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Predictive Modeling for Chickpea Blight (*Ascochyta rabiei*) Occurrence in the Semi-Arid Zone Using Meteorological Data from Faisalabad, Pakistan

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Chickpea blight is the most destructive disease in the semi-arid zone of Punjab and is mainly controlled through fungicides. However, in this area, the use of fungicides is excessive and non-judicious which could be rationalized through the use of a predictive model based on meteorological variables. The aim of the current research was to develop a disease predictive model of chickpea blight based on temperatures (maximum and minimum), rainfall, relative humidity (RH), and wind speed. Relationship of meteorological variables with disease severity was determined through correlation analysis, and stepwise regression was used to develop the model. For this purpose, 2 yr (2011–12) data of meteorological variables and chickpea blight severity was used. A significant correlation was found between all environmental variables and blight severity. A model based on weekly meteorological variables fit the data well (R^2 = 0.82). Predictions of the model were evaluated on two statistical indices, root mean square error (RMSE) and error (%), which were ≤ ± 20, indicating that the model was good. The model was validated with 5 yr (2006–10) independent data set. Homogeneity of the regression equations of the two models, 2 yr (2011–12) and 5 yr (2006–10), showed that they validated each other. Scatter plots showed that blight severity was high at maximum (20–24°C) and minimum (12–14°C) temperatures, 65–70% RH, 5–6 mm rainfall and 5–6.5 km/h wind speed). The chickpea blight model developed during this study is the first meteorological variable model in the semi-arid zone of Punjab and will help to make the predictions of chickpea blight well before the occurrence of the disease; thus, the model can make early an prediction of the time of fungicide application, lessen the use of fungicides, curtail input cost of farmers, and help to mitigate environmental pollution.

Key Words: chickpea blight, meteorological model, predictive modeling

Abbreviations: ARRI – Ayub Agriculture Research Institute, CSMA – chickpea seed meal agar, RH – relative humidity, UAF – University of Agriculture Faisalabad

INTRODUCTION

The chickpea blight disease, caused by *Ascochyta rabiei* (Pass) Labrousse (teleomorph: *Didymella rabiei* (Kovachevski) v. Arx. Syn. *Mycosphaerella rabiei* Kovachevski), is a potential threat in all chickpea-growing areas of the world (Islam and Ahmed 2016; Sharma and Ghosh 2016). The disease in its severe occurrence causes a hundred percent loss in yield (Pande et al. 2005). In Pakistan, chickpea blight is the most vital limiting factor to sown chickpeas, resulting in heavy yield losses in the semi-arid zone of the country where this crop is cultivated (Jamil et al. 2010; Shah et al. 2015). In the semi-arid zone, blight starts to appear on chickpea crop from the 1st week of February and its maximum severity occurs in the last week of March upon the death of the susceptible genotypes.

Cultivation of chickpea-resistant varieties is the best strategy to control blight, but most of the chickpea germplasm has moderate resistance. Due to lack of high degree resistance in chickpea germplasm, a high level of resistance to chickpea blight has not been bred into varieties (Pande et al. 2005). Eventually, moderately resistant genotypes become susceptible owing to appearance of new pathotypes (Li et al. 2015). Batal-2016, NIAB-CH-2016, Bhakkar-2011, Punjab-2008, Balaksar-2000 and Batal-98 are the most commonly cultivated varieties in the semi-arid zone. Among these, only Batal-2016 and NIAB-CH-2011 are partially resistant against the disease while the rest are susceptible (Government of the Punjab 2018). Growers under such situations employ excessive foliar fungicides to manage the disease. Several systemic protectant and curative fungicides are being used against blight. Among them, the most common are boscalid, azoxystrobin, chlorothalonil, mancozeb, difenoconazole, tebuconazole and pyraclostrobin. However, the blight fungus has developed resistance against azoxystrobin and pyraclostrobin (Gan et al. 2006; Mehmood et al. 2017).

