area infected
3	Intermediate (MRMS)	11-25% leaf area infected
4	Moderately susceptible (MS)	26-40% leaf area infected
5	Susceptible (S)	41-100% leaf area infected

1.2 Evaluation of host plant resistance of against *Puccinia striiformis* f. sp. *tritici* causing stripe rust of wheat

A total of thirty-three wheat cultivars were sown in a randomized block design in three rows (2 m in length) at a 25 cm row to row distance in the student's farm at Khalsa college, Amritsar in the rabi season 2024-2025. Each cultivar was artificially inoculated with *Puccinia striiformis* f. sp. *tritici* spores at tillering stage. Disease severity was recorded at regular intervals and different parameters *viz.* final rust severity (FRS), area under rust progression curve (AURPC), relative area under rust progression curve (rAURPC), coefficient of infection (CI), infection rate (r), were calculated to categorize the cultivars into different categories depending upon their resistance response.

Disease severity was recorded six times at a ten-day interval according to the modified Cobb's scale (Peterson *et al.*, 1948) and the response of individual genotype referred to the infection types (ITs) was categorized as resistant (R), moderately resistant (MR), moderately susceptible (MS) and susceptible (S) reactions based on Roelfs et al. (1992). The FRS is assessed sixty to eighty days after the onset of the disease. The Modified Cobb's Scale is primarily used to determine the Disease Severity Percentage. Coefficient of Infection (CI) was calculated by multiplying disease severity and constant values of infection type (IT). Constant values for infection types were used based on, Immune = 0, R = 0.2, MR = 0.4, M = 0.6, MS = 0.8 and S = 1 (Stubbs *et al*., 1986). Area under the disease progress curve (AUDPC) and relative area under the disease progress curve (rAUDPC) for rust development on each genotype were calculated from multiple disease severity readings using the following formula (Milus and Line 1986).

$$\text{AURPC} = \frac{1}{2}\sum_{i-1}^{n}\{(X_i + X_{i+1}) \times t_i\}$$

Where, X_i and X_{i+1} are severities on date i and date i+1, respectively;

t_i is the number of days in between date i and date i+1;

n is the number of observations recorded

$$\text{rAUDPC} = \frac{line\ AUDPC}{Susceptible\ AUDPC} \times 100$$

Apparent infection rate (r) is the increase or decrease in disease per unit time. It is estimated in terms of disease severity recorded on cultivars at different times (Van der Plank, 1963).

$$r = \frac{1}{t}\left(\log\frac{X2}{1-X2} - \log\frac{X1}{1-X1}\right)$$

where, X_1 =disease severity at date t_1

X_2=disease severity at date t_2

t=time interval between two date

X_1, X_2 are rust intensities recorded on first and second recording date

1.3 Management of stripe rust through biological compounds

For the present investigation popular wheat variety PBW 343 was selected which is grown over a large area but has now become susceptible to the yellow rust. The crop was grown with standard agronomic practices keeping three replications for each treatment in randomized block design (RBD) during the Rabi season 2024-2025. Four compounds namely, neem leaf extract (NLE), Garlic clove extract (GCE), fermented buttermilk (FBM) and wood vinegar (WV) along with control were used during the study programme. Artificial inoculation was carried out using a hand sprayer to apply the stripe rust uredospore suspension. 500g of neem leaves were taken and churned in a blender using 1litre of water. The filtrate was then taken as stock solution and reduced to concentration as per required (Kanwar *et al.*, 2022). One litre of milk was taken and curd was made out of it. The curd was diluted to make lassi. The lassi/buttermilk was kept in a plastic container for one week. After one week, about one-meter-long copper wire (after making spiral) was dipped in the lassi. The content was kept for at least 5 days. When the buttermilk became greenish-blue it was ready to use. The buttermilk was diluted to appropriate concentration (Tak *et al.*,2021). Fresh and healthy cloves of garlic were collected and washed thoroughly with clean water and finally with sterilized distilled water. These cloves were churned in grinder adding equal amount of sterilized distilled water to get stock solution. The mixture was then squeezed with double-layered sterilized cheese cloth. The extract thus obtained was considered as 100 per cent concentration. The obtained material was then used according to the required concentration (Kanwar *et al.,* 2022). Wood vinegar is a brown condensed acidic liquid which is a by-product of wood charcoal production. Its principal components are acetic acid, methanol, acetone, phenol, tar with a pH of 3.4.

