EPIDEMIOLOGICAL STUDIES OF STRIPE RUST OF WHEAT CAUSED BY *Puccinia striiformis*

By

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(J-13-M-308)

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in partial fulfillment of the requirements
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PLANT PATHOLOGY

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Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu
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CERTIFICATE – I

This is to certify that the thesis entitled **"Epidemiological studies of stripe rust of wheat caused by *Puccinia striiformis*"** submitted in partial fulfillment of the requirements of the degree of **Master of Science in Agriculture (Plant Pathology),** to the Faculty of Post-Graduate Studies, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, is a record of bonafide research carried out by **Mr. Arun Khajuria,** Registration No. **J-13-M-308,** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that such help and information received during that course of investigation have been duly acknowledged.

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We the members of Advisory Committee of **Mr. Arun Khajuria**, Registration No**. J-13-M-308,** a candidate of the degree of **Master of Science in Agriculture (Plant Pathology),** have gone through the manuscript of the thesis entitled **"Epidemiological studies of stripe rust of wheat caused by *Puccinia striiformis*"** and recommended that it may be submitted by the student in partial fulfillment of the requirements for the degree.

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A tribute to my father

Late Sh. D. B. Khajuria

I dedicate this thesis to my mother

Smt. Kamla Khajuria

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Date:

ABSTRACT

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ABSTRACT

The effect of epidemiological factors such as minimum temperature, maximum temperature, maximum relative humidity, minimum relative humidity, rainfall, soil temperature, canopy temperature, cloud cover (morning and evening), wind speed, sunshine hours, vapour pressure (morning and evening) and crop age on the severity of stripe rust in four wheat varieties (RSP 561, HD 2967, Agra Local and PBW 343), under three sowing conditions (early, normal and late), were studied during two rabi seasons of 2013-14 and 2014-15 under random block design (RBD) with four replications. The experiment regarding effect of three leaf wetness durations (12, 24 and 36 hours) on four wheat varieties on disease severity was conducted under laboratory conditions.

The disease appeared in 1st standard meteorological week (SMW) in both the rabi seasons of 2013-14 and 2014-15 in all the tested wheat varieties, under different sowing conditions (early, normal and late), when the crop was at 73, 53 and 29 days after sowing, respectively. Sharp increase in disease severity was observed during 6th to 8th SMW due to the conducive weather conditions which prevailed during the previous fortnight. Epidemiological factors like maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure, evaporation, canopy temperature, soil temperature and age of the crop had significantly positive correlation with the disease severity in the tested wheat varieties, whereas, maximum relative humidity had significantly negative correlation, followed by rainfall which had moderately positive correlation with the disease severity. The predictive models generated through stepwise multiple regressions analysis revealed that thermic, hydric and light variables contributed significantly for variance in disease severity of selected wheat varieties. Gompertz model was observed to be the best fitted in predicting the severity of stripe rust in comparison to the Logistic model, when compared with observed disease severity.

Among the three principal components, Pc_1 accounted for maximum variance in disease severity that was contributed by various epidemiological factors (thermic and biological), followed by Pc_2 (light variables) and Pc_3 (hydric variables). Under laboratory conditions, 24 hours of leaf wetness duration was found to be adequate for the appearance of stripe rust in all the four selected wheat varieties, whereas, minimum latent period of 7.25, 9.50, 7.5 and 7.25 days, maximum pustules size of 10.03, 9.38, 11.05 and 10.98 mm and maximum disease severity of 57.50, 30.00, 60.00 and 54.34 per cent was recorded during 36 hours of leaf wetness duration.

Keywords: stripe rust, epidemiology, correlation, stepwise multiple regressions, prediction equations.

Signature of Major advisor **Signature of Student**

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CERTIFICATE – IV

Certified that all the necessary corrections as suggested by external examiner/ evaluator and the advisory committee have been duly incorporated in the thesis entitled "**Epidemiological studies of stripe rust of wheat caused by *Puccinia striiformis***" submitted by **Arun Khajuria**, Registration No**. J-13-M-308.**

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CHAPTER-1

INTRODUCTION

Wheat (*Triticum aestivum* L.*)* is second only to rice as a source of calories (21%) and is first as a source of protein (20%) in the diets of consumers. India witnessed record production of food grains (265 million tonnes) during 2013-14 which is five times higher since 1950-51 (51 million tonnes). Out of total food grain production, wheat contributes 36 per cent which is cultivated over an area of 30.75 million hectares with production and productivity of 95.91 million tonnes and 31.19 quintals/hectares, respectively (Anonymous, 2015), whereas, in Jammu province it is cultivated over an area of 247.4 thousands hectare with production of 5050 thousands quintals and productivity of 20.41 quintals/hectares, respectively (Anonymous, 2014a). To feed the ever increasing popultion, approximately 100 million tonnes of wheat shall be needed by 2030 (Tiwari *et al.,* 2011) and considering the limited resources, production challenges, biotic stresses and also aberrations in weather parameters, it is a big challenge.

Among the biotic constraints, rust diseases of wheat cause significant damage to wheat yield (Kolmer *et al.*, 2005). In winter wheat production system, stripe rust caused by *Puccinia striiformis* Westend. is reported as the most destructive one, though earlier it was considered as least damaging but, has emerged as major disease in last decade (Chen 2005; Fu *et al.,*2009), occurring in areas having cool and moist weather conditions during the growing season of wheat. Historically, epidemics of stripe rust has been reported in New Zealand (Welling and Mclntosh, 1990), United States (Line, 2002), Australia (Welling *et al*., 2000), Middle East (Akar *et al.,* 2007), China (Chen *et al.,* 2009) and in South Asian countries (India, Pakistan and Nepal) where stripe rust often causes severe losses in yield every year (Singh *et al*., 2004). The disease is continually extending the geographical limits, showing movement towards warmer areas due to the appearance of more aggressive strains having affiliation towards higher temperatures (Hovmoller *et al.,* 2008; Milus *et al.,* 2009). Yield losses in wheat are usually the result of reduced kernel number and size, low test weight, reduced dry matter, poor root growth and reduced kernel quality (Prescott *et al*., 1986; Wellings, 2011). In India, stripe rust is confined to the cooler regions of the North-West (Punjab, Haryana, U.P. and Jammu and Kashmir) as well as in Nilgiris hills of South India and is responsible for considerable yield losses (Nagarajan *et al.,* 1984; Kumar *et al.,* 1989). During 2014-15, the disease appeared in north-western plains and north western hill zones having severity of 10-60S, 40-60S, 10-40S, 80S and 70S in Punjab, Haryana, Himachal Pradesh, Jammu and Kashmir and Uttrakahnd, respectively (Anonyms, 2014b).

Weather factors such as temperature, relative humidity and rainfall are the main predisposing factors in stripe rust development and the pathogen (*Puccinia striiformis*) is highly sensitive to these factors. Minimum, optimum and maximum temperatures for urediniospore germination are 0°C, 7–12°C and 20–26°C, respectively (Schroder and Hassebrauk, 1964), whereas, the minimum, optimum and maximum temperatures for urediniospore penetration, growth and sporulation in host are 2°C, 12–15°C and 23°C; 3°C, 12–15 °C and 20°C and 5°C, 12–15°C and 20°C, respectively (Singh *et al.,* 2002).

P. striiformis also requires free water or dew for germination, production of germ tubes and causing infection (Rapilly, 1979) and duration of free water (moisture) availability differ at different temperatures (Burleigh, 1965). The appearance of epidemics is governed by long distance dispersal of urediniospore which is mainly influenced by the earth rotation and the latitude of the region (Roelfs *et al.,* 1992). Low wind velocities cause dry conditions and liberate the spores from the uredinia, whereas, high wind velocities result in the release of more spores, but simultaneously dilute the concentration of urediospores, particularly in case of long-distance dispersal than the local spread. Rain also plays a role by dispersing the inoculum and depositing of urediospores on the host and subsequently increasing the humidity, a pre disposing factor for disease development (Chen *et al.,* 2014).

Breeding of resistant varieties is the main method to avoid epidemics and minimize yield losses caused by stripe rust of wheat but changes in pathogen virulence, emergence of new races and lack of effective durable resistance, provide an imperative need for search of alternative strategies to manage the disease. Application of fungicides emerged as effective and economical approach in reducing yield losses (Wanyera *et al.,* 2009) but without adequate planning and proper timing of its application adversely affect the sustainable production, environment and its efficacy, especially when the risk of severe epidemics is low or at times during the season when they are less effective due to conducive environmental conditions (Gilles *et al.,* 2000). Further, the stripe rust disease is complex interrelationship between weather, amount of inoculum, rate of disease development, and host response, therefore a reliable forecasting system is essential if fungicides are to be made more effective and economical in reducing yield losses (Eversmeyer and Burleigh, 1969).

Crop models, meteorological data and remote sensing techniques are widely used for forecasting the occurrence of diseases (Hatfield, 1990). Prediction of wheat rust epidemics have been successfully made by using mechanistic and empirical approaches (Coakley *et al*., 1988; Benizri and Projetti, 1992) which were either based on meteorological factors alone or in combination with biological factors (Eversmyer and Karmer, 1992). Various statistical models based on multiple regression, stepwise regression, simple linear regression, Gompertz and Logistic regression approaches were employed widely between disease severity and epidemiological factors in forecasting plant diseases (Chen, 2009; Eddy, 2009). Modeling of plant diseases facilitates the prediction of disease initiation, the scale of severity of disease, for estimating the frequency of the epidemics and development of management strategies (van Maanen and Xu, 2003).

To develop an effective management strategy for the stripe rust, it is essential to evaluate key factors involved in the disease progress and forecasting system. Many factors affect the stripe rust severity including susceptibility of varieties, date of transplanting and weather factors such as daily relative humidity, daily temperature, amount of precipitation, dew, velocity, direction of wind and sunshine. Thus to introduce a forecasting model, it is necessary to consider the effects of these factors on the disease occurrence and its severity. Understanding of weather conditions is essentially required to provide base line information for developing simple and reliable disease prediction system. Keeping in view, the importance of the wheat in Jammu region, the present study is undertaken with the following objectives:

1. To evaluate the effect of abiotic factors on the severity of stripe rust of wheat.
2. To evaluate the comparative reliability of different equations for predicting stripe rust of wheat.

CHAPTER-2

REVIEW OF LITERATURE

Meteorological factors play a decisive role in the initiation and progress of stripe rust of wheat caused by *Puccinia striiformis* and the same have been studied and analysed worldwide. Various studies had been conducted to assess the impact and significance of various abiotic variables *viz*., temperature, relative humidity, sunshine hours, wetness duration, etc., on the severity of stripe rust, in order to develop forecasting models.

2.1 Effect of abiotic factors on severity of stripe rust of wheat.

The stripe rust pathogen, *Puccinia striiformis*, is highly sensitive to environmental factors. Temperature is the most important factor influencing its survival and disease development, although moisture wind and light also contribute to disease epidemics (Line, 2002).

Tu and Hendrix (1967) reported maximum temperature of 20-23^{o}C as critical for the infection, whereas, under field conditions, infection was even observed at temperatures of 19-30°C (Park, 1990). An exponential growth rate (r = -4) was recorded at temperature 0 and 3^{0} C (Naoumova, 1937; Zadoks, 1961; Burleigh, 1965) under field conditions. However, de Vallavieille-Pope *et al.* (1995) observed that under controlled conditions maximum infection efficiency of *P. striiformis* was at temperature 5-12^{o}C, with inhibition of infection at more than 15^{o}C.

Coakley (1978) while summarizing the effect of climate variability on stripe rust reported that an increase in temperature by 2.4^{0}C, then normal in the month of January play a major role for the epiphytic condition. Whereas, average increase of temperature from 1.67 to 2.7^{0}C above normal in the month of February resulted in wide spread of the disease with less severity because of reduction in latent period and in April, low temperature accompanied with more precipitation were found favourable for the progress of stripe rust.

Rapilly (1979) has reported that temperature influences the latent period of *P. striiformis* which is shortest (11 days) at 12-19^{o}C and also vary among different isolates; isolates collected after 2000 had longer latent periods 9-13 days, as compared of 11 days for isolates collected before 2000 in the U.S. Isolates with short latent periods caused 2.5 times more disease in the field compared to isolates with longer latent periods (Milus and Seyran, 2006).

Hyde (1982) reported that air temperature not only affects survival, latent period, growth, infectious period of leaf rust pathogen but also the age and relative susceptibility of host and with increase in temperature resulted in gradual decrease in relative humidity (maximum and minimum).

Temperature in January and February was significantly correlated with severity of yellow rust of wheat (Christensen *et al.,* 1993). Vechet (1994) observed that the temperature below -10^0C halted the pathogen development, whereas, temperature 10 to 15^0C along with relative humidity of 100 per cent was found conducive for urediospore production, air dispersal and infection.

The minimum average temperature of 11.7^0C with range of 10.8-12.5^0C and maximum average temperature of 27.7^0C with a range of 26.8-28.5^0C coupled with 8.2 hours of bright sunshine per day were found favourable for faster development of brown rust, stripe rust, leaf blight and powdery mildew diseases of wheat (Singh and Tiwari, 2001).

Temperature had a significant role in germination, infection, latent period, sporulation and survival of spores (Line, 2002). In the presence of dew, urediniospores germinate when temperatures was between 2 and 15^0C, with an optimum at 7^oC, whereas, germination and infection has also been observed under field conditions at subfreezing temperatures (Burleigh, 1965). Wiik and Ewaldz (2009) observed that mild winters and spring having temperature of 0 - 21^0C with optimum at 10 -15^0C favoured stripe rust infection.

Relationship between the weather variables (temperature, dew period and light quantity) and the life cycle characteristics (basic reproductive number and latent period) of *Puccinia striiformis* was studied by Papastamati and van den Bosch (2007), who observed that at temperature of < 6^0C and >16^0C population of the pathogen decreased, whereas, the maximum pathogen population was recorded at 14 and 16^0C. The study also revealed that low temperature of 7^0C usually led to longer latent period of 19 days and temperature of >14^0C delayed the sporulation by 12 days.

