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Impact of Epidemiological Factors on Development of *Puccinia Triticina* Sp. *Tritici* on Wheat in Pakistan

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Abstract

The weather changes after the host-pathogen interaction play a vital role in the wheat leaf rust development. This study presents the impact of weather changes at wheat growing areas of Faisalabad, Bahawalpur and Sakrand on development of wheat leaf rust by taking into account the disease and weather data (from 4th February -5th March) of the respective years from 2003-2009. For the purpose multiple regression analysis of the temperature, relative humidity and wind velocity with the disease severity on six wheat cultivars namely Morroco, Inqilab-91, Sarsabz, Kirin-95, Soughat-90 and Tandojam-83 was conducted. It was found that temperature and relative humidity both played a significantly positive effect in disease development while wind velocity had negative impact on disease development. The most favorable conditions for leaf rust development on wheat in Pakistan were recorded at Bahawalpur, where the temperature (16.85-20.44°C), relative humidity (57.08-76.95%) and wind velocity (1.98-4.07 km/hr) acts collectively in onset of leaf rust. When these weather parameters were individually regressed no clear trends were noticed keeping in view their coefficient of determination (R^2), regression coefficients/lines. This study depicts that all these factors interact with each other in a multi-colinear interaction, and had a collective effect on onset of leaf rust in the natural environment.

Key words: Climate change, wheat, leaf rust, weather parameter.

Introduction

Climate change affects wheat crop, a rich source of carbohydrates, fats, proteins and dietary fibers, that contributes 21% of food and 200 million hectares of land, cultivated worldwide (Ortiz et al., 2008). In Pakistan in 2009-10, wheat was cultivated on an area of 9.042 million hectares with an annual production of about 23.864 million metric tons (GOP, 2010). Wheat production is severely affected by abiotic and biotic stresses (Singh et al., 2008) like leaf and stripe rust are a constant threat to wheat production in Asia and all over the world (Singh et al. 2005; Chen, 2005). The leaf (*Puccinia triticina*) rust is the most widespread of three types of rusts over large geographical areas caused significant yield losses in wheat production worldwide (Kolmer 2005; Bolton et al., 2008).

In Asia, leaf rust affects approximately 60 million hectares i.e., 63% of production, if susceptible cultivars are grown (Singh et al., 2005). Quality losses due to leaf rust include reduced protein levels and softness equivalent scores (Everts et al., 2001). In Pakistan, leaf rust epidemics caused great yield losses in wheat production in 1973 and 1978 (Hassan et al., 1973; Hussain et al., 1980). The leaf rust of wheat appears on wheat during anthesis period (Rattu et al., 2010). The combination of inoculum (urediniospores), favorable environment and susceptible host plants results in the development of disease epidemics (Duveiller et al., 2007). The disease is favored by three important weather factors that are moisture, temperature and wind (De-vallavieille-Pope et al., 2002; Wiik and Ewaldz, 2009). Thus, influencing the severity and frequency of leaf rust epidemics (Shaw et al., 2008; Chakraborty et al., 2010). Moisture affects spore germination, infection, and survival of the urediniospores, requires at least 3 hrs of continuous moisture on the plant surfaces to germinate and infect plants (Bolton et al., 2008). Temperature affects spore germination, infection, latent period, sporulation, spore survival, and host resistance. The pathogen requires a favorable temperature ranging between 10-30°C (Singh et al., 2002; Bolton et al., 2008) and free water on the leaf surface (Bolton et al., 2008).Wind can affect drying of urediniospores of *P. triticina* that results in reduction in on-site germination and infection. It also increases the duration of spore viability and plays a major role in the spread of leaf rust (Chen, 2005).

This changing climate ultimately affects the wheat production, generate food security issues and influence plant disease epidemics. Accordingly the objectives were to study the effect of weather changes on development of wheat leaf rust in Pakistan, and find an appropriate relationship between leaf rust severity on wheat cultivars with meteorological data.

Materials and Methods

Collection of disease data: Leaf rust data of six wheat cultivars (Morroco, Inqilab-91, Sarsabz, Tandojam-83, Soughat-90 and Kirin-95) from 2003-2009 was obtained from Crop Disease Research Programme (CDRP), National Agricultural Research Centre (NARC), Islamabad. The disease data was of three locations viz., Faisalabad (31°15′N73°03′E), Bahawalpur (29°23′44″N71°41′1″E) and Sakrand (27.08°N 68.16°E). The leaf rust data was recorded according to the modified Cobb's scale as described by Peterson *et al.*, (1948) and converted to co-efficient of infection (C.I.) using method reported by Loegering, (1959). The disease data was from (4th February – 5th March) in each year as this is considered the most crucial time period for disease development in wheat growing areas of Pakistan.

Collection of meteorological data: The meteorological data for the years 2003-2009 of Faisalabad, Bahawalpur and Sakrand was collected from Pakistan Meteorology Department. One month (4th February-5th March) data of each year of average temperature (°C), average relative humidity (%) and average wind velocity (Km/hr) was used.

Statistical analysis: The relationship of temperature, relative humidity and wind velocity with the wheat leaf rust both individually and collectively was determined using Mstatc and Microsoft Excel Analysis Tools.

Results

Analysis of disease data: The disease data of each variety was regressed collectively. The statistical analysis showed that most favorable place for the leaf rust infecction was Bahawalpur where highest leaf rust severity on wheat was recorded followed by Sakrand. The lowest leaf rust severity was recorded at Faisalabad. None of the variety was found to be completely resistant to leaf rust except Inqilab-91, while Morroco (check) was the most susceptible.