A comprehensive understanding of the epidemiology of chickpea blight is prerequisite for rationalizing the use of fungicides (Gaur and Singh 1993). As a prognostic approach, a predictive model helps in decisions about the control measures by quantifying disease pressure. A predictive model can give an advance forecast of chickpea blight and subsequently help in making decisions whether there is need of fungicide application or not (Golani et al. 2016; Khan et al. 1999). Multiple regression model studies based on meteorological variables to forecast chickpea blight are not conducted in the semi-arid zone of Pakistan. Therefore, the present study was conducted to develop a predictive model for chickpea blight disease based on meteorological conditions. Current research will be useful as baseline information for developing a system of prediction in the future for the chickpea-growing areas of Pakistan. The study aims to develop a predictive model for chickpea blight based on the environmental conditions of two crop seasons and to validate it on five crop seasons.

MATERIALS AND METHODS

Meteorological data of 2 mo (February to March) were collected from the Meteorological Station, Department of Plant Pathology, University of Agriculture (UAF), Faisalabad, Pakistan during 2 yr (2011–12) for model development. Faisalabad has a semi-arid climate and is located 73°74 east, 30°31.5 north and 184 m above sea level. For validation of the model, 5 yr (2006–10) meteorological data were collected from the Agromet Department, Ayub Agriculture Research Institute (ARRI), Faisalabad. The distance between the Department of Plant Pathology, UAF and AARI is 5 km. The weekly average of maximum and minimum temperatures, RH, wind speed, and total rainfall were calculated from the 1st week of February to the last week of March.

Development of a Disease Predictive Model Based on Two Year (2010–12)

Data Data Collection of Chickpea Blight Disease Severity

Disease severity data of four highly susceptible to susceptible genotypes (K-97006, K-97007, K-95058, and D-91224) were collected. The genotypes were sown for 2 yr (2011–12) at the field area of the Department of Plant Pathology, UAF, Faisalabad. Genotypes were sown in randomized complete block design (RCBD) in three biological replications. Each genotype was planted on a 5-m long row in blocks (3 x 10 m). Seeds were planted through a dibbler at a distance of 10 cm. Each genotype entry had 50 plants. Row-to-row distance between two entries was 50 cm.

For isolation of *A. rabiei*, infected pods were collected from the research area of AARI where research trials of pathotype-III, a highly virulent pathotype of *A. rabiei*, were conducted. Pathotype-III was isolated using the procedure developed by Ilyas and Iqbal (1986). For this procedure, pods were heated on sprit lamp flame by holding them in forceps in such a way that the outer surface of the pods gets sterilized while the inner pod layer remains undamaged. Surface-sterilized pods were then opened and infected seeds were brought out from the pods with sterilized forceps. Infected seeds were placed on the autoclaved chickpea seed meal agar (CSMA) medium and placed in an incubator at 20 ± 2°C. When colonies of *A. rabiei* formed around the plated infected material on CSMA medium, they were isolated, and purified by single spore culture method (Choi et al. 1999). The purified culture of *A. rabiei* was prepared and maintained at 5°C. The pathogenicity of pathotype-III was reconfirmed on a set of three chickpea differentials: ILC-3279 (resistant), ILC-482 (tolerant), and ILC-1929 (susceptible) (Jamil et al. 2000).

After isolation, the mass culture of *A. rabiei* was prepared based on the method of Ilyas and Khan (1986). Blocks were sprayed with spore suspension of 10^5 spores/mL of *A. rabiei* twice in a day to start the infection of blight and continued until the appearance of symptoms (Pande et al. 2011). Spore suspension was prepared with haemocytometer while spray was done with a locally made knapsack sprayer twice in a day (morning and evening). Disease severity data were recorded visually during early morning on a weekly basis from February to March for 2 yr. A 0–9 rating scale was used, where 0 indicates no disease severity while 9 indicates more than 85% disease severity (Jhorar et al. 1997) (Table 1).