Sajid *et al.* (2010) studied the relationship between weather variables and disease severity of *P. striiformis* and *P. triticina* and observed linear relationship between maximum temperature of 30-35^{0}C, minimum of 15-16^{0}C and maximum humidity of 35-42 per cent with maximum severity of leaf and stripe rust diseases, respectively. Rainfall of >1mm during the growth period of wheat had little effect on the progress of both rust diseases.

Maddison (1970) reveled that germination of *P. striiformis* and formation of appresoria occurred when dew along with 2-15^{0}C temperature persisted and also the germination and sporulation decreased with the increase in time of exposure to sunshine hours.

Nagarajan and Joshi (1978) analyzed the data related to temperature, rainfall and number of rainy days in epidemic and non epidemic years and concluded that number of rainy days were important in determining the build-up of brown rust caused by *P.* Sache *et al*. (2000) studied the effect of rain in the epidemiology of leaf rust caused by *P. triticina* and stripe rust caused by *P. striiformis* of wheat and reported that continuous rains instantly enhanced the spore removal, whereas, further spore production got inhibited by the violent or extended rainfall. They also reported that rain was also responsible for deposition of airborne spores to the leaves and initiation of infection. Presence of moisture enhances germination and infection, but too much availability of free water adversely affects the infection by reducing the viability of the urediniospore (Chen, 2005).*triticina* and stripe rusts caused by *P. striiformis* in wheat over North West India.

Relative humidity of 42.80 - 88.20 per cent and rainfall of 59.7 mm along with numbers of rainy days (12/month) were found to be favourable for the development of brown rust, stripe rust, leaf blight and powdery mildew of wheat (Singh and Tiwari, 2001).

Dadrezaei and Torabi (2001) observed that low temperature was the limiting factor for the activities of *P. striiformis* such as germination, penetration and development. But, increase in maximum temperatures (above normal) in late April, checked the further development of disease.

Penetration of germ tube takes place in darkness, whereas, the minimum temperature played a critical role in the development of the stripe rust (de Vallavieille- Pope *et al*., 2002; Chen, 2005). Milus and Seyran (2006) observed that when urediniospore reached on susceptible host, continuous presence of moisture for at least three hours along with temperature of 12-18^{0}C was conducive for germination and causing infection. Rise in temperatures during winters were also found critical for stripe rust infection (Gladders *et al*., 2007).

Nagarajan and Singh (1990) reported that wind plays a significant role in urediniospores dissemination, especially in long distance dispersal, which subsequently affects the release, take off and movement of spores. Urediniospores could be lifted to thousands of meters by air turbulence (Little, 1981) and could spread to more than 800 km from the area of origin (Zadoks 1961) which demonstrated the incursion of the pathogen into geographically distant areas (Wang *et al.,* 2010). Wind also imparts an adverse effect on disease initiation by desiccate the moisture or dew present on host surface and thus making unfavourable for spore germination and infection.

Sache (2000) studied the effect of rain in the epidemiology of leaf rust caused by *P. recondita* f. sp. *tritici* and stripe rust caused by *P. striiformis* of wheat and reported that continuous rains instantly enhanced the spore removal, whereas, further spore production got inhibited by the violent or extended rainfall. They also reported that rain was also responsible for deposition of airborne spores to the leaves and initiation of infection. Presence of moisture enhances germination and infection, but too much availability of free water adversely affects the infection by reducing the viability of the urediniospore (Chen, 2005).

2.2 Effect of abiotic factors on severity of diseases

Bulger *et al.* (1987) conducted a study regarding the influence of temperature and leaf wetness duration on infection by *Botrytis cinerea* in strawberry flowers which revealed that optimal temperature of 20^{0}C along with 24 hours of leaf wetness duration resulted in 100 per cent inflection.

The effects of temperature and leaf wetness duration on the leaf spot of peanut caused by *Cercospora arachidicola* were studied by Lijun Wu *et al.* (1999) and reported that optimal temperature of 22.8^{0}C with wetness periods of 26, 30 and 36 hours resulted in lesion density of 96, 17 and 6, respectively

Pfender (2000) developed disease severity prediction model for stem rust caused by *P. graminis* f. sp. *graminicola* in ryegrass and tall fescue based on temperature and latent period and observed that latent period of 54 and 69 days at 3.5^{0}C to 5.9 and 8.5 days at 26.5^{0}C in ryegrass and tall fescue, respectively, were conducive for the disease progress. He further reported that optimal temperature of 26^0C was conducive for the latent period in both ryegrass and tall fescue grasses.

Sullivan *et al.* (2002) while studying the effects of temperature and wetness period on the progress of spinach white rust caused by *Albugo occidentalis* in controlled conditions, found that temperature (12-18^0C) and wetness period (3-84 hours) were conducive for the disease progress, whereas, maximum disease severity (90%) was recorded at 12^0C having wetness duration of 84 hours, concluding that temperature and leaf wetness duration played a crucial role in the development of disease prediction models.

Maximum temperature (20-23^0C), average relative humidity (67-73%), frequent rains (70mm) with maximum frequency of 6-13 rainy days during crop season were found favourable for spread of Alternaria leaf blight caused by *A. brassica* (Kolte, 2002).

Belmont *et al.* (2003) analysed the importance of planting dates and climate factors on the incidence and severity of sorghum grain molds caused by *Fusarium thapsinum* in Mexico from 1998 to 2000 and observed that crop sown on 29^{th} June had maximum disease incidence (83%) with a significant regression coefficient (1.64) for mean temperature and coefficient of determination (R^2=0.35) for relative humidity which validated their relationship with severity of sorghum mould disease.

Pannu *et al.* (2005) recorded maximum disease severity of brown leaf spot (19.8 and 32.8%) in rice caused by *Heliminthosporium oryzae* during 2002 and 2004 when rainfall was low (225.5 and 280 mm) respectively. Even at low humidity, the disease progress was higher, as 4-6 h of leaf wetness period was sufficient for the germination and infection by *H. oryzae.* Rainy days followed by bright sunny days were conducive for conidial multiplication of *H. oryzae*. Rice crop at maturity stage was reported to be more vulnerable to brown leaf spot disease under water-stress conditions (Lore and Raina, 2003).

Epidemiological study was conducted by Rathore (2008) regarding the development of downy mildew of bond pryllium (*Plantago ovate)* caused by *Peronospora alta.* He observed that inoculum (10^5 conidia/ml) coupled with susceptible age of plant (70 to 80 days), low temp. (15-20^0C) for 48 hours along with high relative humidity (100 % for 96 hours) were conducive for the progress of disease. He further observed a positive correlation between progressive disease index (PDI) and temperature (minimum and maximum), whereas, a negative correlation with relative humidity, signifying that temperature played a vital role in disease initiation and progress.

Thind *et al.* (2008) analysed the functional relationship of sheath blight of rice caused by *Rhizoctonia solani* with the crop age and weather factors and reported that temperature range of 20- 30^{0}C with relative humidity of 80-100 per cent during tillering to panicle emergence stage showed the highest disease severity (65%). They also observed that tillering to panicle stage was most favourable for sheath blight development. Early crop stages were less susceptible as compared to tillering and later growth stages (Tan *et al.,* 1995).

Sangeetha and Siddaramaiah (2007) studied the epidemiology of white rust caused by *Albugo candida,* downy mildew by *Peronospora parasitica* and alternaria blight caused by *Alternaria brassicicola* of Indian mustard (*Brassica juncea)* and reported that symptoms of white rust appeared at 38 days after sowing when minimum temperature (15 to 16^{0}C), maximum temperature (28 to 29^{0}C) along with average relative humidity (> 65%) prevailed. While in downy mildew, symptoms were noticed after 75 DAS when minimum temperature of 14-16^{0}C, maximum temperature of 26-29^{0}C of and average relative humidity of more than 58 per cent prevailed, whereas, in case of Alternaria blight, symptoms appeared on 53 DAS when minimum temperature of 14-15^{0}C, maximum temperature of 27-28^{0}C and average relative humidity of more than 60 per cent, persisted. They also reported high positive correlation of 0.8245, 0.7211 and 0.8263 between temperature and disease index of white rust, downy mildew and alternative blight, respectively.

Yadav *et al.* (2008) studied the development of Alternaria blight caused by *A. brassica* and white rust caused by *A. candida* in two varieties of *Brarssica juncea* (Laremi and Vallina) at two location (Delhi and Sri Ganganagar) during 2006 and 2007 and observed that variation in local weather variables affected the progress of diseases. During 2006, Alternaria blight appeared in 48th and 52nd standard meteorological week when rainfall of 0.7 and 6.7mm during 46th and 47th and 2.4 mm in 52nd standard meteorological week persisted at Sri Ganganagar and Delhi, respectively. While, in 2007 Alternaria blight appeared between 6th to 8th at both the locations. They attributed the variation in disease appearance to rainfall which created maximum (>80%) and minimum (>45%) relative humidity, that was conducive for the progress of the disease. Whereas, white rust appeared in 49th SMW at Sri Ganganagar and during 52nd at New Delhi when maximum temperature was below 21^0C at both the stations. Maximum temperature (< 25^0C) and minimum (<10.8^0C) along with relative humidity (maximum >83% and minimum > 73%) with more than 6.2 hours of bright sunshine was found conducive for the periodical increase of white rust pustules on host leaves (Saharan, 2000).

Singh and Singh (2009) studied the relationship between environmental variables and spot blotch disease incited by *Cochliobolus satovois* in six different wheat cultivars at different growth stages and observed a significant positive correlation between mean minimum temperature (0.949 and 0.972) and mean maximum temperature (0.959 and 0.938) with disease severity at booting to pre–maturity stages while at jointing to pre-maturity, the correlation with mean minimum temperature was 0.914 and 0.973 and mean maximum temperature 0.86 and 0.923 during 2001-02 and 2002-03, respectively.

Singh *et al.* (2013) conducted *in-vitro* survivability of *Uromyces viciae fabae* causing rust in field pea in Uttrakand (2006-2010) at different temperatures, durations and depths, and observed that survival of urediospore declined (65 to 8.67%) when stored at 10^0C for four months, while, only 5 per cent survived at 5^0C. They further observed that at high temperatures (>30 to 40^0C) survivability was 0.4 per cent when stored for one month which resulted that low temperature was favourable for the production of urediospores. The pathogen survived maximum at the depth of 10 cm followed by 5, 15 and 20 cm when stored for 4 week duration.

Margar and Kurundkar (2005) studied the effect of mean temperature, relative humidity (maximum and minimum) and wind speed on grain mold disease at two growth stages of sorghum. At 50 per cent flowering to harvest stage, a significant positive correlation was observed between mean temperature (0.868), relative humidity (maximum 0.835 and minimum 0.762) and wind-speed (0.805) with the grain mold severity, whereas, in case of 15 days before harvesting stage, correlation of 0.027 and 0.544 of wind speed and rainfall, respectively.

Meena *et al.* (2011) analyzed weekly meteorological data for consecutive five years (2003-2007) from boot leaf to grain formation stage in pearl millet and observed that maximum temperature of 33.2-34.9^0C and minimum temperature of 23.7-27.9^0C during July to August, showed negative correlation, while maximum relative humidity (70.3-79.5%) and minimum (43.0-56.7%) were positively correlated with the progress of smut disease caused by *Moesziomyces penicillariae.*

Ruth and Rao (2013) studied the influence of weather variables on incidence of groundnut bud necrosis virus in tomato caused by *Tospovirius* which is transmitted by *Thrips palmi* and observed that during rabi (2007 and 2008) the thrips population was positively correlated with temperature (maximum and minimum) and relative humidity with coefficient determination (R^2) of 0.953 and 0.853, respectively, whereas, negatively correlated with minimum relative humidity and rainfall during kharif (2007 and 2008) with coefficient determination (R^2) of 0.953 and 0.487 respectively. Weather played a crucial role in the activity and migration of thrips and had significant correlation with bud necrosis incidence (Harding 1961; Reddy *et al*., 1983; Cho *et al.,* 1987; Reddy and Wightman, 1988)

2.3 Prediction models for stripe rust of wheat

Krause and Massie (1975) classified disease forecasting models as empirical models based upon statistical relationships between environmental variables and disease and fundamental models based upon laboratory, greenhouse, or field experiments.

A series of studies were conducted for developing forecasting models for prediction of stripe rust of wheat. Coakley and Line (1981) quantified the relationships between temperature and stripe rust epidemics on winter wheat during 1963 to 1979 in Pullman, WA and found significant correlation between stripe rust disease index and cumulative negative (December 1 to January 31) and positive degree days (April 1 to June 30). These weather descriptors were further used to develop simple linear regression models for predicting stripe rust disease severity for the Pullman area which were further extended to other locations in the Pacific Northwest (Coakley *et al.,* 1982). Predictive models with multiple regression approach were also developed to estimate disease intensity by analysing temperature and other meteorological factors such as the amount and frequency of precipitation from 1968 to 1986 at Pullman, WA (Coakley *et al.,* 1988). However, the simple linear models based on negative and positive degree days have been used mostly in forecasting for stripe rust in the PNW (Line, 2002; Chen, 2005). Another forecasting models for stripe rust disease severity with logistic regression approach was developed by Eddy (2009) based on relative humidity (>87%), leaf wetness duration and mean relative humidity that predicted infection with 93, 80 and 76 per cent accuracy, respectively.

An epidemiological was study conducted by Ahmed *et al*. (2010) for predicting yield loss in wheat by stripe rust which revealed that minimum temperature and relative humidity remained positively correlated while the maximum temperature showed negative correlation with the disease severity. They further observed that infection severity increased with the rise in minimum temperature and relative humidity, whereas, it decreased with rise in maximum temperature

Sharma and Chen (2011) identified weather factors responsible for stripe rust epidemics and developed models for predicting potential yield loss by conducting correlation and regression analyses of weather parameters and yield loss data from 1993 to 2007 for winter wheat and 1995 to 2007 for spring wheat. They observed that in winter wheat the sum of daily temperatures and accumulated negative degree days were significantly (55.9 to 87.6%) correlated to yield loss, whereas, in spring wheat, it was 34.9 to 64 per cent correlated to rainfall-days.