Treatment sprays were applied thrice to the leaves at appropriate concentrations. The second application of the same treatment was done 10 days after the first foliar spray and repeated again after 10 days, which was made when 5 percent of the leaves began to show the early signs of infection. Using the Modified Cobb's scale given by Peterson *et al.*, 1948, and the scale given by Wellings and Bariana, 2004 disease severity was measured as a percentage of infection taken randomly from each line and the mean disease severity was used to explain the results.

RESULTS AND DISCUSSION

2.1 Epidemiological studies on stripe rust of wheat

The present investigation was done to evaluate the effect of epidemiological parameters on the intensity of disease severity during the Rabi season 2024-2025. The first appearance of the disease occurred in the 3rd standard meteorological week (13th Jan, 2025 to 19th Jan, 2025) with 11 per cent of severity coinciding with the early jointing stage of the crop (64 days after sowing) corresponding with the weather parameters having maximum temperature of 20.99^{0}C, minimum temperature of 6.66^{0}C, relative humidity of 44.89 per cent, rainfall of 0.04 mm and wind speed of 2.27 km/h. The disease gradually progressed from the 7th SMW to 10th SMW reaching 83 per cent of cumulative disease severity when the crop was at heading to milking stage (120 to 140 days after sowing), with maximum temperature of 25.54 to 27.67^{0}C, minimum temperature of 10.70 to 12.24^{0}C, relative humidity of 36.83 to 31.17 per cent, rainfall of 0.00 to 0.11mm and wind speed of 2.66 to 3.47 km/h. at the maturity stage (days after sowing) in the 11th SMW, cumulative disease severity of 95 per cent was observed having maximum temperature of 29.51^{0}C, minimum temperature of 16.19^{0}C, relative humidity of 43.19 per cent, rainfall of 0.87mm and wind speed of 2.46 km/h.

The correlation analysis (Table 2.1) was carried out to determine the relationship between different weather parameters and disease severity. The results showed that maximum temperature had a significant and positive correlation with disease severity (0.776*), while minimum temperature exhibited a highly significant positive correlation (0.958**). Relative humidity showed a non-significant and negative correlation with disease severity (-0.094 *), whereas, rainfall had a non-significant effect on the disease severity (0.347). Wind speed was found to be significant positively correlated with the disease severity (0.668). Among the weather parameters, minimum temperature (T min) exhibited the highest positive and highly significant correlation (r=0.958) with disease severity, indicating that the increased night temperature favored the development and progression of yellow rust. Warmer nights likely reduced the dew evaporation, extended the duration of leaf wetness and created favorable conditions for pathogen infection and sporulation. These findings are in accordance with Murray *et al.* (2005), who reported that stripe rust showed a highly significant positive correlation with minimum temperature concluding its major role in disease occurrence. Similar results were reported by (Gupta *et al.*, 2017; Papastamati and Vandenbosh, 2007) who observed a significant positive correlation of minimum temperature with disease severity and wind speed showed a significant positive correlation with disease severity indicating its supporting role in the disease occurrence and spread to increase the intensity. Maximum temperature (r=0.776) was recorded between 20-29^{0}C, however the maximum disease development was observed between 20-27^{0}C, showing a stagnant disease development beyond 27^{0}C. Total rainfall (r=0.347) had no significant influence on disease severity, likely because rainfall during the study period was low and sporadic, contributing minimally to disease establishment and spread which was in compliance with the results obtained by Sandhu *et al.* (2017), who reported that rainfall showed a negative non-significant effect on the disease severity indicating its minor role in disease occurrence. Relative humidity (-0.094) also showed a negative non-significant correlation with disease severity indicating that R.H alone cannot determine the yellow rust severity. Crop requires ample amount of leaf wetness and dew formation for the pathogen to establish and hence spread, which was provided by the minimum temperature rather than relative humidity. Similar results were reported by Sandhu *et al.*

(2017) who noted that relative humidity had a negative effect on disease severity. Wind speed (r=0.668) exhibited a significant positive correlation (r=0.668) with disease severity attributing the role of wind in facilitating the dispersal of uredospoes across the canopy and nearby fields. Gupta *et al*. (2017) reported that the moderate positive influence of wind speed emphasizes its contribution to epidemic build up, though not as dominantly as temperature.