Analysis of meteorological data: At Faisalabad, temperature, relative humidity and wind velocity ranged from 15.82-21.31(°C), 37.23-64.07(%) and 2.62-5.26 (km/hr), respectively. The parameters (temperature, relative humidity and wind velocity) at Bahawalpur ranged from 16.85-20.44(°C), 57.08-76.95(%) and 1.98-4.07(km/hr), respectively. While at Sakrand, the values observed for temperature (15.59-22.33°C), relative humidity (52.78-60.87%) and wind velocity (6.05-8.67 km/hr) were given, respectively.

Multiple regression analysis of disease and meteorological data: The disease data showed a high degree of variation and appeared misleading because the disease was not observed in years 2005-2009 at Faisalabad, in 2007-2009 at Bahawalpur and in year 2005, 2007-2009 at Sakrand. Furthermore, in the year 2008, the wheat crop had completely escaped leaf rust infection and no disease developed throughout Pakistan. So, to bring consistency in our data statistical analysis was conducted of those years and locations, when and where, disease appeared.

Multiple regression analysis of Morroco: The regression analysis of Morroco showed positive effect of temperature and relative humidity with the disease severity. With the increase in temperature and relative humidity disease incidence also increased. However, there exists a strong negative relationship between wind velocity and disease severity. This reflects that when the wind velocity increases the disease decreases while the coefficient of determination remained 67.7% (Table 1).

Multiple regression analysis of Inqilab-91: The regression analysis for Inqilab-91depicted a same positive impact of temperature and relative humidity, while a negative impact of wind velocity with disease severity. The temperature showed 1.3055 and relative humidity 1.3851 regression coefficient values. Increased temperature and relative humidity helped in successful infection development. Wind velocity has again showed a negative effect with a value of -2.7798. The coefficient of determination was 72.3% (Table 2).

Multiple regression analysis of Sarsabz: When leaf rust severity on Sarsabz was regressed with corresponding weather data, the same effect was observed among the temperature and relative humidity. But this time, the regression coefficient of temperature and relative humidity was 2.3042 and 6.9345, respectively. Wind velocity showed a stronger negative interaction with a value of coefficient -7.0618. The coefficient of determination was 93.4% (Table 3).

Multiple regression analysis of Kirin-95: The regression analysis of Kirin-95, the disease severity was positively interacted with temperature and relative humidity. The regression coefficient for temperature was 1.8357 and of relative humidity it was 1.4243 showing an increase in disease severity with a 1ºC rise in temperature and 1 % rise in relative humidity. The wind velocity again showed a strong negative, regression coefficient with a value of -5.0132 towards the disease development. The coefficient of determination remained 69.0% (Table 4).

Multiple regression analysis of Soughat-90: The regression analysis of Soughat-90 showed an increase in disease severity with the rise in temperature rise in relative humidity. The regression coefficient value for both the parameters remained 1.4367 and 3.9529, respectively. The wind velocity showed a negative impact with a regression coefficient value of -7.6549. The inoculum level near plant canopy decreases as the strong winds blew. The coefficient of determination was 80.3% (Table 5).

Multiple regression analysis of Tandojam-83: In disease severity data of Tandojam-83, the temperature and relative humidity showed a positive impact on disease development when there regression coefficient values were 3.0377 and 4.2981. The wind velocity exhibited a negative impact by a regression coefficient of -1.8606 on disease development. The coefficient of infection remained 91.1% (Table 6).

Interaction of individual weather factor and the leaf rust severity:

The results in the present study depicted that temperature, relative humidity and wind velocity interact simultaneously in nature and contribute collectively in making the environment favorable for the leaf rust development, which showed that multi-colinearity exists among them. When effect of these weather factors were assessed individually and found that there exists no significant positive impact between leaf rust development and individual weather factors. If one of these weather factors was missing the disease would not develop. However, if disease develops, its severity fluctuates with changing environmental conditions.

Effect of temperature: The leaf rust development was investigated with temperature as a single factor against all the cultivars. It was found that the temperature solely was not responsible for successful infection. The interaction of temperature with disease was shown in Figure 1a, 1b, but none of the variety had shown any interaction as low R^2 values ranging from (0.007- 0.510). The temperature alone cannot help in disease development. It also required suitable amount of water and wind.

Effect of relative humidity : Relative humidity being important for infection process but when assessed in pooled disease data of all three stations showed no dependence on single factor as their R^2 value were between (0.014 – 0.230) (Figure 2a, 2b) for all the six cultivars.

Effect of wind velocity: Wind velocity being important in provision of inoculum and cause agitation among leaves, had shown no effect on leaf rust development as a single factor having R^2 value between (0.180 – 0.527) (Figure 3a, 3b). The regression analysis showed that there was a negative impact of wind velocity on disease development.

Discussion

The leaf rust (*Puccinia triticina* f. sp. *tritici*) of wheat is an important disease in Pakistan appears first at anthesis period, when the development of wheat grain is in progress. The disease was favored by moderate temperature and high humidity for longer period of time. Bahawalpur had the optimum conditions as compared to Faisalabad and Sakrand, where favorable temperature and moisture were prevailing while low wind velocity on the other hand had also contributed. The leaf rust data of wheat cultivars (Morroco, Inqilab-91, Sarsabz, Tandojam-83, Soughat-90 and Kirin-95) from 2003-2009 showed that disease was more in Bahawalpur > Sakrand > Faisalabad.

The disease data of 7 years reflected clearly that high disease incidence was observed at Bahawalpur as compared to Faisalabad. The reason was the suitability of climate for disease development. At Bahawalpur, the temperature (16.85-20.44°C), relative humidity (57.08-76.95%) and wind velocity (1.98-4.07 km/hr) favored the disease infection. Stubbs et al. (1986) reported that the low temperature and humid conditions were required for successful infection establishment. The disease incidence was also greater in Sakrand than in Faisalabad.