2.4 Prediction Models for severity of diseases in other crops

Eversmeyer and Burleigh (1969) adopted stepwise multiple regression computer programme to generate epidemic prediction model for wheat leaf rust caused by *P. triticina* by incorporating weekly urediospores numbers, cumulative urediospore numbers, average maximum and minimum temperatures and hours of free moisture (dew, rain per day and days of precipitation) and observed a variation of over 70 per cent in actual and predicted disease severity. They further observed that minimum temperature was responsible for the variation in severity than the maximum temperature and inclusion of precipitation increased the accuracy of the model

Khan (1997) developed multiple regression models for forecasting leaf rust caused by *Puccinia triticina* in wheat and found that linear relationship between minimum temperature (12 to 18^0C) along with relative humidity (70 to 85%) having coefficient of determination (R^2) of more than 0.90 for the development of leaf rust disease. He further revealed that a single prediction model for rust of wheat cannot be proposed for different environmental conditions due to diverse prevailing temperature patterns which affected the severity of disease (Eversmeyer and Burlergh, 1969).

Moschini *et al*. (1999) developed model for predicting wheat leaf rust caused by *Puccinia triticina* by using planting dates, genetic resistance and weather variables and found that rust severity of early planting data was best predicted on basis of daily mean temperature (>12^0C) and relative humidity (>70%) without any precipitation.

Gilles *et al*. (2000) studied the epidemiology of leaf spot of winter rape oil seed crop (*Brassica napus*) caused by *Pyrenopeziza brassicae*, and noticed that epidemics of the disease was initiated primarily by ascospores produced from apothecia that survived on the infected debris during summer, while in winters the epidemic was commenced by rain splashed conidia that spread the disease from foci to the main crop. They also concluded that the roles of ascospores and condia were very crucial for the life cycle and forecasting the severity of leaf spot.

Uddin *et al.* (2003) developed a prediction model for gray leaf spot caused by *Pyricularia grisea* of perennial ryegrass turf based on four different temperatures (20, 24, 28 and 30^0C) and leaf wetness duration (3 to 36h at 3 hour interval), and observed that disease severity increased with the increase in leaf wetness duration at each temperature selected. They inferred that at 20^0C with leaf wetness duration of 3 to 9h, low disease incidence were reported, which increased with the wetness duration from 12 to 18 hours and attained maximum severity (57%) at 36 hours of wetness duration at 28^0 C. They found that increase in temperature from 20 to 32^0C with leaf wetness duration of 3 to 6h resulted an increase in disease incidence but it decreased with increase in leaf wetness duration (> 21 hours).

Paul and Munkvold (2004) combined regression and Artificial Neural Network (ANN) modeling approach to develop a prediction model for grey leaf spot caused by *Cercospora zea maydis* of maize from 1998-2002 in Iowa and revealed that daily temperature (20 to 30^0C), night relative humidity more than 90 per cent, maize residue (0 to 100%), planting date (112 to 182 days of the year) were most valuable predictors for forecasting the onset of the grey leaf spot disease. They further observed that the model had coefficient of determination (R^2) ranging from 0.70 to 0.75, with mean square error of 174.70 to 202.80 indicated the validity of the model.

Sunkud *et al*. (2005) observed that environmental conditions in 31st standard meteorological week *viz*., maximum temperature (33.6 and 33.1^0C), morning relative humidity (82 and 80.1%) along with rainfall (81 and 66.6 mm) during 2002 and 2003, respectively, were most favourable for the appearance of groundnut rust symptoms caused by *Puccinia archinds*. However, maximum disease incidence of 88.20 and 80.10 per cent were reported during the 39th

SMW in both the years. They further adopted the logistic method to develop the prediction model and found a high coefficient of determination value (98 and 99 % in 2002 and 2003) for the appearance of ground rust symptoms.

Ponte *et al*. (2006) developed empirical rainfall models to predict the severity of asian soyabean rust caused by *Phakospora pachyrhizi* based on the meteorological data recorded during 2002-03 to 2004-05 in Brazil and found that temperature had very low correlation with disease severity in comparison to rainfall which was considered as a major predictor variable to forecast the soyabean rust.

Kuar *et al.* (2007) worked on development of epidemiological model and decision support system for Karnal bunt of wheat caused by *Tilletia indica* and observed that amount of sporidial inoculum at heading stage (GS51-65) correlated better and fitted best with polynomial equations developed having temperature of 8-21^{0}C, relative humidity of 64 to 100 per cent, mean temperature of 14.5 ± 1^{0}C and relative humidity of 82 ± 5 per cent. They further reported that moderate temperature and high humidity created moist host surface and continuity of these conditions favoured germination of primary inoculum and survival of the sporidial colony. Timing and duration of rainfall was critical for disease development especially for viability of secondary sporidia which are short lived (Smilanick *et al.,* 1989; Smiley, 1997; Kaur and Kaur, 2005). weather based forecasting model of bacterial leaf blight (*Xantomonas oryzae* pv.*oryzae*) was developed by Sharma *et al*. (2007), which reported that disease severity showed a positive correlation of 0.73, 0.57 and 0.40 with rainfall (68.6-260 mm), number of rainy days (4-13) and with average relative humidity (>80 %), respectively and these three weather variables along with temperature between 20 to 30^{0}C were conducive for the severity of the disease.

Sharma *et al*. (2008) compared three weather based linear forecasting models for bacterial blight caused by *Xanthomonas axonopodis* pv. *malvacearum* of cotton and observed that the disease intensity showed positively correlation of 0.40 with maximum temperature and 0.38with minimum temperature during one week previous to 35th to 42nd standard meteorological week at boll-development growth stage of cotton which was found to be conducive for the initiation of bacterial blight. They also found that predicted disease intensity showed a positive correlation (0.881) with disease intensity

Jamshed *et al.* (2008) assessed various meteorological variables to develop regression equations for predictions of wheat leaf rust caused by *Puccinia triticina* from the data collected at Bahawalpur and Faislabad during 2002 to 2007 and reported that relative humidity along with total precipitation were critical for the onset of leaf rust having coefficient of determination (R^2) of more than 0.75. Further, comparison of different models revealed that trivariate model with maximum temperature (15-22^{0}C) and average relative humidity (>60%), was best suited for forecasting the leaf rust severity.

Krishaveni *et al.* (2008) conducted simple, multiple correlation and regression analyses of the weather data of Coimbatore (1991-2001) with the downy mildew of pearl millet caused by *Sclerospora graminicola* and observed a positive correlation of 0.7566 and regression value of 0.73 (at 5% level of significance) between average rainfall (55.3 mm) and average minimum temperature (21.4^{0}C). They further inferred that rainfall (avg. 45.3 mm) and minimum temperature (20.8^{0}C) during the vegetative phase (30 days after the sowing) were favourable for the maximum incidence of the disease.

Lal *et al,* (2008) compared logistic with gompits equations to predict the severity of lentil rust caused by *Uromyces fabae* and found logistic equation was more effective (-4.306 to 2.623) in forecasting the disease severity. Further regression analyses of the data revealed that maximum severity (83%) was reported in 10-week old crop during February 12 to March 11 in 2000-01 and 2001-02, when minimum temperature of 7.7 to 13^{0}C and maximum of 23.8 to 28^{0}C, relative humidity of 81 to 97 per cent along with cloud cover 0 to 3.0 and 0 to 2.8 okta persisted, respectively.

Based on weather parameters collected from Kalyani during June to September, 2009, Dutta *et al*. (2011) developed a prediction model of black rot of cabbage caused by *Xamthomonas compestris* and reported that disease progression was positively correlated with maximum and minimum relative humidity along with rainfall, while it was negatively correlated with maximum, minimum and mean temperatures. They also reported maximum disease severity (98.4%) when average temperature of 27 to 30^{0}C and average relative humidity of more than 85 per cent along with rainfall persisted.

A study on forecasting foliar disease of groundnut caused by *Arachis hypogaea* was conducted over three Rabi seasons and it was observed that disease progressed with the decrease in maximum temperature (<34.2^{0}C) and increase in relative humidity (>87.8 %) along with pre-monsoon rainfall (6.00 mm) during the later growth stages of crop (Adiveer *et al*.,1998).

Medina *et al.* (2009) reviewed various tools employed in decision making and development of forecasting models for disease severity and analysed that apart from statistical tools, visual evaluations, pictorial assessment and mathematical tools *viz*., Linked Differential Equations (LDE), Area Under Disease Progress Curve (AUDPC) and computer simulation were effective in developing disease prediction models. They further observed that conjugation of more than one mathematical tool could result in prediction model with better fitness.

Te Beest *et al*. (2009) developed early warning weather-based prediction model for Septoria leaf blotch caused by *Mycospharella graminicola* of wheat and observed that the accumulated rainfall more than 3 mm in 80-day period along with minimum base temperature (0^{0}C) in 50-day period preceding growth stage (GS31) extremely favored the development of disease. They further found that disease model had a run-length of 3 window-pane with low misclassification value (<0.20) which indicated its good predictive value. Also, a positive proportion value of 0.61, specificity of 0.18 along with sensitivity value of 0.83 further validated the developed prediction model.

Sharma *et al*. (2010) analysed 14 years meteorological data (1991 to 2004) to study the epidemiology of kernel smut caused by *Tilletia barclayana* of rice and found positive correlation of 0.24 and 0.22 between maximum temperature (33.5^{0}C) and sunshine duration (7.5 h) respectively, during 33rd standard meteorological week with the disease intensity. They further revealed that high temperature during day time coupled with bright sunshine hours favoured the formation and multiplication of sporidia, whereas, other weather variables *viz*., rainfall and number of rainy days showed least impact.

A risk algorithms based forecast model developed by Foster *et al.* (2011) for Sclerotina rot of carrot caused by *Sclerotina sclerotiorum,* revealed that initial inoculum developed when the soil metric potential (soil moisture) was more than -20 kPa along with maximum soil temperature (24^{0}C). They further reported that risk algorithm model predicted the initiation of epidemics by forecasting the formation of apothecia and ascospores which commenced when the mean and maximum temperature ranged from 13 to 21^{0}C and 16 to 25^{0}C along with daily soil mean and maximum temperature from 16 to 20^{0}C and 21 to 25^{0}C, respectively during the preceding one or two week. The history of the disease in the region and soil moisture data were the two critical variables to develop the prediction model for Sclerotina rot (Hunter *et al*., 1984, Turkington, 1988; Bom and Boland, 2000; Kora, 2003).

Biswas *et al.* (2011) investigated the effect of meteorological factors on rice sheath blight caused by *Rizoctonia solani* and observed that maximum (34^0C) and minimum temperatures (26^0C) along with maximum relative humidity (>90%) were favourable for the spread of disease. They also noticed high coefficient of determination (R^2) of 0.80 between weather parameters and disease incidence which significantly validated the model.

Kumar (2014) selected humid thermal ratio, maximum temperature and special humid thermal ratio as predictor variables to developed weather based prediction models of wheat leaf rust and observed that weather during 7–9^{th} standard meteorological weeks at Ludhiana, Faizabad and Sabour and 10-12^{th} SMW at Kanpur had the highest correlation coefficient of 0.53 with minimum temperature, 0.64 with relative humidity, 0.85 with humid thermal ratio and 0.77 with special humid thermal ratio in Indo-Gangetic plains of India. He further reported that in all four locations, highest average seasonal humid thermal ratio coincided with the highest disease severity which established it as a critical predictor variable for disease development model.

Mahapatra and Das (2014) compared weather based Logistic and Gompertz prediction model for Alternaria leaf blight caused by *A. brassicae* and *A. brassicicola* of mustard under different dates of sowing and found that Gompertz transformation model best fitted to 5^{th} November date of sowing with morning wind velocity of 1.634 units and total rainfall of 0.67units and also to 20^{th} November date of sowing with minimum temperature (1.57 units), maximum relative humidity (1.083 units), maximum wind velocity (17.83 units), bright sun-shine hours (1.65 units) along with total rainfall (0.113 units) having high R^2 (0.37 for logit and 0.64 for gompit) for 5^{th} November sowing and 0.78 for logit and 0.84 for gompit for 20^{th} November sowing.

CHAPTER-3

MATERIALS AND METHODS

The experiments were conducted during rabi seasons of 2013-14 and 2014-15 to study the effect of various epidemiological factors on the severity of stripe rust of wheat caused by *Puccinia striiformis* at the University Research Farm, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha. Materials and methods used for conducting experiments are described as:

3.1 Experimental material

Four wheat varieties *viz.*, RSP 561, HD 2967, Agra Local and PBW 343 based upon their response against disease (HD 2967: moderate resistance, RSP 561: moderate resistance, Agra Local and PBW 343: highly susceptible) were selected for the study. The seeds of HD 2967 and RSP 561 were procured from Mega Seed Unit, SKUAST–Jammu and Agra Local and PBW 343 from the Division of Genetics and Plant Breeding, Faculty of Agriculture, SKUAST-Jammu.

3.2 Layout of experiments

Experimental plots were layed out in the Research field of Division of Plant Pathology, during both the rabi season of 2013-14 and 2014-15. The selected wheat varieties were sown in plots of 9m^2 size on three different dates of sowing, last week of October (44 SMW) as early sowing, 2nd week of November (46 SMW) as normal sowing and 1st week of December (49 SMW) as late sowing conditions. The experiments were laid out in RBD with four replications and having row to row spacing of 22.5cm having 12 lines of wheat in each plot.