Table 1. Disease rating scale for chickpea blight (Jhorar et al. 1997).

Scale	Disease Severity	
	Class	Mid-value
0	0	0
1	0.1-5	2.5
2	5.1-10	7.5
3	10.1-15	12.5
4	15.1-25	20
5	25.1-35	30
6	35.1-50	42.5
7	50.1-70	60.0
8	70.1-85	78.5
9	85.1-100	92.5

Model Evaluation

The model was evaluated based on procedures described by Chatterjee and Hadi (2006) and Snee (1977). The procedures are as follows:

1) Physical theory comparison with dependent variable and regression coefficients
2) Comparison of observed vs. predicted data
3) Collection of new data to check predictions

Assessment of predictions was done by computing statistic indices such as root mean square error (RMSE) and error (%). The formulas used for RMSE and error (%) were as follows:

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n} {(p_i - o_i)^2}/{n}\right]^{0.5}$$

$$\mathrm{Error}(\%) = \left(\frac{(p - o)}{o}\right)100$$

where P_i and O_i are the predicted and observed data points for studied parameters, respectively, and n is the number of observations. The predictive model is considered good if RMSE and error (%) between observed and predicted values are ≤ ± 20 (Snee 1977).

Model Validation

For validation of the model, 5-yr (2006–10) data of the disease severity of chickpea blight of four highly susceptible to susceptible genotypes were obtained from ARRI, Faisalabad to develop a 5-yr model. The severity data were of pathotype-III but the varieties were different. At ARRI, the experimental design and other procedures were the same as those used at the Department of Plant Pathology, UAF. The 2-yr model was validated with the 5-yr model by comparing homogeneity of regression coefficients of F-test (Harrell 2001).

Data Analysis

Data were analyzed using software Meet Minitab 15 by Minitab Inc., U.S.A. All data of meteorological variables and disease severity were subjected to analysis of variance (ANOVA), and means separations were determined at P = 0.05 by least significant difference (LSD) test. Effect of meteorological parameters on disease severity was determined by correlation analysis (Steel et al. 1997). A predictive model for chickpea blight disease based on meteorological variables was developed using stepwise regression analysis (Meyer and Woodroofe 2002). Coefficient of determination (R^2) and adjusted R^2 were calculated using formulas (Steel et al. 1997) shown as follows:

$$R^2 = \frac{\text{Regression sum of squares}}{\text{Total sum of squares}} = 1 - \frac{\text{Error of sum of squares}}{\text{Total sum of squares}}$$

$$R^2_{\text{Adj.}} = 1 - \frac{(1 - R^2)(n - 1)}{(n - k - 1)}$$

where n is the size of the sample and k is the number of independent variables in the model. The purpose of using R^2 and $R^2_{\text{Adj.}}$ was to test the accuracy of the model for prediction, and further to determine the strength of the relationship between blight severity and meteorological parameters. Mallows' C_p statistic and mean square error (MSE) were calculated using formulas (Steel et al. 1997) shown as follows:

$$Cp = (n - p)\left[\frac{\text{MSE (reduced)}}{\text{MSE(full)}} - S\right] + p$$

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(yi - \hat{y}i)$$

where n and p in the C_p equation are sample size and the number of beta coefficients in the model, respectively, while n, yi and $\hat{y}i$ in the MSE equation represent the number of data points, observed values and predicted values, respectively. C_p and MSE were used to judge the performance of the model on the basis of independent variables. Meteorological variables that showed a significant relationship with disease severity were graphically plotted and critical ranges of meteorological variables conducive to the development of chickpea blight were determined.

RESULTS

Relationship of Meteorological Variables with Disease Severity of Chickpea Blight

Maximum temperature was negatively correlated while minimum temperature, rainfall, RH and wind speed were positively correlated with disease severity of chickpea blight during 2011 and 2012 (Table 2).