At all the three locations, temperature and relative humidity showed an important role in creation of suitable environment for disease development. Increase or decrease in temperature was supported by increase or decrease in relative humidity. The infection increases with increase in dew period. The duration of leaf wetness period determines amount of spore germination and successful host infection where as temperature determines the rapidity and extent of infection. Similar resuts were reported by Lalancette et al. (1988) and Madden and Ellis (1988).

However, the third environmental factor, wind velocity did not contribute directly in disease development but it plays a major role in dispersal of spores both at short and long distance. The statistical analysis of disease and weather data indicated a negative effect of wind velocity. These results were found at all three locations and for all six cultivars.

Among the six cultivars most cultivars showed susceptibility against leaf rust except Inqilab-91. None of the variety proved to be completely resistant against the pathogen. This was due to continuous breakage of resistance by the leaf rust pathogen under the influence of environmental conditions. Inqilab-91 carrying *Lr*10, *Lr*27 + *Lr*31genes showed partial resistance to leaf rust. Fayyaz et al. (2008) reported that most of commercial varieties have shown susceptibility at Karachi, Nawabshah and Bahawalpur except Inqilab-91. This differential response of the cultivars was might be due to difference in virulence spectrum of *P. triticinia* f. sp. *tritici* at all the locations. These findings were in agreement with Kurt (2002) whose work indicated that rate of disease progress depends on the resistance level of cultivars grown.

The weather factors i.e., temperature, relative humidity and wind velocity are important in development of disease. These factors act in such a way that each of them compliments each other's effect on disease development. None of the factor acts as a signal significant factor in disease development. For leaf rust development temperature ranging between 10°C and 30°C (Singh et al. 2002), 7-10 days period at optimum and constant temperature from spore germination to sporulation and maximum spores can be reached in about 4 days at 20°C (Stubbs et al. 1986). The relative humidity played an important role in the penetration of haustorium of fungus as it makes the leaf tender due to moisture content. The change in temperature due to rain certainly influences the disease progress. Similar results were reported by Singh et al. (2002). Spores of *Puccinia triticina* f. sp. *tritici* are dispersed by wind (Geagea et al. 2000). Wind velocity plays a significant in air-borne dispersal mechanism of leaf rust. The high wind velocity causes long distance dispersal of urediniospores while low wind velocity agitates or rubs the leaves against each other, makes the canopy dry and releases the spores from the uredinia (Singh et al. 2002). The values of R^2 and P (Table, 1, 2, 3, 4, 5 and 6) of all the cultivars showed the validity of the analysis. High value of coefficient of temperature in all the regression analysis indicated that the temperature was the most important factor and showed a positive interaction. Though the relative humidity had also shown very important impact but the interaction of temperature and relative humidity was the most dominant in development of disease.

Conclusion

The environment, locations and cultivars all had significant effects on leaf rust severity and progress rate on wheat. It is therefore important to conduct surveillance of leaf rust seasonally. This would help us to determine occurrence and spread of disease, resistant or susceptible cultivars and virulence phenotypes present in the local conditions

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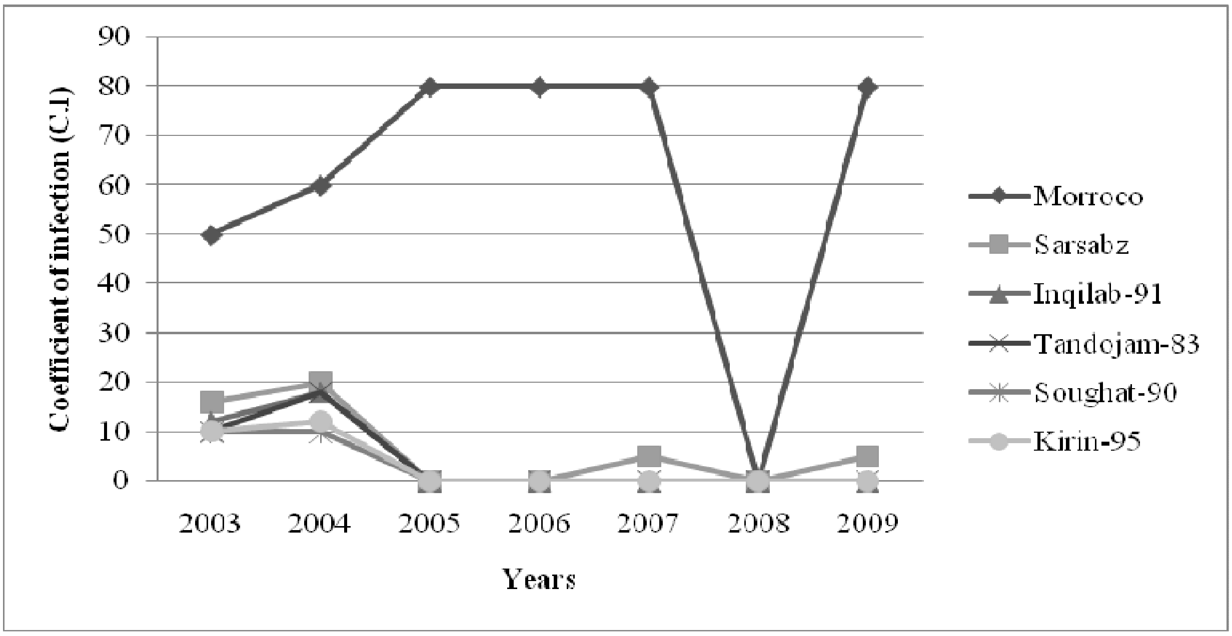

Figure1. Coefficient of infection of leaf rust on six wheat cultivars at Faisalabad from 2003-2009 as obtained from CDRP, NARC.