3.3 Preparation of spore suspension for mass inoculum

The spore dust containing urediniospores of mixed pathotypes of *Puccinia striiformis* was collected from Regional Rust Research Centre, Indian Institute of Wheat and Barley Research (ICAR), Flowerdale, Shimla during Oct., 2013. The suspension was prepared by suspending the inoculum dust in sterile distilled water (95ml) in which 5ml of Tween-20 was added and shaked vigorously for uniform mixing for inoculation of susceptible varieties *viz.,* Agra Local and PBW 343. Prior to surface inoculation, the seedlings of Agra Local and PBW 343 were sprayed with fine mist of distilled water followed by smooth rubbing of leaves by fingers to disturb the wax layer and to open the stomata of leaves. After inoculation, plants were misted again with hand sprayers and the pots were kept in saturated moisture chamber prepared by covering with polythene bags, for 48 hours of wetness duration. After that regular mist-sprays of water were applied for creating optimum humidity in the pots. With the appearance of symptoms of disease after 12 days of inoculation, the pots were shifted to experimental plots for disease initiation for epidemiological experiment. The fresh spores dust collected from the symptomatic plants were also sprayed to all the selected wheat varieties (tillering stage) by atomizer. The inoculation was done in late afternoon to reap the benefits of night-dew for creating leaf wetness conditions, a pre-requisite for rust infection. The field was irrigated frequently to maintain moisture conditions in the field for the buildup of disease.

3.4 Epidemiological studies

The effect of different epidemiological factors *viz.*, minimum temperature, maximum temperature (^{0}C), maximum relative humidity, minimum relative humidity (%), rainfall (mm), soil temperature (^{0}C), canopy temperature (^{0}C), cloud cover (Okta), wind speed (km/h), sunshine hours (hrs/day), vapour pressure (mmHg) and evaporation were studied on the development of stripe rust of wheat in four wheat varieties namely RSP 561, HD 2967, Agra Local and PBW 343, during rabi seasons of 2013-14 and 2014-15. The above mentioned metrological data corresponding to the date of observation were collected from Agro-meteorological section, SKUAST-Jammu. The canopy temperature was recorded with infrared thermometer (Ramson make) at 12 O'clock to 1 pm and soil temperature with soil thermometer (Japson make) at three different depths of 5, 10 and 20 cm.

3.5 Disease severity observation and rating

From the last week of December onwards during 2013-14 and 2014-15, the wheat plants of s elected varieties in the experiment plots were monitored regularly to observe the initial foci of *Puccinia striiformis.* Disease severity (per cent infection) was recorded by modified Cobb's scale (Peterson *et al.,* 1948) on randomly tagged plants (4/plot), with the appearance of symptoms. The severity of stripe rust was observed on weekly interval during both the rabi seasons of 2013-14 and 2014-15, from initiation of disease to 14^{th} SMW. For severity below 5 per cent, the intervals used were traces to 2 per cent, 5 per cent intervals, from 5 to 10 per cent severity and 10 per cent intervals between 20 to 100 per cent severity were used for recording the observation.

3.6 Correlation Analysis:

Correlation analysis of the disease severity data of rabi seasons of 2013-14 and 2014-15, for four wheat varieties *viz*., RSP 561, HD 2967, Agra local and PBW 343 was conducted with the epidemiological factors (independent variable) *viz.,* minimum temperature, maximum temperature (^{0}C), maximum relative humidity (%), minimum relative humidity (%), rainfall (mm), soil temperature (^{0}C), canopy temperature (^{0}C), cloud cover (Okta), wind velocity (km/h), sunshine hours (hrs/day) and evaporation (mm) along with age of crop with the date of observation to evaluate the degree of association among the different epidemiological factors in causing the onset and the progress of the disease severity of stripe rust. The analysis was performed by using SPSS 16.0 (Jamshed *et al.,* 2008). The correlation coefficients (r) were analyzed to find out effect of single as well as combination of different epidemiological factors on the disease progression of stripe rust of wheat (Madden, 1986; Cornell and Berger, 1987).

3.7 Multiple regression (stepwise)

To determine the cumulative effect and prediction of the disease severity of stripe rust from epidemiological factors on the, significant epidemiological factors having high correlation coefficients (R), were subjected to further stepwise regression, to generate models by forward and backward selection process through SPSS 16.0 (Dikes and Roming, 1970) having coefficient of determination (R^2), Adjusted coefficient of determination (Adj R^2) and F-value <0.0001. The tolerance and VIF values of each steps were also generated for the goodness of fitness of predictive models. Further, graphs of observed and predictive values generated by the stepwise regression model were plotted to evaluate the accuracy of equations in predicting the disease.

3.8 Logistic model

To predict the severity of disease, the Logistic model (Naragund, 1989) was incorporated to transform the observed disease severity data with time to generate prediction values, by using following equation:

$$Y_t = K_1 + \frac{K_2}{1+ea^{b-t}}$$

Where, Y_t = expected severity at time 't', t = time interval, a and b = constant, K_1 and K_2 are upper asymptotes of the logistic curve.

3.9 Gompertz model

For the prediction of severity of stripe rust over time, the Gompertz transformation (Berger, 1981) of the observed disease severity data recorded over weekly interval for three different dates of sowing over time, averaged over two Rabi seasons (2013-14 and 2014-15) were analysed by following equation.

Gompertz = Gompit (Y) = -ln [-ln (Y)]

Where 'Y' = disease severity

3.10 Principal Component Analysis

The averaged epidemiological and disease severity data of the four selected wheat varieties were subjected to Principal Component Analysis (Xi *et al.,* 2013) by SPSS 16.0 software to reduce the large set of epidemiological variables into smaller ones. Based on the proportion of eigenvalues (with eigenvalues ≥ 1), principal components were selected for interpretation of result. Principal axis method was used to extract the components followed by Orthogonal rotation (Hatcher and Stepanski, 2005).

3.11 Leaf wetness experiment

To evaluate the effect of different leaf wetness duration of 12, 24 and 36 h on the severity of stripe rust of wheat, four different varieties of wheat *viz*., Agra local, PBW 343(S), RSP 561(MR) and HD-2967(MR) were selected. In plastic cups, seeds of selected varieties were sown and three seedlings per cup were maintained in which at two leaf stage, each leaf was inoculated with uredinospore dust by using lancet needle method (Nayar *et al*., 2003). The inoculated varieties were covered with the polythene bags for creating the saturation moisture conditions. The inoculated plants were taken out from the moisture chamber at different wetness duration *viz.,* 12, 24 and 36 h. With the appearance of symptoms, observations regarding latent period (number of days between inoculation and disease appearance), pustule size (mm) and severity percentage (Modified Cobb's scale) were recorded for three different wetness durations.

CHAPTER-4

RESULTS

4.1.1 Effect of epidemiological factors on the severity of stripe rust of wheat under early sowing conditions

Field experiments were conducted during rabi seasons of 2013-14 and 2014-15 to assess the effect of various epidemiological factors on initiation and severity of stripe rust in four wheat varieties (RSP 561, HD 2967, Agra Local and PBW 343). The data thus collected are presented in Table 1 (Fig. 1) which indicate that during both the seasons, under early sowing conditions, primary infection appeared in first standard meteorological week (2^{th} Jan. 2013 and 4^{th} Jan. 2014, respectively) when the crop was at jointing growth stage (73 days after sowing) in all the selected wheat varieties. The corresponding weather factors were maximum temperature of 17.5^{0}C, minimum temperature of 5^{0}C, maximum relative humidity (RH) of 92.5 and minimum of 59 per cent, mean wind velocity of 1.6 km/h, vapour pressure (morning 8.2 mmHg and evening 9.9 mmHg), sunshine (2.9 h/day), evaporation (1.1 mm), cloud cover (morning 3.5 and evening 6.0 okta), soil temperature (11.4^{0}C) and canopy temperature (11.7^{0}C). At the onset of the disease, the severity was more in RSP 561 and Agra Local (2.33% each) followed by HD 2967 (1.67%) and PBW 343 (1.0%). Thereafter, disease gradually progressed with age of the crop and increased sharply from 28.33 to 55.00 per cent in RSP 561, 20.83 to 45.00 per cent in HD 2967, 32.50 to 56.67 per cent in Agra Local and 26.67 to 63.33 per cent in PBW 343, during 6^{th} to 8^{th} SMW when the crop was at heading to milk stage (108 to 122 DAS), with corresponding maximum temperature of 19.4 to 24.1^{0}C, minimum temperature of 10.2 to 8.8^{0}C, maximum RH of 82 to 96 per cent, and minimum RH of 64 to 57 per cent, mean wind velocity of 3.3 to 1.2 km/h, vapour pressure (morning 11 to 14.5 mmHg and evening 12.5 to 16.5 mmHg), sunshine (3.8 to 6.9 h/day), evaporation (1.5 to 1.6 mm), cloud cover (morning 6.5 to 4.5 and evening 3.0 to 1.5 okta), soil temperature (13.7 to 15.7^{0}C) and canopy temperature (18 to 16^{0}C). At the maturity stage (164 DAS) in 14^{th} SMW, maximum disease severity was recorded in Agra Local (90%) followed by PBW 343 and RSP 561 (86.67% each) and HD 2967 (81.67%) with maximum temperature of 27^{0}C and minimum of 12.1^{0}C, maximum RH of 82 and minimum of 47.5 per cent, mean wind velocity of 5.4 km/h, morning vapour pressure of 8.8 and evening of 15 mmHg, sunshine of 9.8 h/day, rainfall of 18.7 mm, evaporation of 2.4 mm, morning cloud cover of 1.0 okta, soil temperature of 20.8^{0}C and canopy temperature of 25.7^{0}C.

Table 1: Effect of epidemiological factors on the severity of stripe rust of wheat under early sowing conditions

SMW	Wheat varieties				Age (days)	$C_{Temp.}$ (^0C)	$T_{Max.}$ (^0C)	$T_{Min.}$ (^0C)	$RH_{Max.}$ (%)	$RH_{Min.}$ (%)	$M_{Wv.}$ (km/hr)	$Vp_{Mor.}$ (mmHg)	$Vp_{Evn.}$ (mmHg)	SS (hr)	Rainfall (mm)	Evop. (mm)	$CC_{Morn.}$ (okta)	$CC_{Evn.}$ (okta)	$S_{Temp.}$ (^0C)
	RSP 561	HD 2967	Agra Local	PBW 343															
1st	2.33	1.67	2.33	1.00	72.5	11.7	17.5	5.0	92.5	59.0	1.6	8.2	9.9	2.9	0.0	1.1	3.5	6.0	11.4
2nd	4.00	2.67	5.00	2.83	79.5	13.0	14.7	5.8	94.0	68.5	2.0	8.3	9.3	0.8	0.6	0.6	6.5	5.0	11.8
3rd	7.33	4.17	11.17	6.50	86.5	14.4	15.7	4.3	95.0	71.0	4.8	7.3	10.1	7.2	0.0	1.1	0.5	0.5	11.6
4th	14.17	6.67	15.83	10.83	93.5	16.0	16.0	7.9	91.5	75.0	1.6	9.3	11.0	0.0	5.0	0.7	3.0	5.0	13.3
5th	18.33	12.50	21.67	20.00	100.5	17.5	20.6	4.6	91.5	50.5	2.0	9.4	12.1	4.7	0.0	0.9	2.0	1.5	13.2
6th	28.33	20.83	32.50	26.67	107.5	18.0	19.4	10.2	82.0	64.0	3.3	11.0	12.5	3.8	0.0	1.5	6.5	3.0	13.7
7th	45.00	31.67	50.00	46.67	114.5	21.0	22.6	6.1	93.0	48.5	2.1	10.7	12.8	6.2	0.0	1.7	2.5	2.5	14.9
8th	55.00	45.00	56.67	63.33	121.5	16.0	24.1	8.8	96.0	57.0	1.2	14.5	16.5	6.9	0.0	1.6	4.5	1.5	15.7
9th	61.67	56.67	63.33	68.33	128.5	17.4	17.5	11.7	88.5	77.0	1.9	13.3	14.8	0.5	0.0	1.2	5.0	5.0	14.8
10th	70.00	68.33	70.00	71.67	135.5	18.2	21.5	9.3	89.5	54.0	3.0	12.4	12.3	5.9	14.6	1.0	2.0	2.5	15.1
11th	73.33	71.67	76.67	75.00	142.5	17.4	22.7	9.4	81.0	52.0	2.2	11.8	13.7	4.7	9.8	1.2	4.0	4.0	16.8
12th	78.33	78.34	80.00	81.67	149.5	21.7	27.5	11.7	87.0	46.5	2.1	15.5	15.5	6.8	0.0	2.8	2.0	0.5	19.9
13th	83.33	80.00	83.33	85.00	156.5	22.6	24.0	14.7	83.0	72.0	5.8	14.5	14.1	2.2	3.7	1.7	5.5	5.0	20.9
14th	86.67	81.67	90.00	86.67	163.5	25.7	27.0	12.1	82.0	47.5	5.4	8.8	15.0	9.8	18.7	2.4	1.0	0.0	20.8

C_{Temp} = Canopy temperature, T_{Max}= Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max.}$ = Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity, $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn.}$ =Evening vapour pressure, SS = Sunshine, Evop. = Evaporation, $CC_{Morn.}$= Morning cloud cover,
$CC_{Evn.}$= Evening cloud cover, $S_{Temp.}$ = Soil temperature