Table 2. Correlation of environmental parameters with chickpea blight disease severity during 2011–12.

Environmental Parameter	2011	2012
Maximum temperature	-0.838*	-0.769*
	0.0001	0.0001
Minimum temperature	0.622*	0.542*
	0.0001	0.003
Rainfall	0.740*	0.614*
	0.0001	0.0001
Relative humidity	0.764*	0.689*
	0.0001	0.0001
Wind speed	0.570*	0.628*
	0.002	0.0001

Upper values indicate Pearson's correlation coefficient. Lower values indicate level of probability at $P = 0.05$.

Chickpea Blight Disease Predictive Model Based on 2-yr Data (2011–12)

A multiple regression model ($Y = 73.8 - 3.11x_1 + 1.60x_2 + 1.44x_3 + 0.40x_4 + 2.34x_5$) based on 2-yr environmental conditions data was developed to predict chickpea blight disease. Environmental conditions, maximum and minimum temperatures, rainfall, RH and wind speed contributed significantly to disease development (Table 3). The 2-yr model explained 82% of the variability in disease development. In this model, Y = chickpea blight severity, x_1 = max. temp., x_2 = min. temp., x_3 = rainfall, x_4 = RH and x_5 = windspeed.

Table 3. Summary of stepwise regression models to predict chickpea blight disease during 2011–12.

Parameter	No. in Model	Model R^2	C(p)	MSE	F Value	Prb.>F
Maximum temperature	1	0.71	26.6	66	132.57	0.001*
Minimum temperature	2	0.76	15.7	56	83.07	0.001*
Wind speed	3	0.78	10.9	51	62.55	0.001*
Relative humidity	4	0.80	8.6	48	50.72	0.001*
Rainfall	5	0.82	6.0	45	44.33	0.001*

Model Evaluation

Physical Theory Comparison with Dependent Variable and Regression Coefficients

The predictive model showed high R^2 value (81.6%) with low standard error ≤ 20 (Table 4). F-distribution analysis exhibited significant regression statistics (Table 5). Maximum and minimum temperatures, rainfall, RH and wind speed were found significant in the chickpea blight disease severity model at $P<0.05$ (Table 6). High R^2 value, low standard error, and significance of regression statistics showed that the model was good to predict chickpea blight disease severity (Tables 4–6).

Model Evaluation by Comparing Observed and Predicted Data

For the evaluation of the model, predictions were obtained using the model and evaluated on two criteria, RMSE and error (%). Overall, RMSE and error (%) between observed and predicted data points were ≤ ± 20. Individually, out of 56 error values, only seven values showed error > ± 20 while the rest were ≤ ± 20 (Tables 7–8). Close conformation between observed and predicted data points revealed that the model was good in predicting chickpea blight.

Model Validation

Chickpea blight disease predictive model based on 2 yr environmental data was validated on the past 5 yr (2006–10) data collected from ARRI, Faisalabad. Regression equations of the two models showed good fit into the data (Table 9). Slopes and coefficients of determination of the two models ($R^2 = 0.82$ for model I and $R^2 = 0.72$ for model II) were close to each other. Regression equations

Table 4. Regression statistics of chickpea blight disease predictive model during 2011–12.

Regression Statistics	
R-square	81.6%
Adjusted R-square	83.6%
Standard error	6.73
No. of observations	55

Table 5. ANOVA of chickpea blight disease predictive model based on 2 yr (2011–12) data.

Source	Df	SS	MS	F	*P*-value	Significance F
Regression	5	10063.7	2012.7	44.33	0.001	**
Residual error	50	2270.2	45.4			
Total	55	12333.9				

Table 6. Coefficients of variables, their standard error, t Stat, *P*-value and their significance.