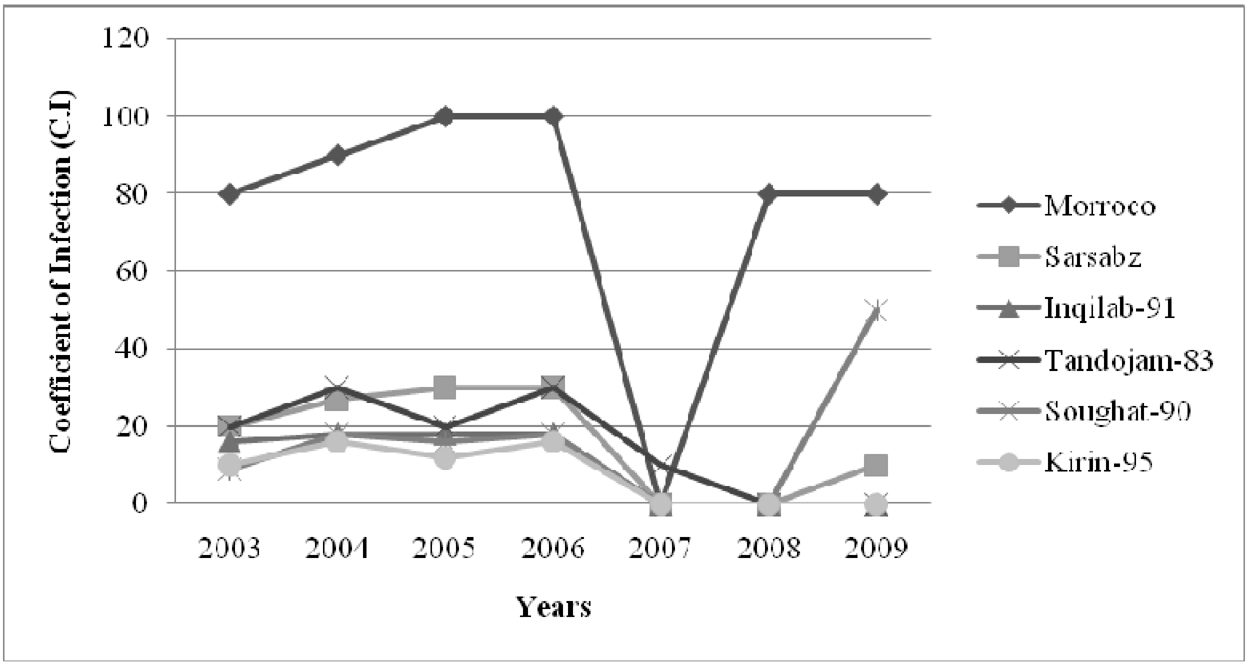

Figure 2. Coefficient of infection of leaf rust on six wheat cultivars at Bahawalpur from 2003-2009 as obtained from CDRP, NARC.

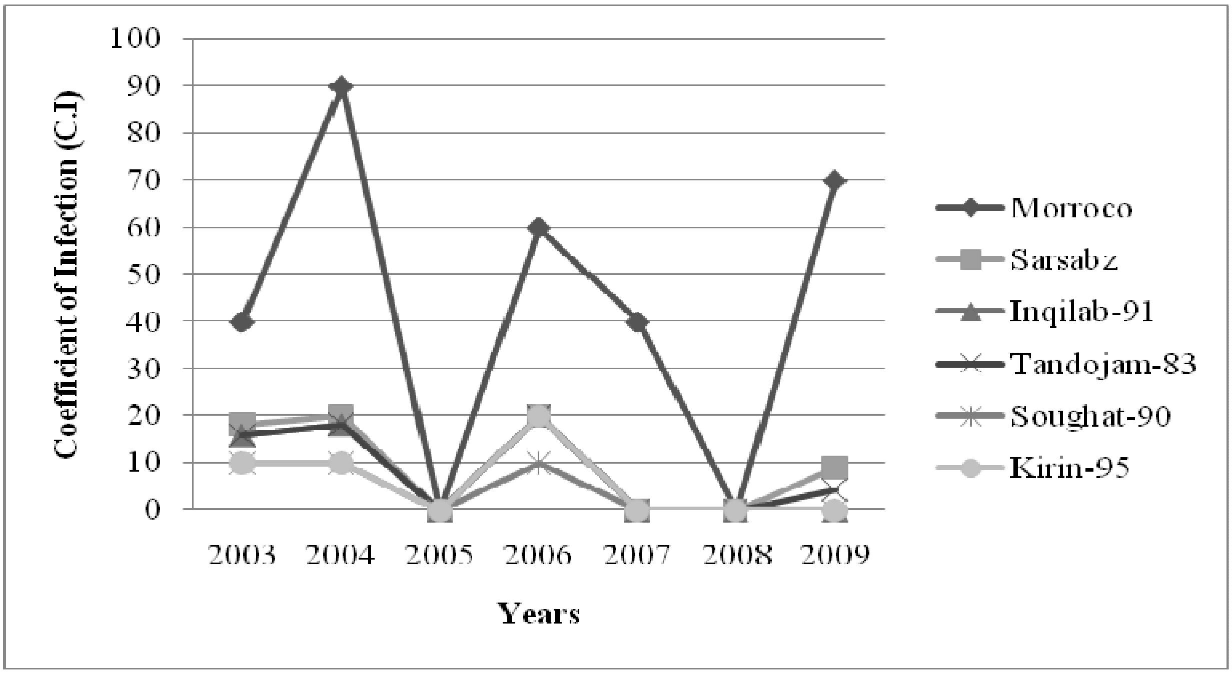

Figure 3. Coefficient of infection of leaf rust on six wheat cultivars at Sakrand 2003-2009 as obtained from CDRP, NARC.