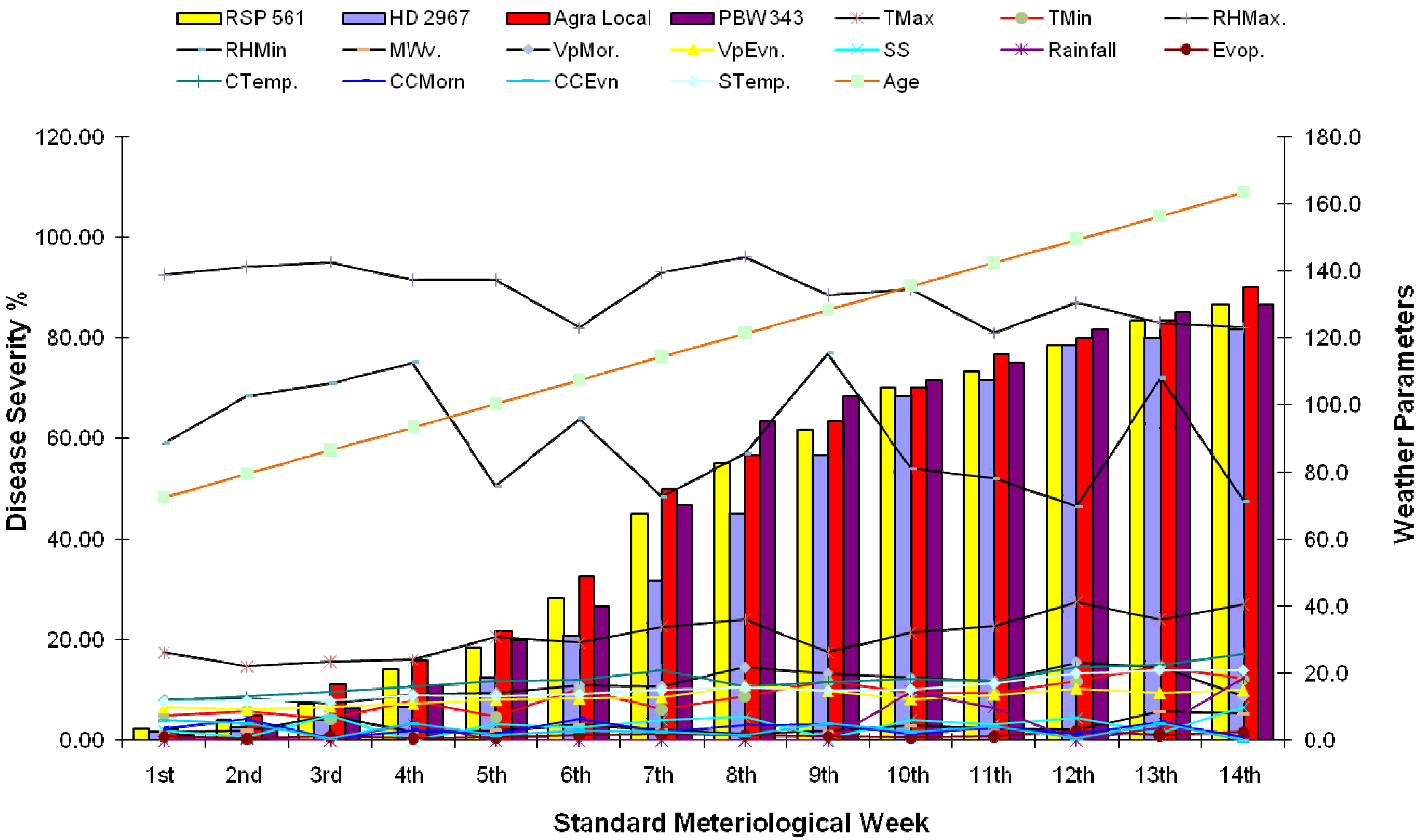


Figure 1: Effect of epidemiological factors on the severity of stripe rust of wheat under early sowing conditions

4.1.2 Effect of epidemiological factors on the severity of stripe rust of wheat under normal sowing conditions

Data in the Table 2 (Fig. 2) revealed that under normal sowing conditions, during both the rabi seasons of 2013-14 and 2014-15, disease appeared in first SMW in all the selected wheat varieties when the crop was at stem elongation stage (53 days after sowing). The corresponding weather factors during the period were maximum temperature of 17.5^{0}C, minimum temperature of 5^{0}C, maximum RH of 92.5 and minimum RH of 59 per cent, mean wind velocity of 1.6 km/h, vapour pressure (morning 8.2 and evening 9.9 mmHg), sunshine (2.9 h/day), evaporation (1.1 mm), cloud cover (morning 3.5 and evening 6.0 okta), soil temperature (11.4^{0}C) and canopy temperature (12.3^{0}C). At onset of the disease, the severity was more in Agra Local (1.83%), followed by RSP 561 and PBW 343 (0.33% each) and HD 2967 (0.17%). Thereafter, disease gradually progressed with age of the crops and increased sharply from 22.50 to 48.33 per cent in RSP 561, 25.83 to 46.67 per cent in HD 2967, 40.00 to 63.33 per cent in Agra Local and 35.00 to 53.33 per cent in PBW 343, during 6th to 8th SMW when the crops were at jointing to booting stage (88 to 102 DAS), having corresponding maximum temperature of 19.4 to 24.1^{0}C, minimum temperature of 10.2 to 8.8^{0}C, maximum RH of 82 to 96 per cent, minimum RH of 64 to 57 per cent, mean wind velocity of 3.3 to 1.2 km/h, vapour pressure (morning 11 to 14.5 mmHg and evening 12.5 to 16.5 mmHg), sunshine (3.8 to 6.9 h/day), evaporation (1.5 to 1.6 mm), cloud cover (morning 6.5 to 4.5 and evening 3.0 to 1.5 okta), soil temperature (13.7 to 15.7^{0}C) and canopy temperature (17.6 to 16.3^{0}C). At the maturity stage (143 DAS) in 14th SMW, maximum disease severity was recorded in Agra Local (86.67%) followed by PBW 343 and RSP 561 (83.33% each) and HD 2967 (73.33%) with maximum temperature of 27^{0}C and minimum of 12.1^{0}C, maximum RH of 82 and minimum of 47.5 per cent, mean wind velocity of 5.4 km/h, morning vapour pressure of 8.8 and evening of 15 mmHg, sunshine of 9.8 h/day, rainfall of 18.7 mm, evaporation of 2.4 mm, morning cloud cover of 1.0 okta, soil temperature of 20.8^{0}C and canopy temperature of 25.7^{0}C.

Table 2: Effect of epidemiological factors on the severity of stripe rust of wheat under normal sowing conditions

SMW	Wheat varieties				Age (days)	$C_{Temp.}$ (⁰C)	$T_{Max.}$ (⁰C)	$T_{Min.}$ (⁰C)	$RH_{Max.}$ (%)	$RH_{Min.}$ (%)	$M_{Wv.}$ (km/hr)	$Vp_{Mor.}$ (mmHg)	$Vp_{Evn.}$ (mmHg)	SS (hr)	Rainfall (mm)	Evop. (mm)	$CC_{Morn.}$ (okta)	$CC_{Evn.}$ (okta)	$S_{Temp.}$ (⁰C)
	RSP 561	HD 2967	Agra Local	PBW 343															
1st	0.33	0.17	1.83	0.33	52.5	12.3	17.5	5.0	92.5	59.0	1.6	8.2	9.9	2.9	0.0	1.1	3.5	6.0	11.4
2nd	3.00	2.33	3.83	3.00	59.5	13.9	14.7	5.8	94.0	68.5	2.0	8.3	9.3	0.8	0.6	0.6	6.5	5.0	11.8
3rd	4.17	5.33	6.50	5.83	66.5	14.9	15.7	4.3	95.0	71.0	4.8	7.3	10.1	7.2	0.0	1.1	0.5	0.5	11.6
4th	6.33	10.83	13.33	10.83	73.5	15.4	16.0	7.9	91.5	75.0	1.6	9.3	11.0	0.0	5.0	0.7	3.0	5.0	13.3
5th	12.50	17.50	24.17	25.00	80.5	18.1	20.6	4.6	91.5	50.5	2.0	9.4	12.1	4.7	0.0	0.9	2.0	1.5	13.2
6th	22.50	25.83	40.00	35.00	87.5	17.6	19.4	10.2	82.0	64.0	3.3	11.0	12.5	3.8	0.0	1.5	6.5	3.0	13.7
7th	35.00	36.67	53.33	46.67	94.5	20.3	22.6	6.1	93.0	48.5	2.1	10.7	12.8	6.2	0.0	1.7	2.5	2.5	14.9
8th	48.33	46.67	63.33	53.33	101.5	16.3	24.1	8.8	96.0	57.0	1.2	14.5	16.5	6.9	0.0	1.6	4.5	1.5	15.7
9th	55.00	53.33	68.33	61.67	108.5	17.7	17.5	11.7	88.5	77.0	1.9	13.3	14.8	0.5	0.0	1.2	5.0	5.0	14.8
10th	68.33	56.67	73.33	66.67	115.5	18.2	21.5	9.3	89.5	54.0	3.0	12.4	12.3	5.9	14.6	1.0	2.0	2.5	15.1
11th	75.00	61.67	76.67	71.67	122.5	17.3	22.7	9.4	81.0	52.0	2.2	11.8	13.7	4.7	9.8	1.2	4.0	4.0	16.8
12th	78.33	63.33	78.33	75.00	129.5	21.6	27.5	11.7	87.0	46.5	2.1	15.5	15.5	6.8	0.0	2.8	2.0	0.5	19.9
13th	81.67	68.33	83.33	81.67	136.5	22.3	24.0	14.7	83.0	72.0	5.8	14.5	14.1	2.2	3.7	1.7	5.5	5.0	20.9
14th	83.33	73.33	86.67	83.33	143.5	25.7	27.0	12.1	82.0	47.5	5.4	8.8	15.0	9.8	18.7	2.4	1.0	0.0	20.8

C_{Temp} = Canopy temperature, T_{Max}= Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max..}$= Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity,. $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn..}$=Evening vapour pressure, SS = Sunshine, Evop. = Evaporation, $CC_{Morn.}$= Morning cloud cover, $CC_{Evn.}$= Evening cloud cover, $S_{Temp.}$ = Soil temperature

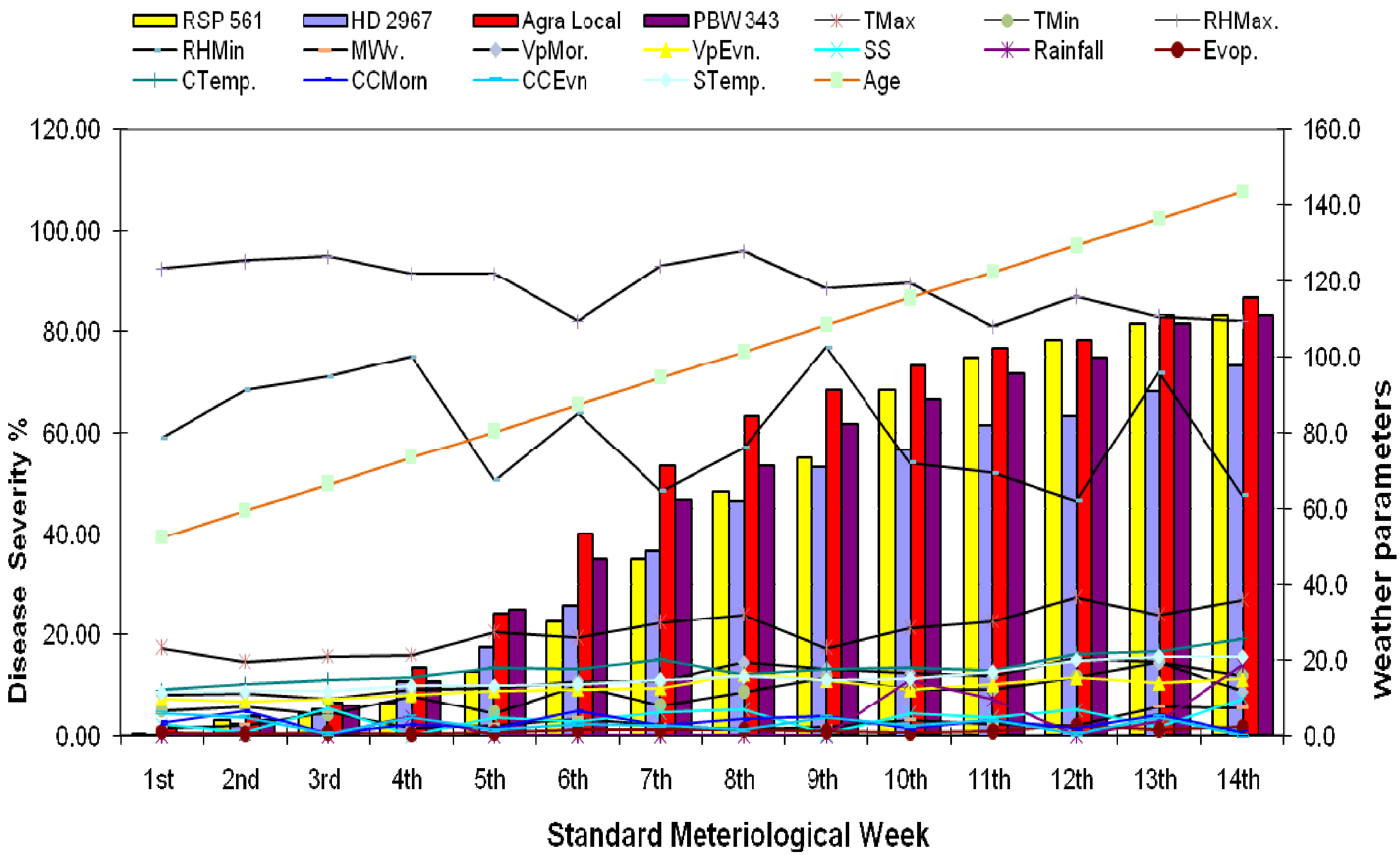


Figure 2: Effect of epidemiological factors on the severity of stripe rust of wheat under normal sowing conditions