Parameters	Coefficients	Standard Error	t-Stat	*P*-value
Intercept	73.80	20.11	3.67	0.001*
Maximum temperature	-3.1092	0.6349	-4.90	0.001*
Minimum temperature	1.6022	0.6156	2.60	0.021*
Rainfall	1.4364	0.6725	2.14	0.038*
Relative humidity	0.4077	0.1866	2.19	0.034*
Wind speed	2.344	1.147	2.04	0.046*

*Significant at $P<0.05$

Table 7. Observed and predicted chickpea blight disease severity (%) on genotypes K-97006 and K-97007 during 2011–12.

Genotype	2011			2012		
	Observed	Predicted	Error(%)	Observed	Predicted	Error (%)
K-97006	15	22	47	20	18	-10
	25	21	-16	25	22	-12
	35	28	-20	40	41	2
	40	36	-10	40	46	15
	50	45	-10	55	52	-5
	65	60	-8	60	58	-3
	85	76	-11	85	78	-8
RMSE (Error %)		3.02 (2.85)			-3.07 (-7.54)	
K-97007	10	22	120	15	18	20
	20	21	5	20	22	10
	30	28	-7	45	41	-9
	35	36	3	50	46	-8
	50	45	-10	60	52	-13
	75	60	-20	70	58	-17
	85	76	-11	90	78	-13
RMSE (Error %)		6.42 (-5.57)			13.22 (10)	

Table 8. Observed and predicted chickpea blight disease severity (%) on genotypes K-95058 and D-91224 during 2011–12.

Genotype	2011			2012		
	Observed	Predicted	Error(%)	Observed	Predicted	Error (%)
K-95058	10	22	120	15	18	20
	20	21	5	15	22	-25
	20	28	40	20	38	90
	30	36	20	35	41	14
	40	45	12	45	46	-2
	55	60	9	55	58	5
	65	76	17	65	78	20
RMSE (Error %)		18.14 (12.08)			19.20 (15.11)	
D-91224	10	22	120	15	18	20
	20	21	5	20	22	10
	30	28	-7	35	38	9
	40	36	-10	40	41	2
	45	45	0	50	46	-8
	65	60	-8	60	58	-3
	65	76	17	70	78	11
RMSE (Error %)		4.91 (4.72)			4.15 (3.79)	

of model I and model II showed quite good proximity. Non-significant *P*-value indicated that the two regression equations were not significantly different from each other, indicating homogeneity of regression.

Table 9. Comparison of two models for validation of chickpea blight disease severity.

Model	Regression Equation	R^2	F-Value	*P*-Value
Model (I)	$Y = 73.8 - 3.11_{x1} + 1.60_{x2} + 1.44_{x3} + 0.40_{x4} + 2.34_{x5}$	0.82		
	vs		0.542	0.999
Model (II)	$Y = 81.8 - 3.17_{x1} + 1.99_{x2} + 0.88_{x3} + 0.25_{x4} + 1.85_{x5}$	0.72		

Model (I) = 2 yr model Significant at $P < 0.05$
Model (II) = 5 yr model
$_{x1}$= Maximum temperature, $_{x2}$ = Minimum temperature,
$_{x3}$ = Rainfall, $_{x4}$ = Relative humidity, $_{x5}$ = Wind speed

Characterization of Meteorological Variables Conducive for Chickpea Blight Disease Severity during 2011–12

On four lines, K-97006, K-97007, K-95058 and D-91224 (highly susceptible to susceptible), a significant relationship was found between meteorological variables and disease severity. Maximum temperature contributed significantly in the development of ascochyta blight of chickpea on four genotypes as indicated by correlation coefficient (r) values of 0.70, 0.71, 0.76 and 0.74, respectively (Fig. 1). The relationship between maximum temperature and blight severity was polynomial. It was observed that with increase of maximum temperature from 24°C to 32°C, disease severity decreased. Maximum disease severity was recorded at the maximum temperature limit of 20–24°C (Fig. 1). Minimum temperature in the range of 12–14°C was found favorable for chickpea blight. Minimum temperature demonstrated positive and linear relationship with blight severity (Fig. 2). Regression models developed on four genotypes on the basis of minimum temperature showed r values of 0.61, 0.65, 0.66 and 0.68, respectively (Fig. 2). Influence of RH on ascochyta blight severity on four lines was positive (Fig. 3). Maximum severity was observed in the range of 60% to 70% RH. Linear regression models explained the significant relationship between RH and disease severity on four lines as indicated by higher r values: 0.88, 0.82, 0.82, and 0.77, respectively (Fig. 3).