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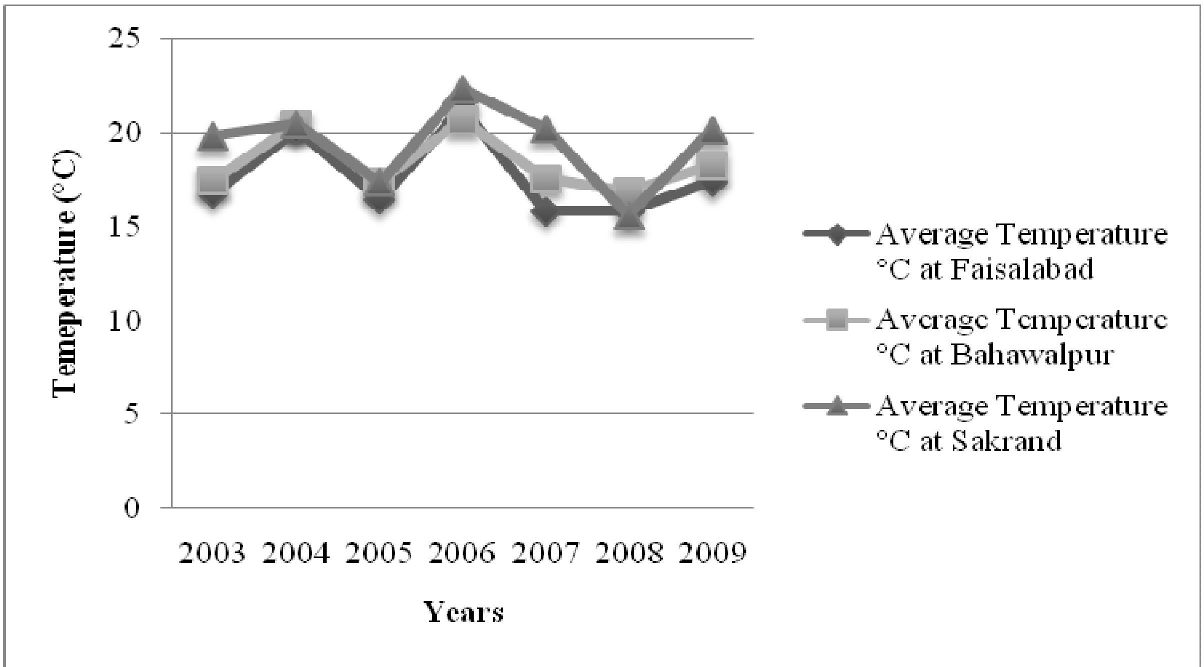

Figure 4. Last month (4th February- 5th March) average value of temperature °C in different years (2003-2009) at Faisalabad, Bahawalpur and Sakrand.

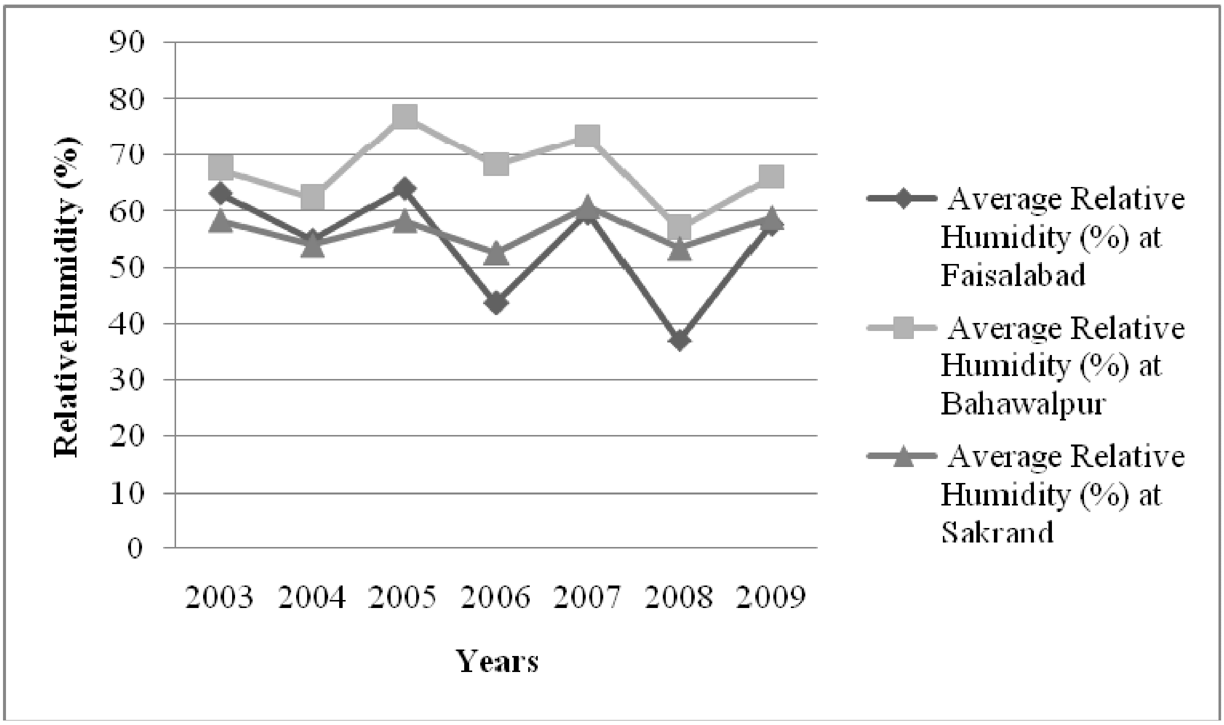

Figure 5. Last month (4th February- 5th March) average value of relative humidity (%) in different years (2003-2009) at Faisalabad, Bahawalpur and Sakrand.

