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Forewarning of stripe rust (*Puccinia striiformis*) of wheat in central zone of Punjab

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ABSTRACT

Wheat crop is attacked by number of diseases some of which cause yield losses and deteriorates quality. Rust pathogens are most important pathogens of wheat which can cause considerable economic losses if uncontrolled. Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici*, is an important wheat disease common in wheat growing areas experiencing cold and humid weather conditions during the crop season. Different meteorological parameters influence occurrence and development of stripe rust in northern India including Punjab. Based on investigations on relationship of stripe rust with weather parameters, weather based prediction model for stripe rust was developed using disease severity and weather data (2007-08 to 2018-19) recorded at Ludhiana. The data of 2009-10 and 2019-20 was used for validation of model. Regression model based on maximum and minimum temperature, morning relative humidity and sunshine hours gave good results. Validation of model indicated that relationship between observed values of disease and predicted values was very close.

Key words: Wheat, stripe rust, meteorological parameters, regression model, validation

Wheat is an important source of food to majority of population of many developing countries. Globally, wheat is cultivated on an area of about 219 million hectares with a production of around 763.2 million tones. India ranks second in production of wheat after China (Bhardwaj *et al.,* 2019).Wheat is predominantly grown in the northern and north-western parts in country and is second most important staple food crop after rice. The most important wheat producing states include Uttar Pradesh, Punjab and Haryana accounting for 60 per cent area of the country. Punjab alone accounts for 13.58 per cent area and 21.77 per cent of wheat production of India (FAOSTAT 2020). During 2018-19, wheat was cultivated on 35.20 lakh ha area with a production of 182.62 lakh tones and average yield of 51.88 q ha^{-1} (Anon., 2020). During the last 30 years, agricultural production has been capable to maintain pace with food demand of increasing population. It has been estimated that approximately 2.5 per cent increase in cereal production will be required to meet food requirement in the next decade.

The susceptibility of commercially available wheat varieties to rust species is one of the serious constraint to maintain the yield and productivity of wheat under changing climatic conditions. Rusts are among the most economically significant fungal diseases in cereal crops worldwide. Stripe rust, caused by *Puccinia striiformis* f. sp. *tritici*, is an important wheat disease common in wheat growing areas experiencing cold and humid weather conditions during the crop season. In 1986, stripe rust (due to breakdown of stripe rust resistance genes YR-9) was first time diagnosed in Kenya from there its *urediospores* reached India in 1997-98 (Amor *et al*., 2008). It occurred in epidemic form in 2008-09 in Punjab and its surrounding areas and caused huge yield losses. Pannu *et al.,* (2010) revealed about occurrence of stripe rust in epidemic form in foot hills of Punjab and neighbouring states during 2008-09 to 2010-11.

In the present situation of rising food demands with decrease in agricultural lands more efficient agricultural system will face challenge from diseases such as stripe rust. Weather plays significant role in appearance, progress and multiplication of diseases. Milus and Seyran (2004) revealed that stripe rust caused by the new isolates tends to grow faster than the previous isolates at comparatively elevated temperatures. Temperature, rainfall, humidity, sunshine duration and wind have the important effect on many plant diseases. Whenever, vulnerable host and active pathotype exist together under most favorable conditions, the probability of disease epidemic increases. Disease forewarning is very important for the timely and effective management of rusts by using fungicides. Many weather based regression models/equations for rust forewarning are available for various locations. But these regression models are site specific and cannot be used for different regions. The unsuitability of use of these models at different locations is due to the climate variability and some bio-physical conditions. Therefore, a need was felt to formulate weather based stripe rust forewarning model for central zone of Punjab. So keeping this in view an analysis was conducted to identify the weather variables and critical periods affecting stripe rust severity in wheat and to develop weather based prediction model for stripe rust.