Rainfall was positively correlated with blight severity, disease severity increased with increase in rainfall. Maximum disease severity was recorded above 5 mm rainfall (Fig. 4). There was significant contribution of rainfall in disease severity as indicated by r values, i.e., 0.80, 0.78, 0.76 and 0.72, respectively. Wind speed also displayed positive correlation with blight severity. With the increase in wind speed, disease severity increased. However, the highest level of disease severity was seen on all four advanced lines at 6.5 km/h range of wind speed (Fig. 5). Regression models developed on four lines to explain the relationship of wind speed with chickpea blight severity showed significantly higher r values (0.88, 0.86, 0.84 and 0.85).

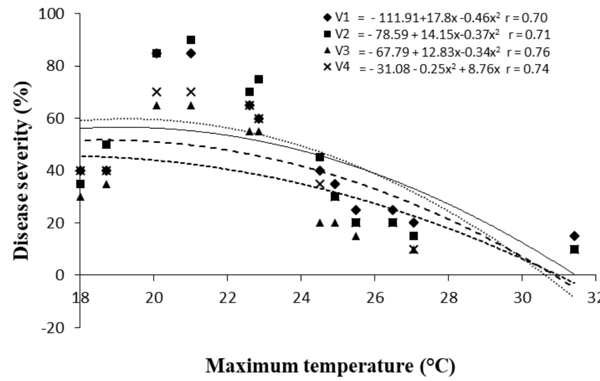

Fig. 1. Maximum temperature relationship with chickpea blight severity recorded on genotypes K-97006(V1), K-97007(V2), K-95058(V3) and D-91224(V4) during 2011–12.

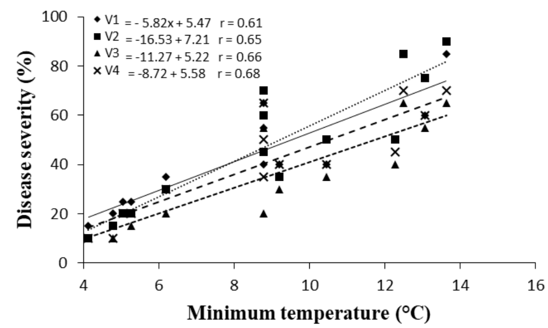

Fig. 2. Minimum temperature relationship with chickpea blight severity recorded on genotypes K-97006(V1), K-97007(V2), K-95058(V3) and D-91224(V4) during 2011–12.

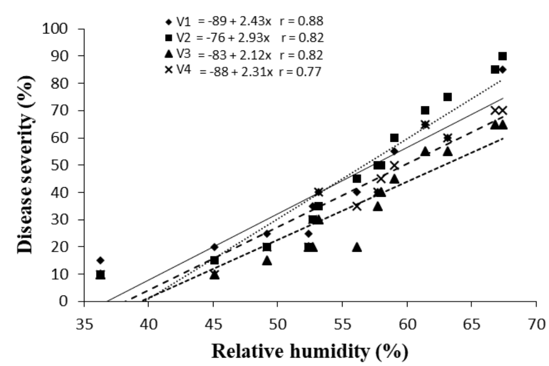

Fig. 3. Relative humidity relationship with chickpea blight severity recorded on genotypes K-97006(V1), K-97007(V2), K-95058(V3) and D-91224(V4) during 2011–12.