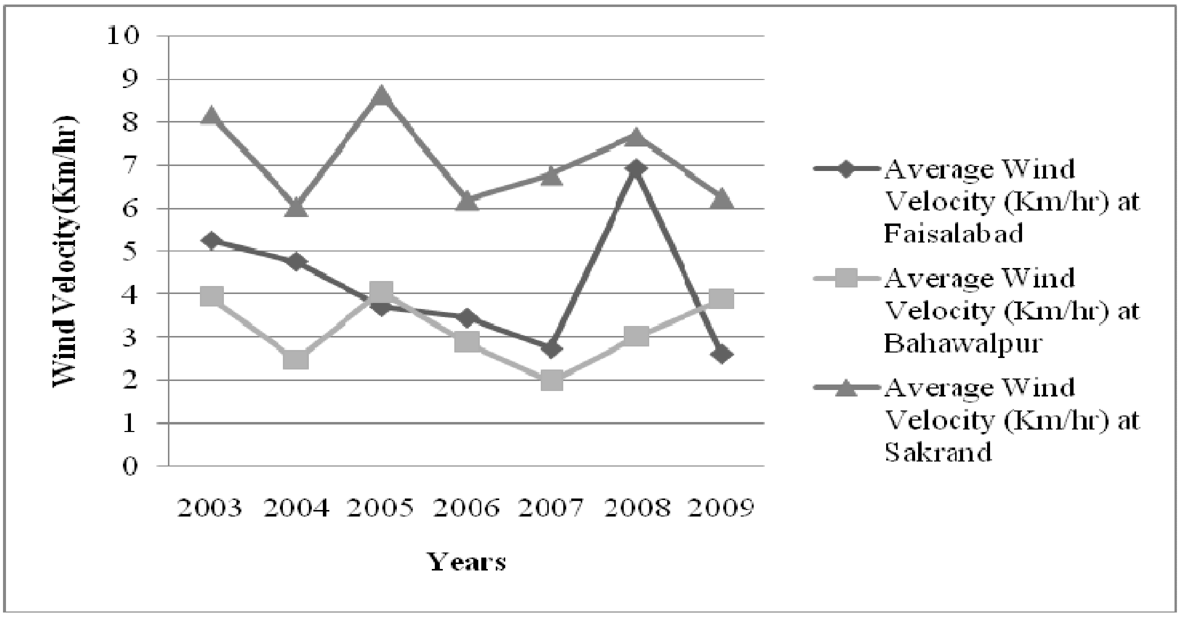

Figure 6. Last month (4th February- 5th March) average value of wind velocity (km/hr) in different years (2003-2009) at Faisalabad, Bahawalpur and Sakrand.

Table 1. Multiple regression analysis for Morroco

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	5.3894e+000	4.2734e+000	4.4878e-001	3.5585e-001	1.261	0.243
RH	1.6248e+000	1.1945e+000	5.7443e-001	4.2231e-001	1.360	0.211
WV	-6.0925e+000	4.0722e+000	-4.8499e-001	3.2417e-001	1.496	0.173

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -101.771391
Coefficient of Determination (R^2-Square) = 0.677

Table 2: Multiple regression analysis for Inqilab-91

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	2.3042e+000	4.5177e-001	8.2044e-001	1.6086e-001	5.100	0.001
RH	6.9345e-001	1.2628e-001	1.0483e+000	1.9090e-001	5.491	0.001
WV	-7.0618e-001	4.3051e-001	-2.4037e-001	1.4654e-001	1.640	0.140

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -16.801981
Coefficient of Determination (R-Square) = 0.723

Table 3 : Multiple regression analysis for Sarsabz

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	1.3055e+000	3.9904e-001	1.0782e+000	3.2957e-001	3.272	0.011
RH	1.3851e-001	1.1154e-001	4.8568e-001	3.9112e-001	1.242	0.249
WV	-2.7798e-002	3.8026e-001	2.1947e-002	3.0023e-001	0.073	0.944

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -62.195224
Coefficient of Determination (R-Square) = 0.934

Table 4: Multiple regression analysis for Kirin-95

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	1.4367e+000	5.6704e-001	7.0448e-001	2.7805e-001	2.534	0.035
RH	3.9529e-001	1.5850e-001	8.2293e-001	3.2997e-001	2.494	0.037
WV	-7.6549e-001	5.4035e-001	-3.5882e-001	2.5329e-001	1.417	0.194

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -29.293268
Coefficient of Determination (R-Square) = 0.690

Table 5: Multiple regression analysis for Soughat-90

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	1.8357e+000	6.7675e-001	9.4661e-001	3.4898e-001	2.713	0.027
RH	1.4243e-001	1.8916e-001	3.1184e-001	4.1415e-001	0.753	0.473
WV	-5.0132e-001	6.4490e-001	-2.4037e-001	3.1790e-001	0.777	0.459

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -36.481603
Coefficient of Determination (R-Square) = 0.803

Table 6: Multiple regression analysis for Tandojam-83

Variable Name	Regression Coefficient	Standard Error	Std. Partial Regr. Coeff.	Std. Err. of Partial Coef	Student T Value	Prob.
T	3.0377e+000	6.3545e-001	8.9189e-001	1.8657e-001	4.780	0.001
RH	4.2981e-001	1.7762e-001	5.3577e-001	2.2141e-001	2.420	0.042
WV	-1.8606e+000	6.0554e-001	-5.2221e-001	1.6996e-001	3.073	0.015

*T- Temperature °C *RH- Relative Humidity (%) *WV- Wind Velocity (Km/hr)
Intercept = -56.603055
Coefficient of Determination (R-Square) = 0.911