MATERIALS AND METHODS

The meteorological data recorded at Agrometeorological Observatory (30°54'N latitude; 75°48'E longitude and altitude of 247 m amsl) of Punjab Agricultural University, Ludhiana for the period of (2007-08 to 2019-20) was considered for the study.

The disease severity was calculated from the proportion of plant tissue infected by the disease as per Modified Mannar's scale for stripe rust of wheat (Peterson *et al.,* 1948). Six categories of the scale were determined on the basis of the per cent area of the leaf covered by infection as follows:

5 = Upto 5 per cent leaf area infected
10 = Upto 10 per cent leaf area infected,
20 = Upto 20 per cent leaf area infected,
50 = Upto 50 per cent leaf area infected,
75 = Upto 75 per cent leaf area infected,
100 =Upto 100 per cent leaf area infected.

Stripe rust severity data was recorded at weekly interval and then percentage weekly disease severity and terminal disease severity was calculated.

Correlation study

Correlation coefficients were calculated between monthly stripe rust disease severity index and different meteorological parameters like temperature, relative humidity, sunshine hours and rainfall for pooled data to develop weather based epidemic window. The correlation coefficient was calculated between terminal stripe rust severity and average meteorological parameters for pooled data of eleven years (2007-08 to 2019-20 barring 2009-10 and 2019-20). The favourable meteorological parameters for disease development and spread were analysed by plotting graphs in software R.

Regression model

Eleven years data (2007-08 to 2019-20 barring 2009-10 and 2019-20) were used for development of regression model. Combinations of disease severity with different meteorological parameters were developed and best regression model with significant R^2 and adjusted R^2 value was selected. The correlation coefficients and regression model was developed using statistical analysis in software R (version 3.5.2).

Model validation

To validate the regression model, disease severity and meteorological data of 2009-10 and 2019-20 (that was not used in development of model) was used by calculating the deviation of predicted value from observed value. After that linear relationship was developed between observed and predicted disease severity.

RESULTS AND DISCUSSION

Occurrence of stripe rust in Punjab

The disease attack on crop depends on weather conditions prevailing in the area. It is a major problem of wheat in Punjab and its surrounding areas due to prevalence of congenial weather conditions for its development. Wheat variety PBW 343, released during 1995, having resistance to 46S119 pathotype of stripe rust, became more popular due to its high yield throughout the North India. Due to wide acceptance of this variety in North West India, new pathotype 78S84 of *Puccinia striformis f.sp. tritici* appeared and its frequency of occurrence started increasing since 2006-07. During 2008-09, stripe rust was observed extensively in sub-mountainous districts of state and further it spread to central Punjab on the widely cultivated wheat cultivar, PBW 343. The disease severity