DISCUSSION

Weather is considered vital for the development of pathogens on any crop, thus quantifying the relationship between meteorological variables and the chickpea blight disease is the key to issue an early warning of its onset (El Jarroudi et al. 2017). Chickpea blight is significantly influenced by meteorological variables (Weltzien and Kaack 1984). The significant relationship of meteorological variables with blight severity found in this study concurs with the findings of Ahmad et al. (1985), who found a significant correlation between chickpea blight and environmental factors. Similar interpretations were reported by Khan et al. (1999).

The significant correlation of temperature with chickpea blight can be explained by the fact that it has a critical role in the different aspects of disease development, pseudothecial maturation, liberation of ascospores, incubation and latent periods, disease establishment and symptom expressions (Atinsky et al. 2005; Galloway and Macleod 2003; Jayakumar et al. 2005). The significant relationship of rainfall with disease severity was due in part to its key role in the infection process which begins with the formation of pseudothecia during rainy days. Rainfall makes plant disease debris wet and keeps the temperature mild which is necessary for the development and maturity of pseudothecia (Trapero-Casas and Kaiser 1992a). Subsequently, ascospores are liberated from developed pseudothecia by rainfall and are disseminated by wind currents to nearby fields (Trapero-Casas and Kaiser 1992b). Rainfall also contributes to secondary disease cycles caused by rain-splashing conidia during the entire growing season (Maden et al. 1975). Frequent showers of rainfall received during the growing season are therefore key factors in

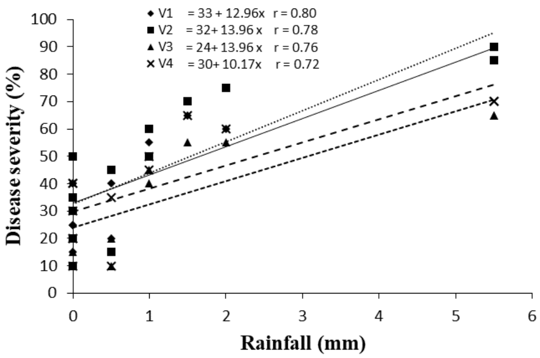

Fig. 4. Rainfall relationship with chickpea blight severity recorded on genotypes K-97006(V1), K-97007(V2), K-95058 (V3) and D-91224(V4) during 2011–12.

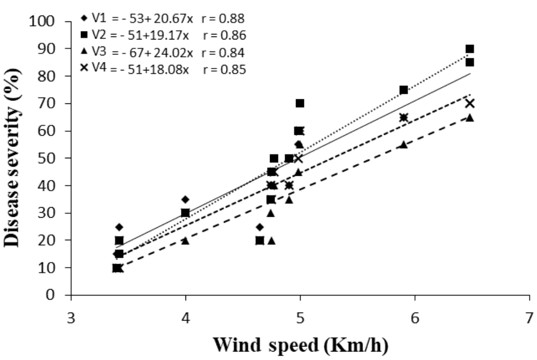

Fig. 5. Wind speed relationship with chickpea blight severity recorded on genotypes K-97006(V1), K-97007(V2), K-95058(V3) and D-91224(V4) during 2011–12.

chickpea blight epidemics (Scott et al. 2006). Significant correlation of RH with ascochyta disease is ascribed to its contribution in the development of chickpea blight (Bedi and Aujla 1970). Due to the positive correlation of RH with the disease, chickpea blight was enhanced with the increase in RH. This result concurs with those of Gaur and Singh (1993) who found a decline in blight incidence when RH was decreased from 100% to 86%. Formation of conidia in pycnidia particularly relies on RH (Muller 1979). Similarly, the teleomorphic stage of ascochyta blight is also affected by RH (Navas et al 1998). Production of ascospores from pseudothecia in *Didymella rabiei* increases with increase in RH. Jhorar et al. (1998) found more production of asci and ascospores in artificially inoculated fields where RH level was kept at 100% than in naturally infested fields. Elucidation of the significant correlation of wind speed with chickpea blight is that it transfers conidia and ascospores from diseased fields to healthy fields (Bretag et al. 2006). Ascochyta blight is a polycyclic disease and spreads by primary and secondary inocula. Wind transfers primary inoculum from infected fields to healthy fields, sometimes over a distance of 1.6 km (Schoeny et al. 2007), thus, in this manner, it also initiates ascochyta disease and increases its severity in chickpea fields.