Table 2.1 Correlation Analysis of weather parameters with disease severity of stripe rust of wheat

Correlation analysis revealed that the minimum temperature was a key determinant in influencing the disease severity as it increased the dew formation, created humid conditions and extended the leaf wetness period which provided enough moisture on the leaf surface for the spores to easily establish and germinate inside the host, increasing the intensity of the disease. Therefore, the results demonstrated that temperature, particularly Tmin, followed by Tmax and wind speed, were the major epidemiological factors influencing yellow rust epidemic. The weak or non-significant role of relative humidity and rainfall in this season indicated that their contribution may vary depending on year-to-year climatic variations and local microclimatic conditions.

2.2 Evaluation of host plant resistance against *Puccinia striiformis* f. sp. *tritici* causing stripe rust of wheat

Meteorological parameters	Correlation coefficient
Tmax (^{0}C)	0.776^{*}
Tmin (^{0}C)	0.958^{**}
R.H(%)	-0.094^{NS}
Rainfall (mm)	0.347^{NS}
Wind Speed (km/h)	0.668^{*}

A total of thirty-three cultivars (Table 2.2) were assessed for slow rusting resistance against *Puccinia striiformis* f. sp. *tritici* on the basis of various parameters such as FRS (Final Rust Severity), AURPC (Area Under Rust Progress Curve), rAURPC (relative Area Under Rust Progress Curve), r (Infection Rate) and CI (Coefficient of Infection) during the Rabi season 2024-25. Based on the AURPC values, twenty-three cultivars showed AURPC between (0-700) showing high level of resistance and slow build-up of disease, while seven cultivars having (701-1400) exhibited moderate level of disease build-up and spread, whereas, three cultivars showed high values of AURPC values ranging between (1600-2400) showing low level of resistance and more area under the disease occurrence. Based upon rAURPC values, ten cultivars exhibited low values of rAURPC ranging between (1-30) showing high level of resistance while, twenty cultivars showed moderate values between (31-60) showing moderate response, whereas, three cultivars exhibited high values of rAURPC of more than (60) and showed a low level of resistance against the pathogen. Based on the coefficient of infection (CI), six cultivars showed low values of CI ranging between (0-20) showing high level of resistance, while twenty-one cultivars showed moderate values ranging between (21-40) showing moderate resistance while, six exhibited high values (41-100) showing low resistance. Based on the infection rate (r), thirty-one cultivars showed value between (0.00-0.05) while, two cultivars exhibited infection rate between

(0.051-0.090), whereas, one cultivar showed the maximum value of (0.101) exhibiting the fastest disease occurrence and spread per unit time.

Table 2.2 Evaluation of wheat cultivars based on AURPC (Area Under Rust Progression Curve), rAURPC (relative Area Under Rust Progression Curve), CI (Coefficient of Infection), r (Infection rate) against stripe rust of wheat during, Rabi season 2024-2025.