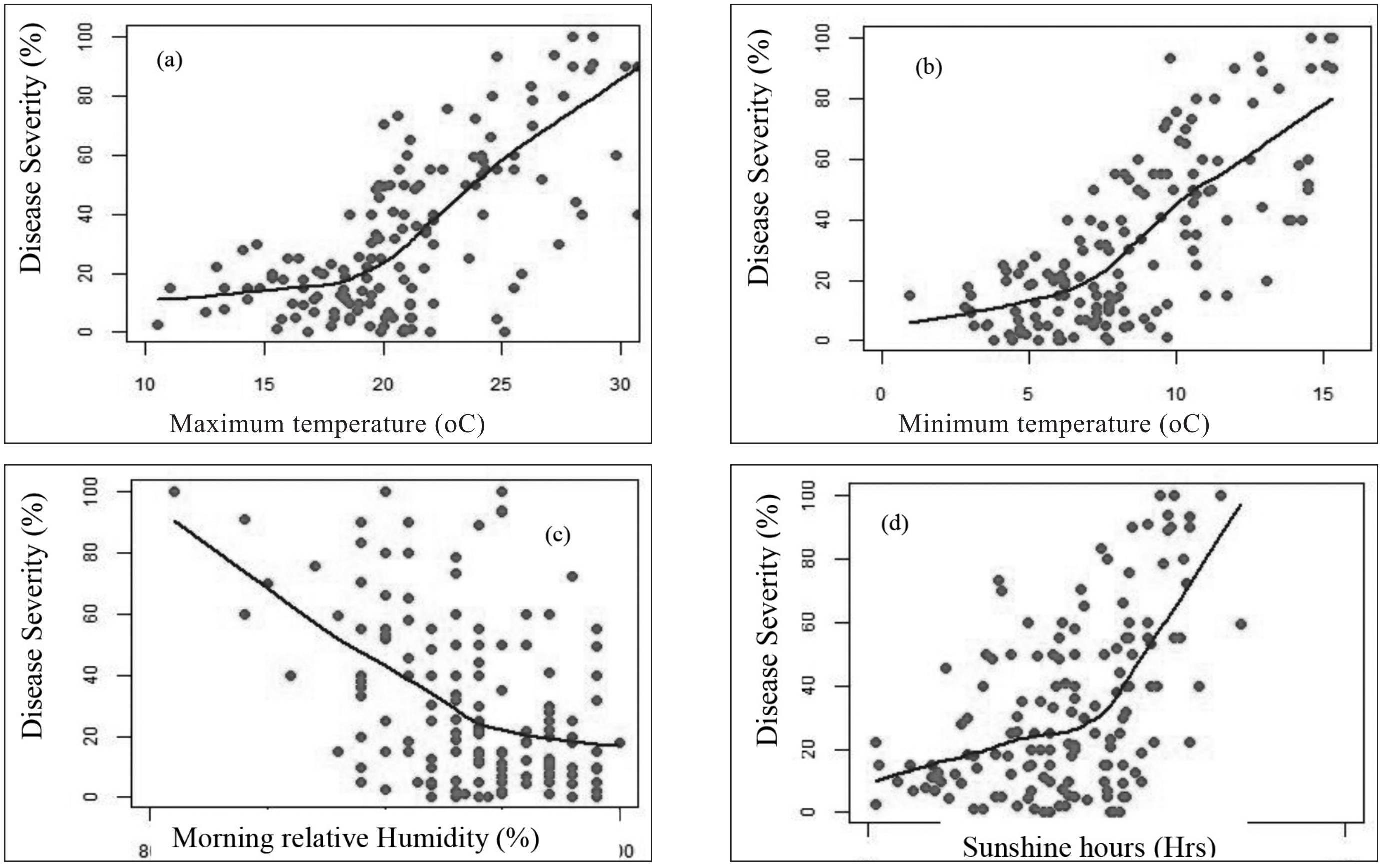


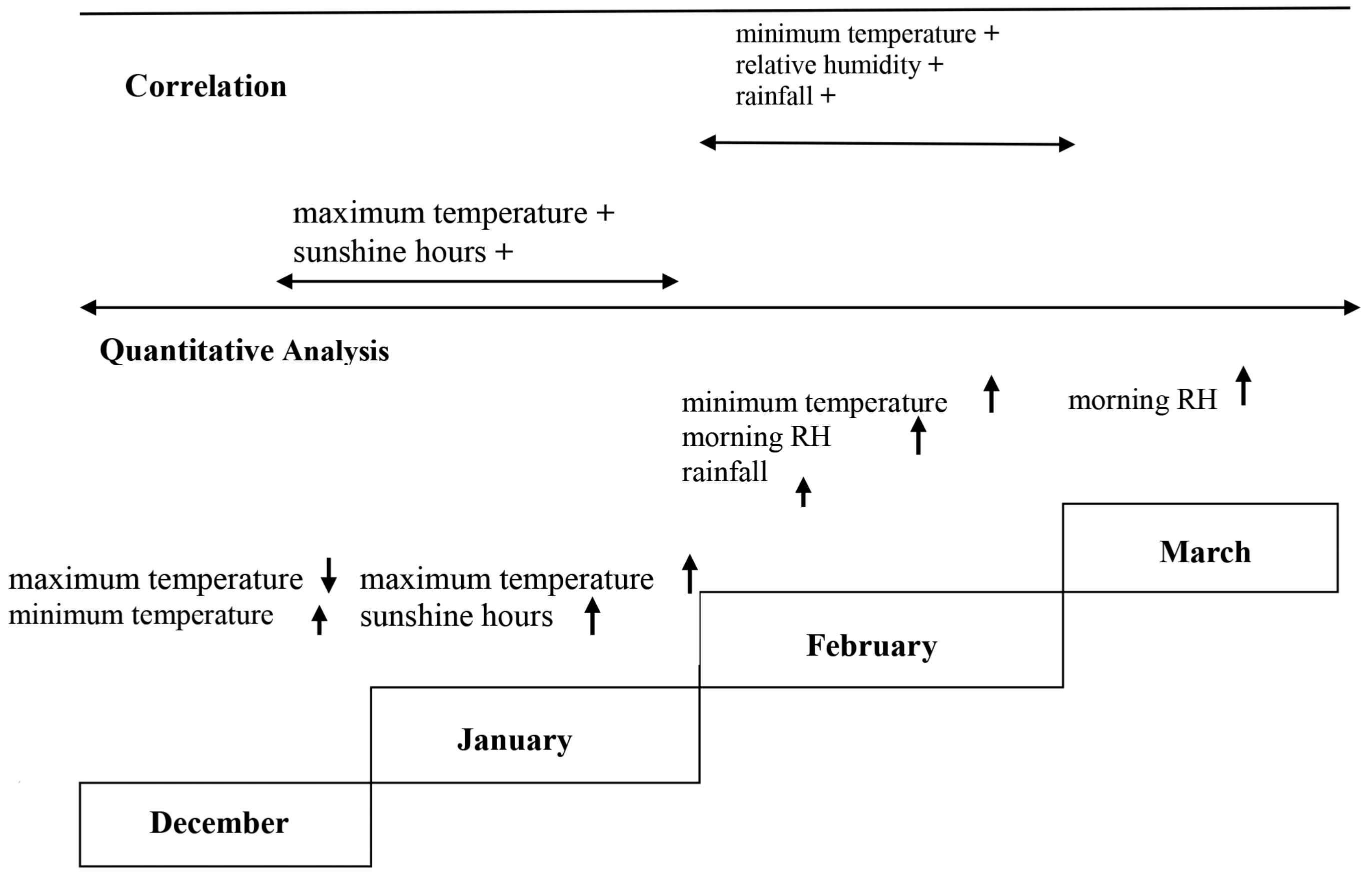
Fig. 1: (a-d): Favourable meteorological parameters for progress and spread of stripe rust

recorded was as high as 60 to 90 per cent which resulted in drastic reduction of yield. From 2007-08 onwards stripe rust disease started appearing in high proportion on a cultivar PBW 343 and certain other genotypes in different locations of state. Terminal disease severity varied in different years. Stripe rust severity during 2008-09 was about 90 percent, it was the first epidemic caused by stripe rust in Punjab. Now the disease appears every year on different wheat cultivars and causing significant yield losses in different areas.

Epidemic window of stripe rust in Punjab

Every insect-pest or disease has a specific window period during which it flourishes well. Stripe rust occurrence, development and spread is influenced by different meteorological parameters throughout disease development and spread period as shown in Fig.1 (a-d). The disease development was observed in maximum temperature range of 12-30^{o}C, however, maximum disease progression was observed in range of 15-25^{o}C. Whereas, minimum temperature in range of 7-13^{o}C was most favourable for rust progression. The disease development was observed in morning relative humidity range of 86-98 per cent but maximum development and progression was observed in 90-98 per cent relative humidity. The disease development is influenced by sunshine hours significantly. The sunshine hours in range of 5-10 hours were observed most favorable for disease development and spread.