In our study, all environmental variables significantly influenced the disease. This was the reason why no single parameter was eliminated in the stepwise regression analysis and all parameters appeared to be predictors of chickpea blight in the predictive model. The multiple regression model developed in this study is the first attempt in the semi-arid zone to make a prediction of blight disease. Formerly, characterization of suitable meteorological conditions for chickpea blight was done based on one growing season data (Ahmad et al. 1985; Khan et al. 1999), but could not prove to be effective on account of the smaller data set used in these studies. Similarly, criteria were set for the epidemics of chickpea blight based on yearly precipitation (Kausar 1965). These criteria are still in practice in Pakistan, but as they do not account for the role of other meteorological factors such as maximum and minimum temperatures, RH and wind speed, therefore accurate prediction of chickpea blight epidemics is still a challenge. Moreover, studies conducted in the past do not explain that the variability in blight disease occurred due to different meteorological conditions. The present multiple regression model provides the answers to these gaps as it explained 82% of the variability in disease severity of chickpea blight while only 18% variability remained unexplained. Models which explain more than 80% variability are considered reliable and give quite accurate predictions (Kumar 2014). The reason behind not explaining 100% variability may be due to the fact that multiple regression models are empirical models. Eversmeyer and Burleigh (1970) reported 50% to 90 % unexplained variability in disease severity when only environmental variables were used. However, by including initial inoculum levels and other biological factors as independent variables, the unexplained variation may be reduced (Kumar 2014). Further, as this study was conducted under field conditions where the amount of inoculum, time of inoculation, and infection efficiency were uncontrolled, an explanation of 100% variability was not possible. Still, the present study remained successful in predicting the disease severity of chickpea blight because the model, having a fairly large data set, has been validated with a 5-yr data set, and has made nearly accurate predictions. Further, a good forecasting power, i.e., $R^2 = 0.82$, of the model shows that it can be used in future for accurate predictions of chickpea blight disease.

Maximum (20–24°C) and minimum temperatures (12–14°C), RH (65–70%), rainfall (5–6 mm) and wind speed (5–6.5 km/h) were found critical environmental ranges for chickpea blight disease during this study. These critical ranges are consistent with previous findings (Jhorar et al. 1997; Khan et al. 1999). The period when these critical ranges prevail in the semi-arid zone may be called a risky period and accordingly, farmers can apply fungicides. Temperature, RH and rainfall ranges explored during this study have been reported optimum for chickpea blight fungus. When the weather conditions are optimum, incubation and latent periods become short and the production of pycnidiospores is increased, which lead to rapid development of chickpea blight (Trapero-Casas and Kaiser 1992a). Further, the high wind speed also helps the spread of blight fungus over larger areas within a shorter period, resulting in an epidemic (Pande et al. 2005). The current findings corroborate that these are the optimum weather conditions of the chickpea blight fungus and when such conditions prevail, fungicides may be applied to avoid epidemics of this disease.

In conclusion, the 2-yr model based on five environmental variables explained 82% variability in disease development. Further, the weather conditions found critical during this study may be considered as optimum conditions for the chickpea blight fungus and accordingly, farmers can plan applications of fungicides. The predictive model is useful in controlling the disease through judicious use of fungicides. However, more tests (data) should be generated in more areas in the semi-arid region to establish the validity of these meteorological parameters.

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