S.no	Wheat cultivars	AURPC	rAURPC	Coefficient of Infection (CI)	Infection rate (r)
1	PBW 644	562.5	28.81	21	0.060
2	Raj 1482	772.5	39.56	36	0.028
3	DBW 222	720	36.88	24	0.040
4	PBW 771	652.5	33.42	21	0.028
5	PBW 677	527.5	27.02	21	0.031
6	PBW 824	1722.5	88.22	75	0.051
7	HD 3226	790	40.46	40	0.043
8	PBW 660	667.5	34.19	21	0.046
9	DBW 187	685	35.08	24	0.044
10	PBW 725	317.5	16.26	6	0.025
11	PBW-Zn-2	545	27.91	24	0.015
12	HD 3406	597.5	30.60	36	0.070
13	PBW 803	827.5	42.38	44	0.072
14	DBW 371	632.5	32.39	21	0.023
15	PBW 826	932.5	47.76	65	0.072
16	WH 1105	667.5	34.19	44	0.079
17	PBW 752	562.5	28.81	21	0.043
18	PBW-1-Chapati	667.5	34.19	21	0.069
19	PBW 757	667.5	34.19	36	0.041
20	DBW 303	440	22.54	8	0.015
21	DBW 332	545	27.91	18	0.043
22	Unnat PBW 550	685	35.08	24	0.044
23	PBW 869	737.5	37.77	36	0.075
24	HD 2851	790	40.46	40	0.059
25	DBW 372	685	35.08	24	0.059
26	PBW 872	597.5	30.60	36	0.054
27	Unnat PBW 343	597.5	30.60	10	0.037
28	DBW 370	512.5	26.25	10	0.025
29	DBW 327	632.5	32.39	36	0.066
30	DBW 621	422.5	21.64	10	0.050

31	PBW 766	562.5	28.81	21	0.023
32	HD 3086	1495	76.57	70	0.058
33	PBW 343	1917.5	100.00	95	0.101

The analyzation of different cultivars against all the parameters studied led to the categorization of the cultivars into three major groups *viz.*, resistance, moderately resistant to moderately susceptible and susceptible, which conferred that six cultivars (PBW 725, DBW 332, DBW 303, DBW 621, DBW 370, Unnat PBW 343) were found to be resistant while twenty-six cultivars (PBW 644, DBW 222, PBW 771, PBW 677, PBW 660, DBW 187, PBW-Zn-2, DBW 371, PBW 752, PBW- Chapati-1, Unnat PBW 550, DBW 372, PBW 766, Raj 1482, HD 3226, HD 3406, PBW 757, PBW 869, HD 2851, PBW 872, DBW 327, PBW 803, PBW 826, PBW 824, WH1105, HD 3086) were considered to be moderately resistant to moderately susceptible while one cultivar (PBW 343) remained as a susceptible variety of wheat.

2.3 Management of stripe rust of wheat through biological compounds

Data presented in (Table 2.3) shows that all the tested biological compounds reduced the disease severity significantly. The level of disease severity was far higher in the untreated control (90%) as compared to treated ones. The most effective plant extract in this regard was fermented buttermilk with least disease severity (58.42%, 56.42%, 53.21%, 51.32%), followed by neem leaf extract (60.32%, 57.39%, 55.67%, 53.61%), and garlic clove extract (73.42%, 68.92%, 67.95%, 64.76%) at (5%, 10%, 15%, 20%) concentration of the treatment, respectively. The least effective treatment was found to be wood vinegar with maximum disease severity (74.21%, 70.32%, 70.00%, 69.22%) at (5%, 10%, 15%, 20%) concentration, respectively. However, the untreated check exhibited the maximum disease severity of (90%).

Table 2.3 Field evaluation of different plant extracts against *Puccinia striiformis* f. sp. *tritici* causing yellow rust of wheat

Treatment	Concentration (%)					Reduction over control (%)
	5	10	15	20	Mean	
NLE	60.32 (50.80)	57.39 (49.23)	55.67 (48.23)	53.61 (47.04)	56.74 (48.83)	36.95
WV	74.21 (59.52)	70.32 (56.91)	70.00 (55.07)	69.22 (53.56)	70.92 (57.57)	15.64
FBM	58.42 (49.83)	56.42 (48.65)	53.21 (46.81)	51.32 (45.74)	54.84 (47.76)	39.06
GCE	73.42 (58.95)	68.92 (56.08)	67.95 (55.48)	64.76 (53.56)	68.76 (56.02)	23.60

Control	90.00 (71.53)	90.00 (71.53)	90.00 (71.53)	90.00 (71.53)	90.00 (71.53)	0
Mean	71.27 (58.13)	68.61 (56.48)	69.15 (56.83)	69.25 (56.31)		
C.D$_{0.05}$	Treatment=0.182 Concentration=0.162 Treatment x Concentration= 0.363					
S.E(d)	Treatment=0.089 Concentration=0.080 Treatment x Concentration= 0.179					