4.1.3 Effect of epidemiological factors on the severity of stripe rust of wheat under late sowing conditions

The data in Table 3 (Fig. 3) indicate that under late sowing conditions, during both the rabi seasons of 2013-14 and 2014-15, disease initiated in first SMW when the crop was at tillering stage (29 DAS) with maximum disease severity in PBW 343 (0.67%) followed by Agra Local (0.58%) and RSP 561 (0.17%). The corresponding weather factors during the period were maximum temperature of 17.5^{0}C and minimum temperature of 5^{0}C, maximum RH of 92.5 and minimum RH of 59 per cent, mean wind velocity of 1.6 km/h, morning vapour pressure of 8.2 mmHg, evening vapour pressure of 9.9 mmHg, sunshine of 2.9 h/day, evaporation of 1.1 mm, morning cloud cover of 3.5 okta and evening cloud cover of 6.0 okta, soil temperature of 11.4^{0}C and canopy temperature of 12.9^{0}C. Whereas, in HD 2967, the disease appeared in 2nd SMW with 2.17 per cent severity, when crop was at late tillering stage (36 DAS). The corresponding weather factors during the period were maximum temperature of 14.7^{0}C, minimum temperature of 5.8^{0}C, maximum RH of 94.0, minimum RH of 68.5 per cent, mean wind velocity of 2.0 km/h, morning vapour pressure of 8.3 and evening vapour pressure of 9.3 mmHg, sunshine of 0.8 h/day, rainfall of 0.6 mm, evaporation of 0.6 mm, morning cloud cover of 6.5, evening cloud cover of 5.0 okta, soil temperature of 11.8^{0}C and canopy temperature of 14.0^{0}C. The disease gradually progressed with age of the crops and increased sharply from 21.67 to 41.67 per cent in RSP 561, 15.00 to 35.00 per cent in HD 2967, 27.50 to 45.00 per cent in Agra Local and 35.00 to 43.33 per cent in PBW 343, during 6th to 8th SMW when the crops were at stem elongation to jointing stage (64 to 78 DAS) with corresponding maximum temperature of 19.4 to 24.1^{0}C, minimum temperature of 10.2 to 8.8^{0}C, maximum RH of 82 to 96 per cent, minimum RH of 64 to 57 per cent, mean wind velocity of 3.3 to 1.2 km/h, morning vapour pressure of 11 to 14.5 mmHg, evening vapour pressure 12.5 to 16.5 mmHg, sunshine of 3.8 to 6.9 h/day, evaporation of 1.5 to 1.6 mm, morning cloud cover of 6.5 to 4.5 and evening cloud cover 3.0 to 1.5 okta, soil temperature of 13.7 to 15.7^{0}C and canopy temperature of 18.4 to 16.0^{0}C. At the milk development stage (120 DAS) in 14th SMW, maximum disease severity was recorded in Agra Local (73.50%) followed by PBW 343 (73.33%), RSP 561 (71.67%) and HD 2967 (61.67%) with maximum temperature of 27^{0}C and minimum of 12.1^{0}C, maximum RH of 82 per cent, minimum RH of 47.5 per cent, mean wind velocity of 5.4 km/h, morning vapour pressure of 8.8 mmHg, evening vapour pressure of 15 mmHg, sunshine of 9.8 h/day, rainfall of 18.7 mm, evaporation of 2.4 mm, morning cloud cover of 1.0 okta, soil temperature of 20.8^{0}C and canopy temperature of 25.7^{0}C.

Table 3: Effect of epidemiological factors on the severity of stripe rust of wheat under late sowing conditions

SMW	Wheat varieties				Age (days)	$C_{Temp.}$ (^0C)	$T_{Max.}$ (^0C)	$T_{Min.}$ (^0C)	$RH_{Max.}$ (%)	$RH_{Min.}$ (%)	$M_{Wv.}$ (km/hr)	$Vp_{Mor.}$ (mmHg)	$Vp_{Evn.}$ (mmHg)	SS (hr)	Rainfall (mm)	Evop. (mm)	$CC_{Morn.}$ (okta)	$CC_{Evn.}$ (okta)	$S_{Temp.}$ (^0C)
	RSP 561	HD 2967	Agra Local	PBW 343															
1st	0.17	0.00	0.58	0.67	29.0	12.9	17.5	5.0	92.5	59.0	1.6	8.2	9.9	2.9	0.0	1.1	3.5	6.0	11.4
2nd	2.33	2.17	3.17	3.17	36.0	14.0	14.7	5.8	94.0	68.5	2.0	8.3	9.3	0.8	0.6	0.6	6.5	5.0	11.8
3rd	4.67	3.83	5.50	7.50	43.0	15.0	15.7	4.3	95.0	71.0	4.8	7.3	10.1	7.2	0.0	1.1	0.5	0.5	11.6
4th	8.17	6.50	11.67	10.83	50.0	14.9	16.0	7.9	91.5	75.0	1.6	9.3	11.0	0.0	5.0	0.7	3.0	5.0	13.3
5th	13.33	10.00	17.50	24.17	57.0	17.5	20.6	4.6	91.5	50.5	2.0	9.4	12.1	4.7	0.0	0.9	2.0	1.5	13.2
6th	21.67	15.00	27.50	35.00	64.0	18.4	19.4	10.2	82.0	64.0	3.3	11.0	12.5	3.8	0.0	1.5	6.5	3.0	13.7
7th	28.33	25.00	38.33	40.00	71.0	20.3	22.6	6.1	93.0	48.5	2.1	10.7	12.8	6.2	0.0	1.7	2.5	2.5	14.9
8th	41.67	35.00	45.00	43.33	78.0	16.0	24.1	8.8	96.0	57.0	1.2	14.5	16.5	6.9	0.0	1.6	4.5	1.5	15.7
9th	46.67	40.00	50.00	50.00	85.0	18.0	17.5	11.7	88.5	77.0	1.9	13.3	14.8	0.5	0.0	1.2	5.0	5.0	14.8
10th	53.33	43.33	55.00	55.00	92.0	18.1	21.5	9.3	89.5	54.0	3.0	12.4	12.3	5.9	14.6	1.0	2.0	2.5	15.1
11th	56.67	48.33	60.00	60.00	99.0	17.2	22.7	9.4	81.0	52.0	2.2	11.8	13.7	4.7	9.8	1.2	4.0	4.0	16.8
12th	60.00	53.33	63.33	65.00	106.0	22.2	27.5	11.7	87.0	46.5	2.1	15.5	15.5	6.8	0.0	2.8	2.0	0.5	19.9
13th	61.67	56.67	66.67	70.00	113.0	23.4	24.0	14.7	83.0	72.0	5.8	14.5	14.1	2.2	3.7	1.7	5.5	5.0	20.9
14th	71.67	61.67	73.50	73.33	120.0	25.7	27.0	12.1	82.0	47.5	5.4	8.8	15.0	9.8	18.7	2.4	1.0	0.0	20.8

C_{Temp} = Canopy temperature, T_{Max}= Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max..}$= Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity,. $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn..}$=Evening vapour pressure, SS = Sunshine, Evop. = Evaporation, $CC_{Morn.}$= Morning cloud cover, $CC_{Evn.}$= Evening cloud cover, $S_{Temp.}$ = Soil temperature

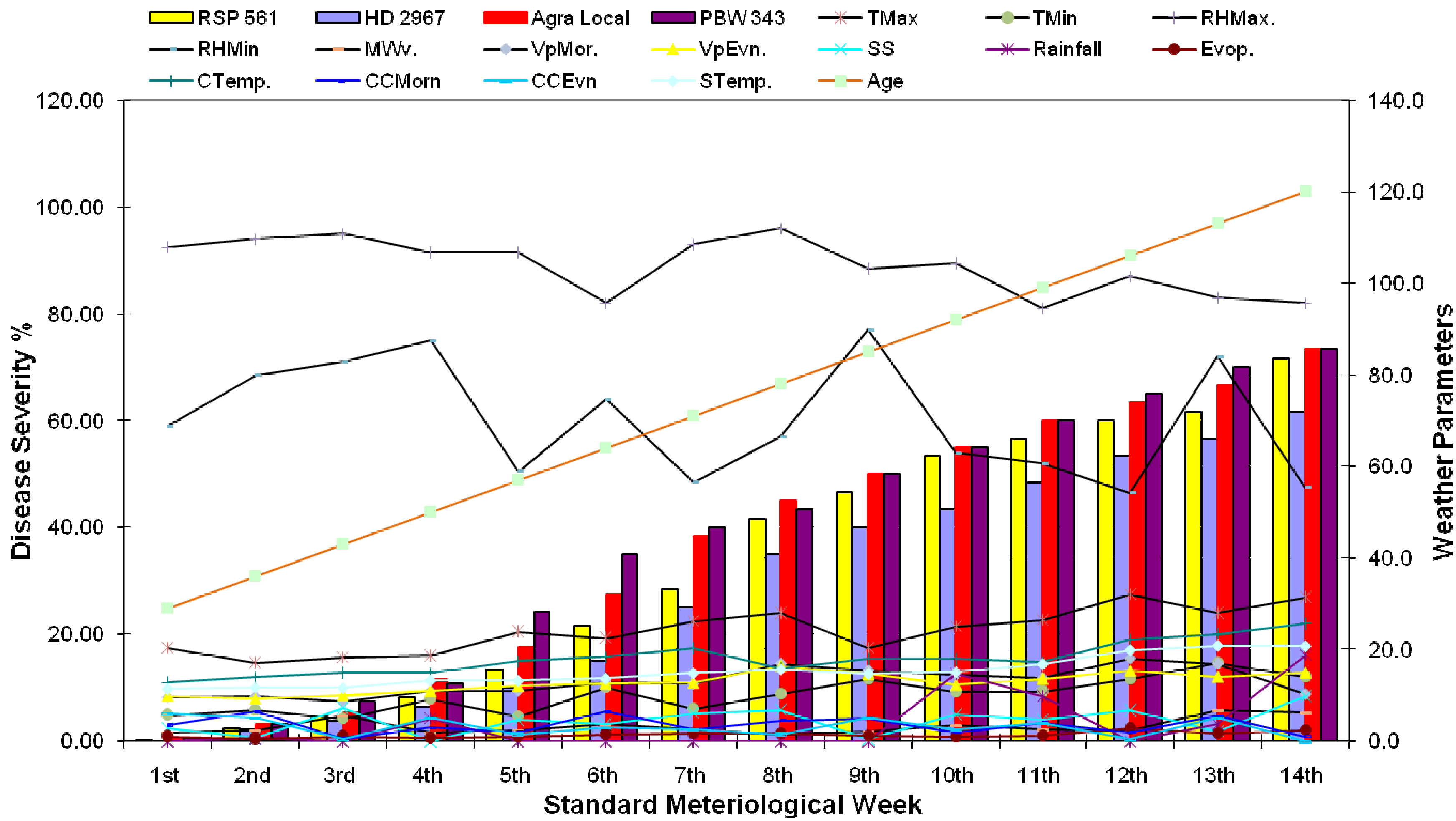


Figure 3: Effect of epidemiological factors on the severity of stripe rust of wheat under late sowing conditions

4.2 Correlation of epidemiological factors with the severity of stripe rust of wheat

Correlation analysis of various epidemiological factors with the severity of stripe rust in four varieties of wheat (RSP 561, HD 2967, Agra Local and PBW 343), during the rabi seasons of 2013-14 and 2014-15 under three different sowing conditions were conducted to analyze whether there was any significant association among them. Perusal of the data presented in Table 4 indicate that under early sowing conditions, in RSP-561, temperature (maximum and minimum), vapour pressure (morning and evening), evaporation, canopy temperature, soil temperature and age of the crop had significantly positive correlation with the disease severity having correlation co-efficient (R) values of 0.833, 0.840, 0.723, 0.838, 0.683, 0.805, 0.916 and 0.986, respectively, followed by rainfall (R=0.546) which was positively but moderately correlated. Whereas, maximum RH (R=-0.630) was significantly, but had negative correlation with the disease severity. Temperature (maximum and minimum), vapour pressure (morning and evening), canopy temperature, evaporation, soil temperature and age had significantly positive correlation with the disease severity in case of HD 2967 having 'R' of 0.813, 0.841, 0.709, 0.798, 0.770, 0.688, 0.912 and 0.979, in Agra Local having 0.840, 0.830, 0.710, 0.844, 0.820, 0.695, 0.915, and 0.989 and in PBW 343 having 0.830, 0.828, 0.754, 0.867, 0.779, 0.678, 0.899 and 0.976, respectively, whereas, maximum relative humidity had significantly negative correlation with severity, having correlation coefficient values of -0.648, -0.637 and -0.586, respectively, followed by rainfall having 'R' of 0.562, 0.543 and 0.502, respectively, which had positive moderate correlation. Table 4 further indicate that under normal sowing conditions, in RSP-561, temperature (maximum and minimum), vapour pressure (morning and evening), evaporation, canopy temperature, soil temperature and age of the crop had significantly positive correlation with the disease severity, having correlation co-efficient (R) of 0.825, 0.835, 0.710, 0.806, 0.673, 0.783 0.916 and 0.981, respectively, followed by rainfall (R=0.561) which was positively but moderately correlated, whereas, maximum RH (R=-0.649) too had significant, but negative correlation with the disease severity. The temperature (maximum and minimum), vapour pressure (morning and evening), canopy temperature, evaporation, soil temperature and age of the crop had significantly positive correlation with the disease severity with 'R' value of 0.831, 0.842, 0.719, 0.853, 0.679, 0.811, 0.911, and 0.988 in HD 2967, in case of Agra Local 0.833, 0.829, 0.749, 0.869, 0.677, 0.797, 0.884, and 0.974, whereas, in PBW 343 having 'R' of 0.841, 0.838, 0.730, 0.852, 0.685, 0.824, 0.908, and 0.987, respectively, whereas, maximum RH had significantly negative correlation with disease severity, having correlation coefficient values

Table 4: Correlation of epidemiological factors with the severity of stripe rust of wheat