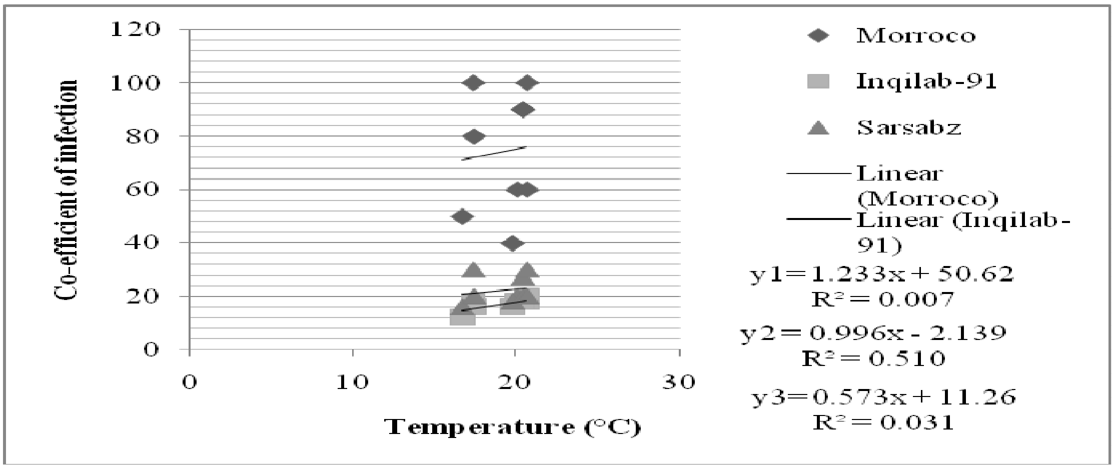

Figure 7a: Effect of temperature on co-efficient of infection of leaf rust on Morroco (Y_1), Inqilab-91(Y_2) and Sarsabz (Y_3).

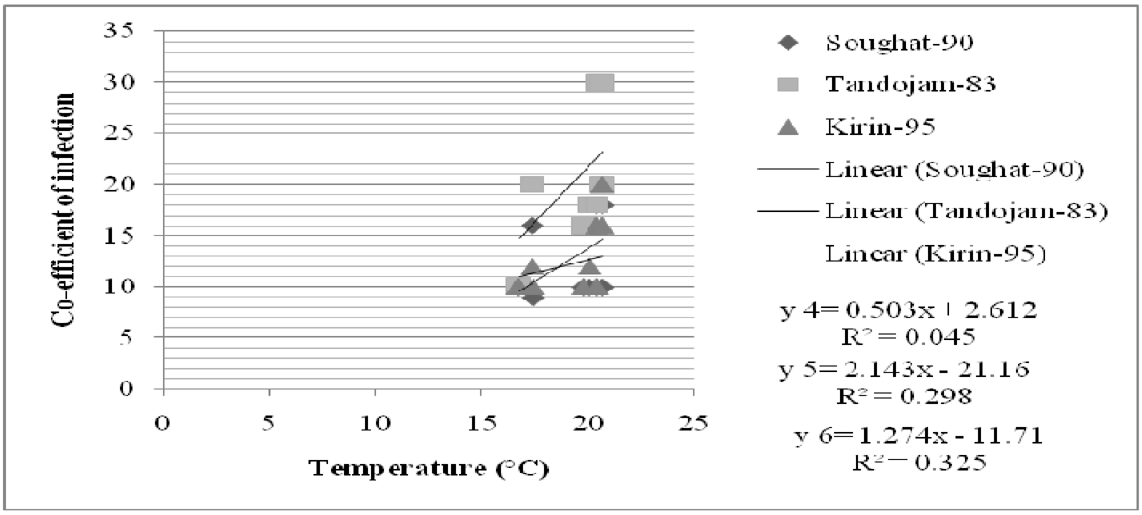

Figure 7b: Effect of temperature on co-efficient of infection of leaf rust on Soughat-90 (Y_4), Tandojam-83 (Y_5) and Kirin-95 (Y_6).

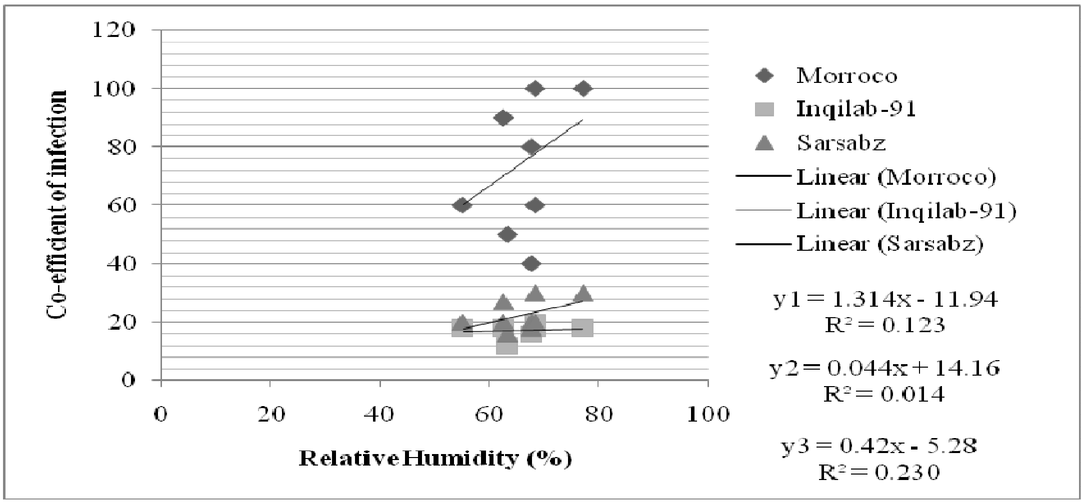

Figure 8a: Effect of relative humidity on co-efficient of infection of leaf rust on Morroco (Y_1), Inqilab-91(Y_2) and Sarsabz (Y_3**).**