These variations in efficacy are attributed to the different modes of action of the treatments. Fermented buttermilk contains fat globules, casein protein, lactose sugar, lactic acid, and small quantities of biomolecules such as lactic acid bacteria, minerals, and vitamins, the foliar application of which reduces the leaf surface pH and forms a protective barrier due to the deposition of fat globules, thereby inducing resistance and restricting pathogen entry (Ferrandino and Smith, 2006). Neem leaf extract possesses anti-fungal components such as gedunin (a tetranortriterpenoid) or azadirachtin (a limonoid terpene) (Suresh *et al.*, 2004) which prevents fungal growth. The above results align with the findings of Tak *et al.* (2021), who reported that fermented buttermilk @20 per cent exhibited a high response in controlling the yellow rust epidemic with a disease severity of (50.1%, 50.0%) during two study season of 2016-2017 and 2017-2018 with a disease control of (34.8%, 33.6%) respectively, while neem leaf extract also showed a comparative result in controlling the disease with the severity of (60.0%, 46.7%), respectively with a control of (21.8%, 37.1%), respectively.

SUMMARY AND CONCLUSION

Epidemiological studies revealed that yellow rust development was greatly influenced by the prevailing meteorological conditions. Temperature and wind speed showed a significant positive correlation indicating that cooler nights and increased air movement favored the initiation and spread of the disease. Relative humidity and rainfall exhibited non-significant effects, suggesting that temperature and wind are the major drivers of epidemic progression in this region.

Phenotypic screening of wheat cultivars showed significant variations in their response to *Puccinia striiformis* f. sp. *tritici.* Some cultivars expressed moderate to high resistance, reflected by lower disease severity and infection rate, whereas susceptible cultivars recorded higher level of disease confirming the existence of genetic diversity in resistance. A total of six cultivars (PBW 725, DBW 332, DBW 303, DBW 621, DBW 370, Unnat PBW 343) exhibited slow rusting behavior and were considered as having high level of resistance while twenty-six cultivars exhibited a moderate level of rusting behavior and were grouped as having moderate level of resistance (PBW 644, DBW 222, PBW 771, PBW 677, PBW

660, DBW 187, PBW-Zn-2, DBW 371, PBW 752, PBW- Chapati-1, Unnat PBW 550, DBW 372, PBW 766, Raj 1482, HD 3226, HD 3406, PBW 757, PBW 869, HD 2851, PBW 872, DBW 327, PBW 803, PBW 826, PBW 824, WH1105, HD 3086), while one cultivar (PBW 343) showed fast rusting behavior and were grouped as the susceptible type having the lowest level of resistance.

Management studies using biological compounds demonstrated promising results in reducing the disease intensity under field evaluation. Among these, fermented buttermilk was the most effective treatment with the maximum control of the disease, followed by neem leaf extract. Integrated approach combining epidemiological studies, selection of resistant cultivars through evaluation of host plant resistance and eco-friendly biological management through management studies provides a sustainable and environment safe strategy for minimizing yellow rust incidence and ensuring stable wheat production.