The quantitative analysis of disease and monthly weather data was done and it was observed that below normal maximum temperature and above normal minimum temperature during December favored occurrence of disease. Epidemic window was developed on the basis of prevailing weather conditions and monthly correlation coefficient between disease severity and meteorological parameters as shown in Fig.2. The maximum temperature in the range of 20 to 24^{o}C and number of sunshine hours (>8 hrs) showed positive influence on disease development during month of January. During month of January and February that was most favourable time for stripe rust



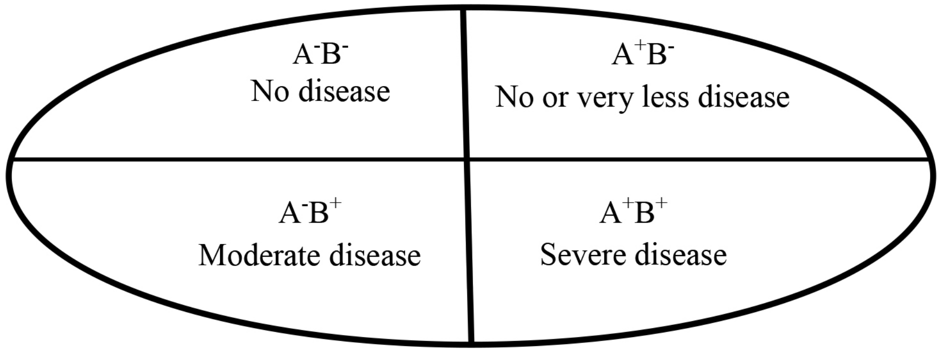
Where, *Upward arrow indicates above normal value of parameter; **Downward arrow indicates below normal value of parameter

Fig. 2 : Epidemic window of stripe rust of wheat in Punjab

development and spread, minimum temperature (7-13°C), morning relative humidity(>95%) and rainfall (>20 mm) favored disease severity and its further spread. In month of March, morning relative humidity (>80%) and frequent rainfall prolonged disease period. Correlation analysis of eleven year data of disease severity and different meteorological parameters indicated that maximum temperature and sunshine hours have positive correlation with disease severity during January. During month of February, minimum temperature, morning relative humidity and rainfall showed positive correlation with disease severity. Whereas, in correlation coefficients analysis, December and March data didn't show any significant correlation between disease severity and different meteorological parameters. On the basis of this analysis, thumb rule was developed for forewarning of stripe rust disease of wheat as shown in Fig.3. This thumb rule has been developed by using two meteorological parameters. According to this thumb rule, during January and February if minimum temperature is in range of 7-13°C with morning relative humidity higher than 95 per cent there are chances of severe disease epidemic. Singh *et al.*, (2016) revealed that different weather parameters significantly affect stripe rust of wheat.

Meteorological parameters and stripe rust

The pooled correlation coefficients between disease severity and different meteorological parameters were calculated on the basis of weekly disease severity and weekly weather data in different years (2007-08 to 2019-20 except 2009-10 and 2019-20) as presented in Table 1. Disease severity and weather data of 2009-10 and 2019-20 years was used for model validation so these years data was not included in pooled analysis for model development. Among correlation coefficient analysis, disease severity showed significant positive correlation with maximum and minimum temperature, sunshine hours whereas disease severity showed significant negative correlation with relative humidity. Similarly, Gupta *et al.*, (2017) revealed that meteorological parameters viz. temperature



Where,

A: Minimum temperature in range of 7-13°C in January and February; B: Morning relative humidity >95%