Epidemiological factor	Disease Severity (%)											
	Early sowing conditions				Normal sowing conditions				Late sowing conditions			
	Wheat varieties				Wheat varieties				Wheat varieties			
	RSP 561	HD 2967	Agra Local	PBW 343	RSP 561	HD 2967	Agra Local	PBW 343	RSP 561	HD 2967	Agra Local	PBW 343
$T_{Max.}$ (^{0}C)	**0.833**	**0.813**	**0.840**	**0.830**	**0.825**	**0.831**	**0.833**	**0.841**	**0.833**	**0.834**	**0.846**	**0.854**
$T_{Min.}$ (^{0}C)	**0.840**	**0.841**	**0.830**	**0.828**	**0.835**	**0.842**	**0.829**	**0.838**	**0.842**	**0.847**	**0.841**	**0.844**
$RH_{Max.}$ (%)	**-0.630**	**-0.648**	**-0.637**	**-0.586**	**-0.649**	**-0.643**	**-0.626**	**-0.655**	**-0.651**	**-0.639**	**-0.654**	**-0.690**
$RH_{Min.}$ (%)	-0.365	-0.354	-0.382	-0.361	-0.370	-0.362	-0.379	-0.381	-0.373	-0.356	-0.385	-0.394
$M_{Wvv.}$ (km/hr)	0.354	0.368	0.360	0.312	0.368	0.352	0.309	0.353	0.375	0.388	0.362	0.392
$Vp_{Morn.}$ (mmHg)	**0.723**	**0.709**	**0.710**	**0.754**	**0.710**	**0.719**	**0.749**	**0.730**	**0.690**	**0.695**	**0.708**	**0.708**
$Vp_{Evn.}$ (mmHg)	**0.838**	**0.798**	**0.844**	**0.867**	**0.806**	**0.853**	**0.869**	**0.852**	**0.836**	**0.830**	**0.850**	**0.845**
SS (hr)	0.398	0.379	0.421	0.396	0.395	0.398	0.400	0.399	0.422	0.406	0.416	0.420
Rainfall (mm)	**0.546**	**0.562**	**0.543**	**0.502**	**0.561**	**0.542**	**0.501**	**0.514**	**0.582**	**0.558**	**0.547**	**0.517**
Evop. (mm)	**0.683**	**0.668**	**0.695**	**0.678**	**0.673**	**0.679**	**0.677**	**0.685**	**0.687**	**0.698**	**0.700**	**0.710**
$C_{Temp.}$ (^{0}C)	**0.805**	**0.770**	**0.820**	**0.779**	**0.783**	**0.811**	**0.797**	**0.824**	**0.809**	**0.819**	**0.831**	**0.858**
$CC_{Morn.}$ (okta)	-0.089	-0.092	-0.102	-0.075	-0.084	-0.076	-0.041	-0.061	-0.100	-0.099	-0.084	-0.071
$CC_{Evn.}$ (okta)	-0.285	-0.261	-0.312	-0.290	-0.271	-0.293	-0.294	-0.299	-0.312	-0.294	-0.310	-0.331
$S_{Temp.}$ (^{0}C)	**0.916**	**0.912**	**0.915**	**0.899**	**0.916**	**0.911**	**0.884**	**0.908**	**0.917**	**0.934**	**0.920**	**0.921**
Age (days)	**0.986**	**0.979**	**0.989**	**0.976**	**0.981**	**0.988**	**0.974**	**0.987**	**0.988**	**0.988**	**0.991**	**0.991**

Values in bold are highly significant at (p=0.05)

C_{Temp} = Canopy temperature, T_{Max}= Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max..}$= Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity,. $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn..}$=Evening vapour pressure, SS = Sunshine, Evop. = Evaporation, $CC_{Morn.}$= Morning cloud cover, $CC_{Evn.}$= Evening cloud cover, $S_{Temp.}$ = Soil temperature

of -0.643, -0.626 and -0.655, respectively, followed by rainfall having R of 0.542, 0.501 and 0.514, respectively, which had positively moderate correlation. Under late sowing conditions, temperature (maximum and minimum), vapour pressure (morning and evening), evaporation, canopy temperature, soil temperature and age of the crop had significantly positive correlation with the disease severity in RSP-561, having correlation co-efficient (R) of 0.833, 0.842, 0.690, 0.836, 0.687, 0.809, 0.917 and 0.988, respectively, followed by maximum relative humidity (R=-0.651) which too was significantly, but negative correlation with the disease severity, whereas, rainfall (R=0.582) had positively moderately correlated. In case of HD 2967, temperature (maximum and minimum), vapour pressure (morning and evening), canopy temperature, evaporation, soil temperature and age had significant positive correlation with the disease severity having 'R' of 0.834, 0.847, 0.695, 0.830, 0.698, 0.819, 0.934, and 0.988, in Agra Local with 'R' of 0.846, 0.841, 0.708, 0.850, 0.700, 0.831, 0.920, and 0.991 followed by PBW 343 with 'R' of 0.854, 0.844, 0.708, 0.845, 0.710, 0.858, 0.921, and 0.991, respectively, whereas, maximum relative humidity had significantly negative correlation with the disease severity having correlation coefficient values of -0.639, -0.654 and -0.690, respectively, followed by rainfall, which had positively moderate correlation having 'R' of 0.558, 0.547 and 0.517, respectively.

4.3.1 Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under early sowing conditions

Stepwise multiple regression analysis were conducted with an aim to identify most significant variable for the prediction of stripe rust severity of wheat in four wheat varieties (RSP 561, HD 2967, Agra Local and PBW 343), out of the epidemiological factors that had significant effect on disease severity data collected during rabi seasons of 2013-14 and 2014-15. From the data presented in the Table 5, it has been depicted that under the early sowing conditions, in RSP 561, step 1 and 2 were highly significant having $F(1, 12) = 29$ and $F(2, 11) = 39$ at $p<0.01$, in predicting disease severity of stripe rust. The step 1 of stepwise regression showed that among different explanatory variables, minimum temperature was highly significant in causing 70.50 per cent variation in the observed severity of stripe rust in RSP 561. Step equation (1) revealed that 8.25 per cent increase/decrease in severity per week by per unit (^{o}C) increase/decrease in minimum temperature, if all the other predictors remained constant with 95 per cent CI from 4.89 to 11.61 per cent, having incremental increase in disease severity to be in the range of 4.89 to 11.61 per cent per week. After adding maximum temperature in the step 2,

Table 5: Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under early sowing conditions

Variety	Step	Stepwise Regression Equation	R^2	F value	95% C I Lower-upper	Tolerance	VIF
RSP 561	1	$Y_1 = -26.85 + 8.25 X_2$	.705	28.7	X_2=4.89-11.61	1.000	1.000
	2	$Y_1 = -82.57 + 3.94X_1 + 5.23 X_2$	.877	39.1	X_2=2.38 - 8.08 X_1=1.72-6.16	.646 .646	1.549 1.549
HD 2967	1	$Y_2 = -32.69 + 8.38 X_2$	.707	28.9	X_2=4.98-11.78	1.000	1.000
	2	$Y_2 = -85.69 + 3.75 X_1 + 5.51X_2$	.858	33.1	X_2=2.40-8.62 X_1=1.33-6.17	.646 .646	1.549 1.549
Agra Local	1	$Y_3 = -105.72 + 11.90 X_6$	.841	28.9	X_6=7.08-16.73	1.000	1.000
	2	$Y_3 = -99.29 + 10.82 X_6 + 2.00 X_5$	.926	32.9	X_6=7.20-14.44 X_5=.705-3.29	.962 .962	1.039 1.039
	3	$Y_3 = -92.50 + 6.06 X_6 + 2.46 X_5 + 4.73 X_3$	.953	32.7	X_6=.59-11.54 X_5=1.27-3.65 X_3=.23-9.24	.306 .832 .317	3.264 1.202 3.154
	4	$Y_3 = -102.44 + 3.13 X_6 + 1.90 X_5 + 5.06 X_3 + 2.57 X_4$	.974	41.8	X_6 =-1.86-8.14 X_5=.84-2.96 X_3=1.46-8.66 X_4 =.41-4.72	.233 .669 .315 .425	4.300 1.494 3.172 2.351
PBW 343	1	$Y_4 = -120.16 + 12.96 X_6$	.747	35.3	X_6=8.21-17.71	1.000	1.000
	2	$Y_4 = -114.16 + 11.95 X_6 + 1.86 X_5$	.863	34.6	X_6=8.19-15.71 X_5=3.21-.52	.962 .962	1.039 1.039
	3	$Y_4 = -106.12 + 6.32 X_6 + 5.61 X_3 + 2.41 X_5$	.926	41.9	X_6=1.13-11.50 X_3=1.28-3.54 X_5=1.34-9.88	.306 .832 .317	3.264 1.202 3.154

Y_1 = Disease severity of RSP-561, Y_2 = Disease severity of HD-2967, Y_3 = Disease severity of Agra Local, Y4 = Disease severity of PBW-343

T_{Max}.= (X_1), $T_{Min.}$= (X_2), $Vp_{Morn.}$= (X_3), C_{Tmp}.= (X_4), Rainfall= (X_5), Vp_{Even} = (X_6)

per cent variation further increased by 17.20 per cent i.e. 87.70 per cent in response variable by the cumulative effect of minimum and maximum temperatures. Step equation (2) predicted increase/decrease in disease severity by 5.23 per cent per week by per unit increase/decrease in minimum temperature, if all the other predictors remained constant having 95 per cent CI from 2.38 to 8.08 per cent, whereas, 3.94 per cent increase/decrease was predicted per week by per unit increase/decrease in maximum temperature if all the other predictors remained constant (95% CI from 1.72 to 6.16%). The contribution of minimum and maximum temperatures (step 2) in the predicted equation was 57 and 43 per cent, respectively. Further, the data in the Table 5 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least multicollinearity (inter correlated) effect. Observed versus prediction plotting of disease severity values (Fig. 4A) showed good association (R^2=87.60%). In case of HD 2967, the Table 5 depicted that step 1 and 2 were highly significant having $F(1, 12) = 29$ and $F(2, 11) = 33$ at $p<0.01$ in predicting stripe rust severity of stripe rust. The stepwise regression showed that in the step 1, among the different explanatory variables, minimum temperature was highly significant describing 70.70 per cent variation in the observed stripe rust severity. Step equation (1) developed for predicting disease severity revealed that 8.38 per cent increase/decrease in disease severity per week by per unit (^oC) increase/decrease in minimum temperature, if all the other predictors remained constant with 95 per cent CI from 4.98 to 11.78 per cent. After adding maximum temperature in the step 2, per cent variation further increased by 15.10 per cent i.e. 85.80 per cent by the cumulative effect of minimum and maximum temperatures. Step equation (2) predicted increase in disease severity by 5.51 per cent per week by per unit increase/decrease in minimum temperature, if all the other factors remained constant having 95 per cent CI from 2.40 to 8.62 per cent, whereas, 3.75 per cent increase/decrease in severity was predicted per week by per unit increase in maximum temperature if all the other predictors remained constant (95% CI from 1.33 to 6.17%). The contribution of minimum and maximum temperatures (step 2) in the predicted equation was 59.50 and 40.50 per cent, respectively. Further, the data in the Table 5 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 4B) of disease severity values showed good association (R^2= 85.70%). In Agra Local, under early sowing conditions, step 1, 2, 3 and 4 were highly significant having $F(1, 12) = 29$, $F(2, 11) = 33$, $F(3, 10) = 33$ and $F(4, 9) = 42$ at $p<0.01$, in predicting disease severity of stripe rust. The step wise regression in the step 1, showed that evening vapour pressure was highly significant

Plate 1: View of experimental plot laid at the University Research Farm, Chatha

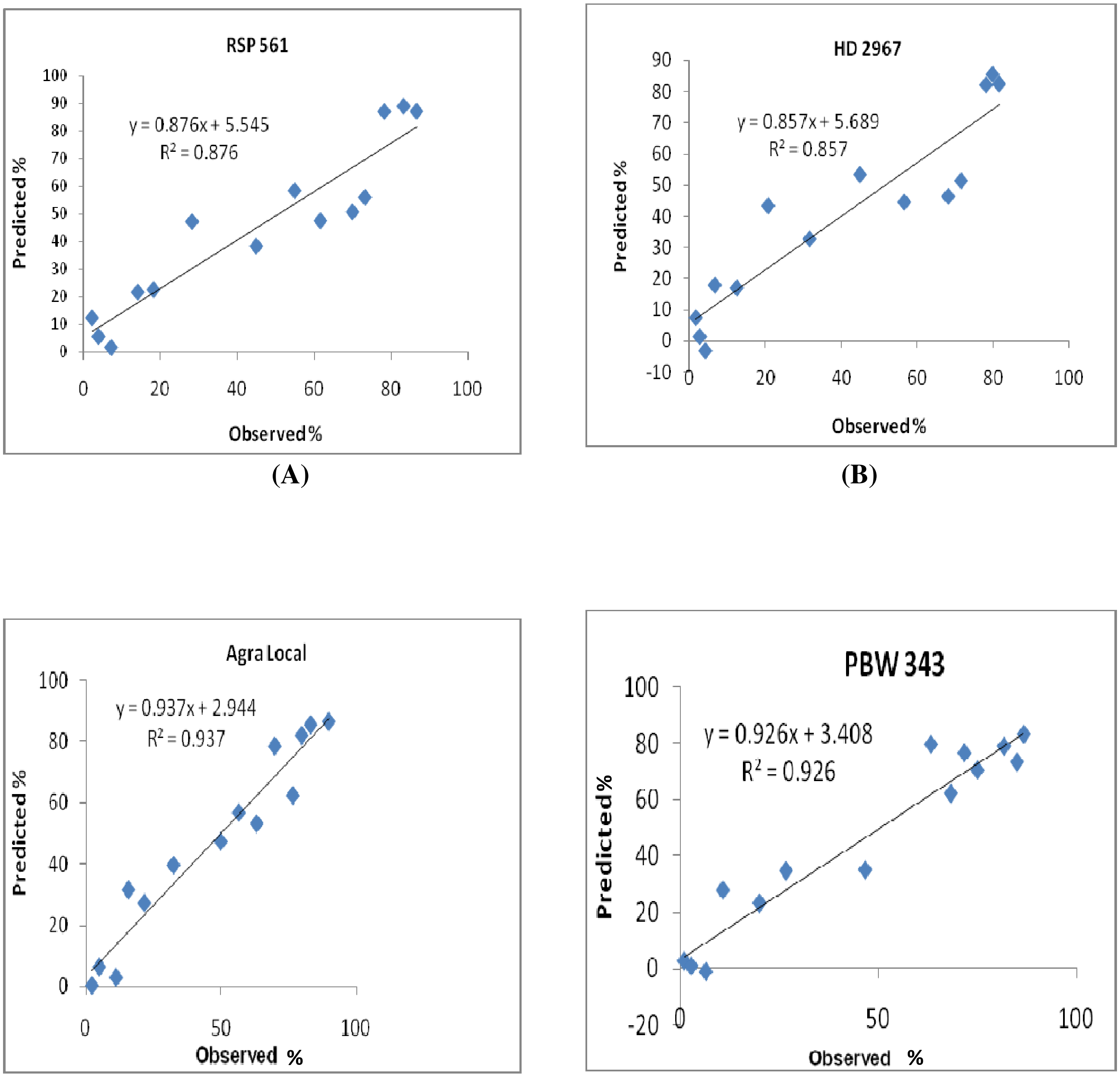
Plate 2: Ssymptoms of stripe rust of wheat