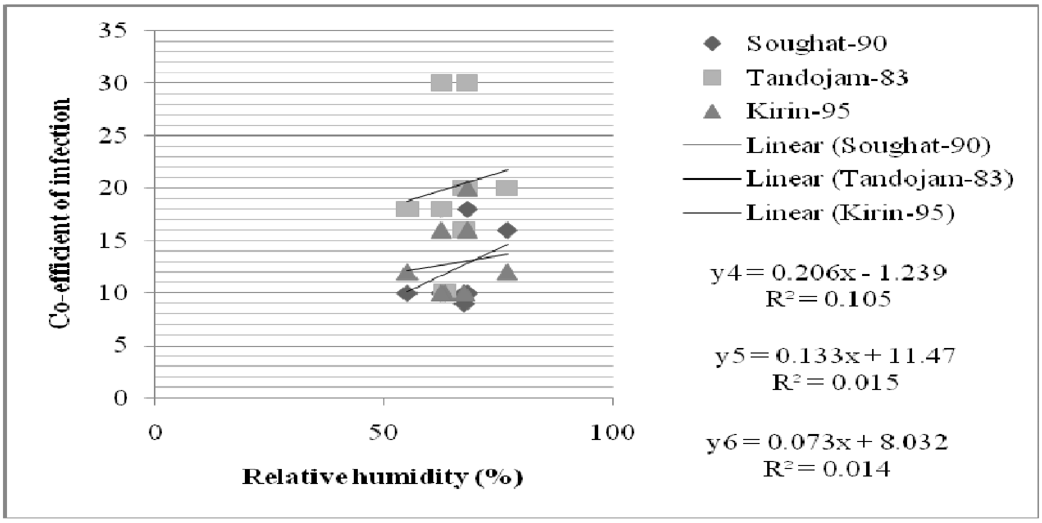

Figure 8b: Effect of relative humidity on co-efficient of infection of leaf rust on Soughat-90 (Y_4), Tandojam-83 (Y_5) and Kirin-95 (Y_6).

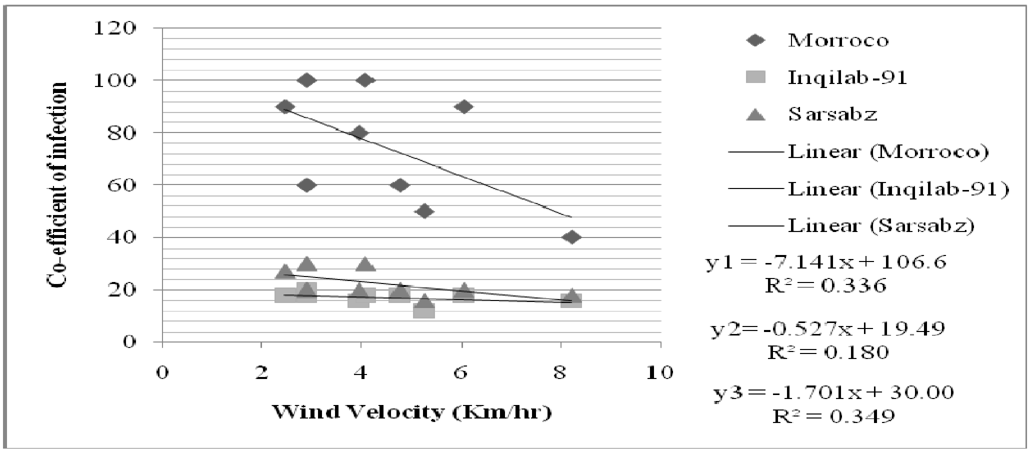

Figure 9a: Effect of wind velocity on co-efficient of infection of leaf rust on Morroco (Y_1), Inqilab- 91(Y_2) and Sarsabz (Y_3).

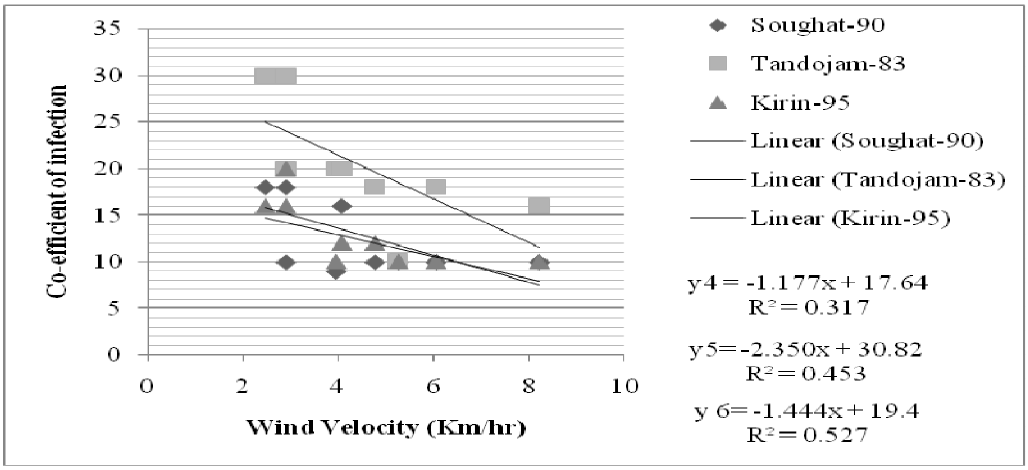

Figure 9b: Effect of wind velocity on co-efficient of infection of leaf rust on Soughat-90 (Y_4), Tandojam-83 (Y_5) and Kirin-95 (Y_6).

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