Fig. 3: Thumb rule for yellow rust in Punjab conditions

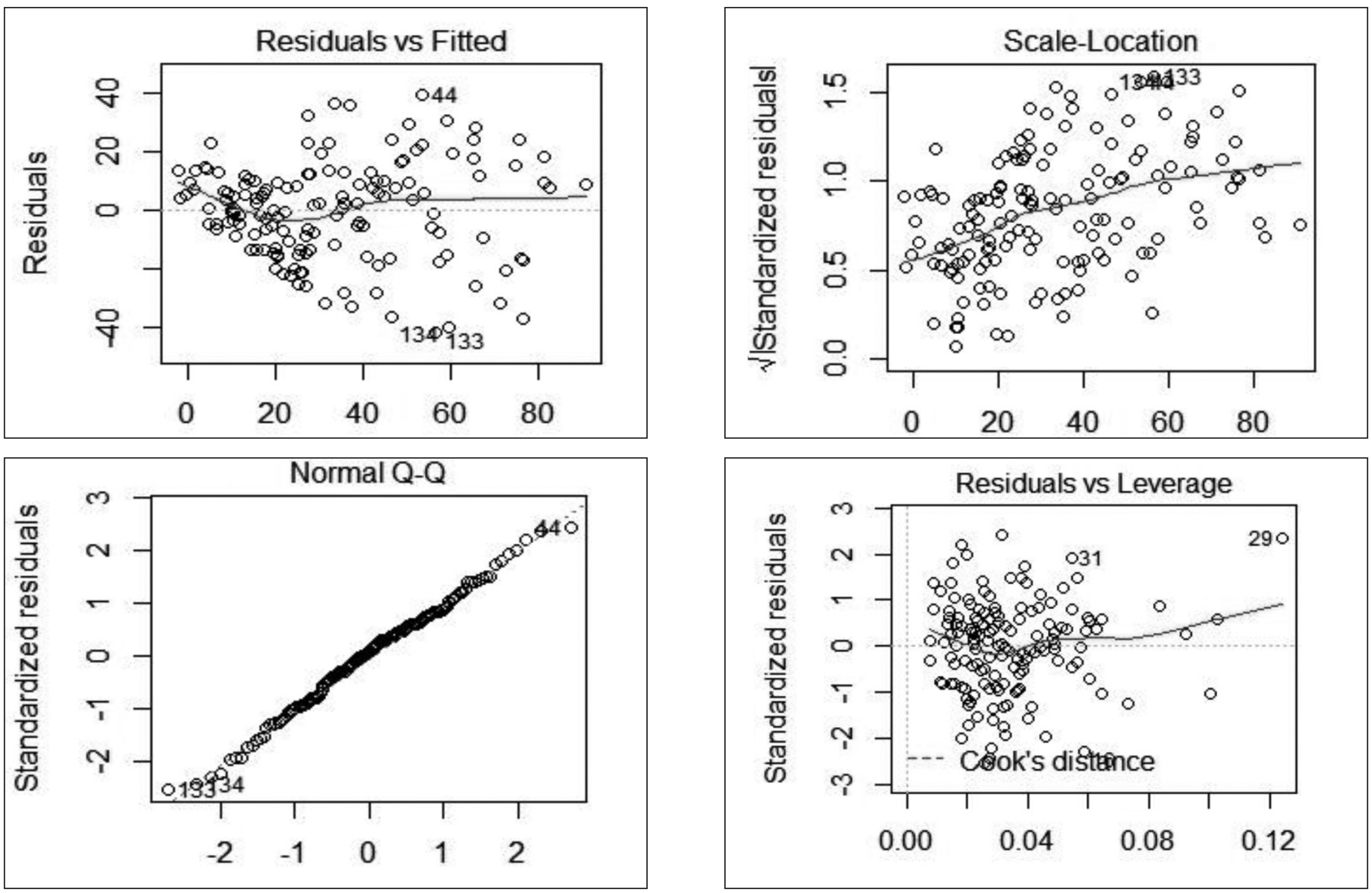


Fig. 4: Diagnostic plots of developed predictive model

(maximum and minimum), morning and evening vapour pressure, and micrometeorological parameters (canopy and soil temperature) showed significantly positive correlation with the stripe rust severity, whereas, morning relative humidity was negatively correlated with rust severity of wheat.