REFERENCES

1. Afzal, S. N., Haque, M. I., Ahmedani, M. S., Bashir, S., & Rattu, A. R. (2007). Assessment of yield losses caused by *Puccinia striiformis* triggering stripe rust in the most common wheat varieties. *Pakistan Journal of Botany 39*(6): 2127-2134.
2. Chen, W., Wellings, C., Chen, X., Kang, Z., & Liu, T. (2014). Wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. *Molecular plant pathology*, *15*(5): 433-446.
3. Ferrandino, F. J., & Smith, V. L. (2007). The effect of milk-based foliar sprays on yield components of field pumpkins with powdery mildew. *Crop Protection*, *26*(4), 657-663.
4. Gupta, N., Batra, N., & Bhardwaj, S. C. (2017). Wheat rust research–Status, efforts and way ahead. *Journal of Wheat Research 9*(2): 72-86.
5. Kanwar, H., Shekhawat, P. S., & Chandrawat, B. S. (2022). Effect of plant extracts against stripe rust of barley caused by *Puccinia striiformis* f. sp. *hordei*. *Ecology, Environment and Conservation Journal 28*: 544-S547.
6. Milus, E.A., & Seyran, E. (2004). New races of Puccinia striiformis f. sp. tritici more aggressive than older races at 18 °C. In Proceedings of the 11th International Cereal Rusts and Powdery Mildews Conference. 22–27 August 2004, John Innes Centre, Norwich, UK. European and Mediterranean Cereal Rust Foundation, Wageningen, Netherlands. Cereal Rusts and Powdery Mildews Bulletin, Abstract. A2.50.
7. Ministry of Agriculture and Farmers Welfare, 2023. pib.gov.in/PressReleaseIframe Page.aspx?PRID=1968931
8. Murray, G., Wellings, C., Simpfendorfer, S., & Cole, C. (2005). *Stripe rust: Understanding the disease in wheat and Management Guide*, 1–12.
9. Papastamati, K., & Van den Bosch, F. (2007). The sensitivity of the epidemic growth rate to weather variables, with an application to yellow rust on wheat. *Phytopathology*, *97*(2), 202-210.
10. Peterson, R. F., Campbell, A. B. & Hannah, A. E. (1948). A Diagrammatic Scale for estimating Rust Intensity of Leaves and Stem of Cereals. *Canadian Journal of Research 26*: 496-500.
11. Prashar, M., Bhardwaj, S. C., Jain, S. K., & Gangwar, O. P. (2015). Virulence diversity in *Puccinia striiformis* f. sp. *tritici* causing yellow rust on wheat (*Triticum aestivum*) in India. *Indian Phytopathology 68*(2): 129-133.

12. Rani, R., Singh, R., & Yadav, N. R. (2019). Evaluating stripe rust resistance in Indian wheat genotypes and breeding lines using molecular markers. *Comptes Rendus Biologies 342*(5-6), 154-174.
13. Rehman, A. U., Sajjad, M., Khan, S. H., & Ahmad, N. (2013). Prospects of Wheat Breeding for Durable Resistance against Brown, Yellow and Black Rust Fungi. *International journal of agriculture & biology 15*(6).
14. Sandhu, S. K., Dhaliwal, L. K., & Pannu, P. P. (2017). Effect of weather parameters on incidence and severity of stripe rust in wheat under natural and artificial conditions. *Journal of Agrometeorology*, *19*: 272-277.
15. Shewaye, Y. and Mohammed, H. (2021). Screening and Evaluation of bread wheat (*Triticum aestivum*) genotypes resistance to stripe rust. *African Journal of Agricultural Research 17*: 766-779.
16. Srinivas, K., Rahman, M. S., Yadav, M., & Sharma, M. (2021). Brown and Yellow Rust of Wheat in India–Significance of Climate on Its Races and Resistance. *International Journal of Environment and Climate Change 11*(11), 72-91.
17. Stubbs, R. W., Prescott, J. M., Saari, E. E., & Dubin, H. J. (1986). *Cereal disease methodology manual*, 1-46.
18. Suresh, G., Gopalakrishnan, G., & Masilamani, S. (2004). Neem for plant pathogenic fungal control: The outlook in the new millennium. *Neem: Today and in the new millennium*, 183-207.
19. Tak, P. S., Pannu, P. P., & Kaur, J. (2021). Effect of foliar application of fungicides, neem extract and butter milk on yellow rust, plant growth and yield parameters of wheat. *Agricultural Research Journal 58*(2): 232-239
20. Van der Plank, J. E. (1968). Disease Resistance in Plants New York. *Academic Press* pp: 17-27.
21. Wellings, C. R. (2007). *Puccinia striiformis* in Australia: A review of the incursion, evolution and adaptation of stripe rust in the period 1979–2006. *Australian Journal of Agricultural Research 58*: 567–575.
22. Zeng, Q., Zhao, J., Wu, J., Zhan, G., Han, D., & Kang, Z. (2022). Wheat stripe rust and integration of sustainable control strategies in China. *Front. Agric. Sci. Eng*, *9*, 37-51.