Development of a regression model

On the basis of different correlation coefficients and relationships of disease severity with different meteorological parameters, most influencing meteorological parameters were identified. These

Table 1: Correlation coefficients between stripe rust severity and meteorological parameters (pooled analysis of 11 years data)

Meteorological parameter	Correlation coefficient (r)
Max. temperature	0.68*
Min. temperature	0.73*
Morning relative humidity	-0.44*
Evening relative humidity	-0.24*
Sunshine hours	0.50*
Rainfall	0.04

*p value indicates level of Significance at 1%

meteorological parameters were from disease development to spread period. After analysing number of regression equations best fit equation with significant R^2-value was selected as a model for forewarning of stripe rust. This regression model includes maximum and minimum temperature, morning relative humidity and sunshine hours as independent variables and disease severity as dependent variable. This model is as follows:

Y=32.7-1.29 Tmax+6.19 Tmin-0.57 RHm+4.57 SShr (R^2=0.64, Adj.R^2=0.62)

(F-statistic: 62.09, p-value: < 0.00001)

Where,

Y= Stripe rust severity (%); Tmax: Maximum temperature (°C); Tmin: Minimum temperature (°C); RHm: Morning relative humidity (%); SShr: Sunshine hours (hrs); R^2: Coefficient of determination; Adj R^2: Adjusted coefficient of determination

On the basis of the model, it can be revealed that temperature, relative humidity along with sunshine hours can act as key indicators for disease development. The significant R^2-value of 0.64 indicates that 64 per cent variability in stripe rust severity was due to maximum and minimum temperature and morning relative humidity and sunshine hours. This model gave significant adjusted R^2 value (0.62) i.e. of more importance for forewarning as adjusted R^2 values includes the specific role of those independent variables which really influenced disease severity. The outcome is in corroboration with findings of Sandhu *et al.,* (2017). The diagnostic plots (Fig. 4) of the model also signify good predictability of the model if a new set of meteorological data fitted into it. So, this model can be used to forewarn stripe rust incidence and thus fungicide application can be scheduled accordingly.

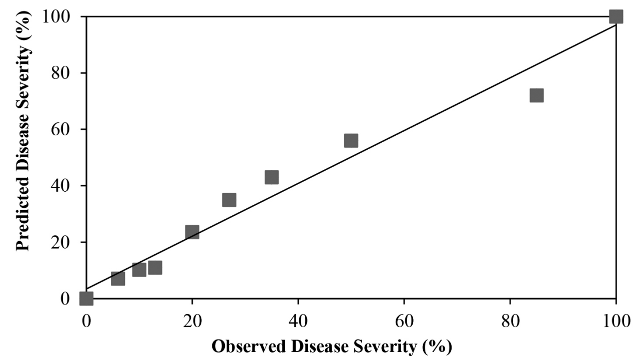


Fig. 5: Performance of developed predictive model

Validation of model

Validation of the regression model was done by calculating the predicted disease severity of two years (2009-10 and 2019-20) data. This validation indicated that developed regression model over-estimated the disease severity by 4 to 8 per cent (Fig.5). A relationship between observed and predicted disease severity values was developed as shown below:

$DS_{pre} = 0.9361 DS_{obs} + 3.39$ R^2=0.96 & Adj. R^2=0.94

Where, DS_{pre}: Predicted disease severity (%)

DS_{obs}: Observed disease severity (%)

Linear relationship with higher R^2-value and adjusted R^2-value indicated that model can be used for stripe rust forewarning in central zone of Punjab.

CONCLUSION

Stripe rust, a prime disease of wheat, starts appearing from December month but it is January and February period weather that influence disease development, spread and severity most. Among different meteorological parameters temperature, relative humidity and sunshine hours act as key factors for disease severity. Forewarning of disease severity can be used for timely and effective management of disease so as to reduce the yield losses caused by this particular disease.

Conflict of Interest Statement: The author(s) declare(s) that there is no conflict of interest.

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