causing 84.10 per cent variation in the observed disease severity of stripe rust in Agra Local. Stepwise equation (1) revealed that 11.90 per cent increase/decrease in disease severity per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 7.08 to 16.73 per cent. Addition of rainfall in the step 2, per cent variation further increased by 8.50 per cent i.e. 92.60 per cent variation in response variable explained by the cumulative effect of evening vapour pressure and rainfall. Step equation (2) predicted increase/decrease in severity by 10.82 per cent per week by per unit increase/decrease in evening vapour pressure, if all the other predictors remained constant having 95 per cent CI from 7.20 to 14.44 per cent, whereas, 2.00 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in rainfall if all the other predictors remained constant (95% CI from 0.70 to 3.29%). The contribution of evening vapour pressure and rainfall (step 2) in the predicted equation was 84 and 16 per cent, respectively. In step 3, after adding morning vapour pressure, variation further increased by 2.71 per cent i.e. 95.30 per cent variation. Stepwise equation (3) predicted increase/decrease in disease severity by 4.73 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 0.23 to 9.24 per cent, whereas, 2.46 and 6.06 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 1.27 to 3.65 and 0.59 to 11.54%, respectively). The contribution of evening vapour pressure, rainfall and morning vapour pressure (step 3) was 36, 18 and 46 per cent, respectively. In step 4, after adding canopy temperature, variation further increased by 2.10 per cent i.e. 97.40 per cent. Step equation (4) predicted increase/decrease in disease severity by 2.57 per cent per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant having 95 per cent CI from 0.41 to 4.72 per cent, whereas, 5.06, 1.90 and 3.13 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in morning vapour pressure, rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 1.46 to 8.66, 0.84 o 2.96 and -1.86 to 8.14%, respectively). The contribution of evening vapour pressure, rainfall, morning vapour pressure and canopy temperature (step 4) in the predicted equation was 20, 15, 40 and 25 per cent, respectively. Further, the data in the Table 5 also revealed that the lower tolerance (<1) and VIF (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 4C) of disease severity values showed good association (R^2=93.70%). Further in PBW 343, the step

1, 2 and 3 were highly significant having F (1, 12) = 35, F (2, 11) = 35 and F (3, 10) = 42 at $p<0.01$, in predicting severity of stripe rust. The stepwise regression showed that in the step 1, among the different explanatory variables, evening vapour pressure was highly significant in describing 74.70 per cent variation in the observed disease severity of stripe rust in PBW 343. Stepwise equation (1) developed for predicting disease severity revealed that 12.96 per cent increase/decrease in disease severity per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 8.21 to 17.71 per cent. After adding rainfall in the step 2, per cent variation further increased by 11.6 per cent i.e. 86.30 per cent variation was in response variable explained by the cumulative effect of evening vapour pressure and rainfall. Stepwise equation (2) predicted increase/decrease in severity by 1.86 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 3.21 to 0.52 per cent, whereas, 11.95 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in evening vapour pressure if all the other predictors remained constant (95% CI from 8.19 to 15.71%). The contribution of evening vapour pressure and rainfall (step 2) in the predicted equation was 86 and 44 per cent, respectively. In step 3, after adding morning vapour pressure, variation further increased by 6.3 per cent i.e. 92.60 per cent variation. Stepwise equation (3) predicted increase/decrease in disease severity by 2.41 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 1.34 to 9.88 per cent, whereas, 5.61 and 6.32 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in morning vapour pressure and, if all the other predictors remained constant (95% CI from 1.28 to 3.54 and 1.13 to 11.50%, respectively). The contribution of evening vapour pressure, morning vapour pressure and rainfall (step 3) in the predicted equation was 44, 39 and 17 per cent, respectively. The lower tolerance (<1) and VIF (<10) showed the least multicollinearity (inter correlated) effect. Observed versus prediction plotting (Fig. 4D) of disease severity values in PBW 343 showed good association (R^2=92.60%).

4.3.2 Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under normal sowing conditions

The data presented in the Table 6 depicted that under the normal sowing conditions, in RSP 561, the step 1 and 2 were highly significant having F (1, 12) = 28 and F (2, 11) = 35 at $p<0.01$, in predicting severity of stripe rust. The stepwise regression showed in step 1, that among different explanatory variables, minimum temperature was highly significant in causing



(A) (B)

(C) (D)

Figure 4: Comparison between observed and predicted values of the severity of stripe rust of wheat under early sowing conditions

69.70 per cent variation in the observed disease severity of stripe rust in RSP 561. Stepwise equation (1) revealed that 8.47 per cent increase/decrease in severity per week by per unit (^{o}C) increase/decrease in minimum temperature, if all the other predictors remained constant with 95 per cent CI from 4.95 to 11.98 per cent. After addition of maximum temperature in the step 2, per cent variation further increased by 16.60 per cent i.e. 86.30 per cent in response variable explained by the cumulative effect of minimum and maximum temperatures. Step equation (2) predicted increase/decrease in disease severity by 5.40 per cent per week by per unit increase/decrease in minimum temperature, if all the other predictors remained constant having 95 per cent CI from 1.60 to 6.42 per cent, whereas, 4.01 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in maximum temperature if all the other predictors remained constant (95% CI from 2.30 to 8.49%). The contribution of minimum temperature and maximum temperature (step 2) in the predicted equation was 57 and 43 per cent, respectively. Further, the data in the Table 6 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 5A) of disease severity values showed good association (R^2=81.00%). The Table 6 further exhibited that, in HD 2967, the step 1, 2, 3 and 4 were highly significant having $F (1, 12) = 31$, $F (2, 11) = 37$, $F (3, 10) = 39$ and $F (4, 9) = 49$ at $p<0.01$, in predicting severity of stripe rust. The step wise regression showed in the step 1, that among different explanatory variables, evening vapour pressure was highly significant in describing 72.20 per cent variation in the observed severity of stripe rust in HD 2967. Step equation (1) developed for predicting disease severity revealed that 10.10 per cent increase/decrease in disease severity per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 6.16 to 14.05, per cent. After adding rainfall in the step 2, per cent variation further increased by 14.80 per cent i.e. 87.00 per cent in response variable explained by the cumulative effect of evening vapour pressure and rainfall. Step equation (2) predicted increase/decrease in severity by 1.66 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 0.62 to 2.70 per cent, whereas, 9.20 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in evening vapour pressure if all the other predictors remained constant (95% CI from 6.29 to 12.10%). The contribution of evening vapour pressure and rainfall (step 2) in the predicted equation was 85 and 15 per cent, respectively. In step 3, after adding morning vapour pressure, variation further increased by 5.1 per cent

Table 6: Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under normal sowing conditions

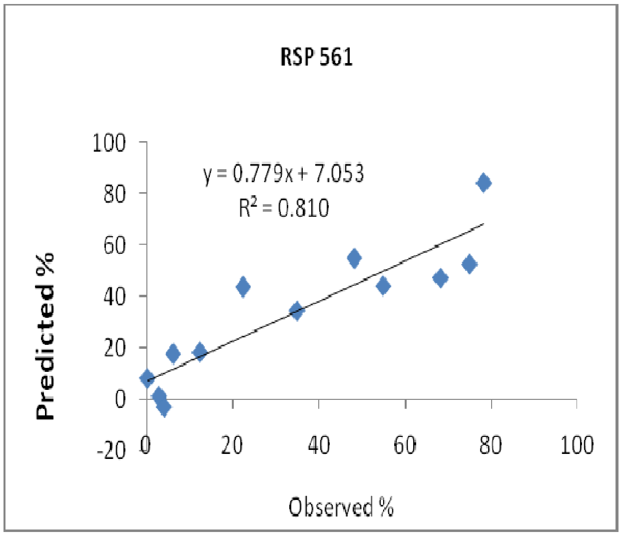
Variety	Steps	Stepwise Regression Equation	R^2	F value	95% C I Lower-upper	Tolerance	VIF
RSP 561	1	Y_1= -32.59 +8.47 X_2	.697	27.5	X2= 4.95-11.98	1.000	1.000
	2	Y_1= -89.29 + 4.01 X_1+ 5.40 X_2	.863	34.8	X_1=2.30-8.49 X_2=1.60-6.42	.646 .646	1.549 1.549
HD 2967	1	Y_2= -92.38 +10.10 X_6	.722	31.1	X_6=6.16- 14.05	1.000	1.000
	2	Y_2=-87.02 + 9.20 X_6 + 1.66 X_5	.870	36.6	X_6=6.29-12.10 X_5=.62-2.70	.962 .962	1.039 1.039
	3	Y_2=-81.28 + 5.18 X_6 + 2.05 X_5 + 4.00 X_3	.921	38.8	X_6 =.92-9.44 X_5=1.13-2.98 X_3=.50-7.50	.306 .832 .317	3.264 1.202 3.154
	4	Y_2= -91.52 + 2.70 X_6 + 1.62 X_5 + 4.42 X_3 + 2.17 X_4	.956	49.4	X_6=-1.25-6.67 X_5 =.80-2.44 X_3=1.61-7.22 X_4=.35-3.99	223 .671 .312 .413	4.488 1.491 3.203 2.419
Agra Local	1	Y_3= -112.54 + 12.52 X_6	.866	36.0	X_6= 7.97-17.06	1.000	1.000
	2	Y_3= -106.79 +11.55 X_6 + 1.79 X_5	.930	35.3	X_6=7.96 -15.13 X_5=.50 -3.07	.962 .962	1.039 1.039
	3	Y_3= -99.41 + 6.38 X_6 + 2.2 X_5 + 5.15 X_3	.961	39.7	X_6=1.26-11.50 X_5=1.17-3.40 X_3=.93-9.36	.306 .832 .317	3.264 1.202 3.154
	4	Y_3= -111.10 + 3.55 X_6+1.79 X_5+5.62 X_3+2.48 X_4	.977	46.6	X_6=-1.39-8.50 X_5=.77-2.82 X_3=2.12-9.12 X_4=.21-4.74	.223 .671 .312 .413	4.488 1.491 3.203 2.419
PBW 343	1	Y_4= -105.56 + 11.61 X_6	.720	30.7	X_6=7.09-16.26	1.000	1.000
	2	Y_4= -99.81 + 10.71 X_6 +1.79 X_5	.846	30.2	X_6 =7.05-14.36 X_5=.48-3.09	.962 .962	1.039 1.039
	3	Y_4= -92.83 + 5.82 X_6 + 2.26 X_5 + 4.86 X_3	.903	30.9	X_6 =.36-11.29 X_5=1.07-3.45 X_3=.37-9.36	.306 .832 .317	3.264 1.202 3.154
	4	Y_4= -107.16 + 2.35 X_6 + 1.65 X_5+ 5.44 X_3 + 3.04 X_4	.955	47.3	X_6=2.32--7.04 X_5=.69-2.62 X_3=2.13-8.76 X_4=.89-5.18	.223 .671 .312 .413	4.488 1.491 3.203 2.419

Y_1 = Disease severity of RSP-561, Y_2 = Disease severity of HD-2967, Y_3 = Disease severity of Agra Local, Y_4 = Disease severity of PBW-343
T_{Max}.= (X_1), $T_{Min.}$= (X_2), $Vp_{Morn.}$= (X_3), C_{Tmp}.= (X_4), Rainfall= (X_5), Vp_{Even} = (X_6)

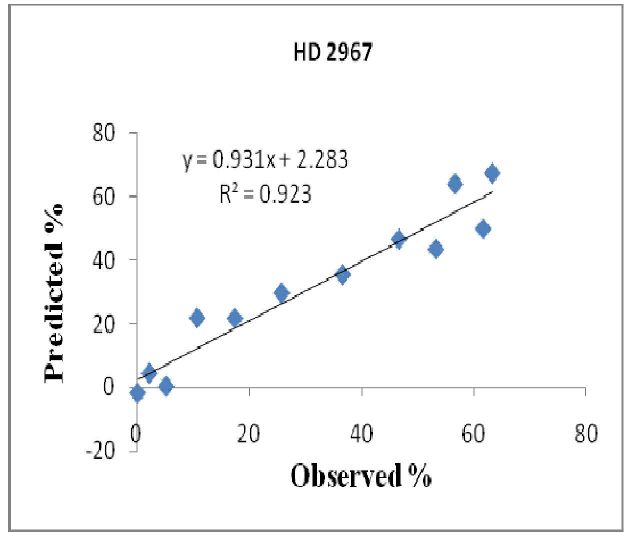
amounting to 92.10 per cent. Step equation (3) predicted increase/decrease in disease severity by 4.00 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 0.50 to 7.50 per cent), whereas, 2.05 and 5.18 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 1.13 to 2.98 and 0.92 to 9.44%). The contribution of evening vapour pressure, rainfall and morning vapour pressure 46, 18 and 36 per cent, respectively, In step 4, after adding canopy temperature, variation further increased by 3.50 per cent i.e. 95.60 per cent. Step equation (4) predicted increase/decrease in severity by 2.17 per cent per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant having 95 per cent CI from 0.35 to 3.99 per cent, whereas, 4.42, 1.62 and 2.70 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in morning vapour pressure, rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 1.61 to 7.22, 0.80 to 2.44 and -125 to 6.67 %). The contribution of evening vapour pressure, rainfall, morning vapour pressure and canopy temperature was 25, 15, 40 and 20 per cent, respectively. The lower tolerance (<1) and VIF (<10) showed the least multicollinearity (inter correlated) effect. Observed versus prediction plotting (Fig. 5B) of disease severity values showed good association (R^2=92.30%). In case of Agra Local, the step 1, 2, 3 and 4 were highly significant having F (1, 12) = 36, F (2, 11) = 35, F (3, 10) = 40 and F (4, 9) = 47 at p<0.01, in predicting severity of stripe rust. The step wise regression in the step 1, showed among different explanatory variables, evening vapour pressure was highly significant in causing 86.60 per cent variation. Step equation (1) revealed that 12.52 per cent increase/decrease per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 7.97 to 17.06 per cent. After adding rainfall in the step 2, per cent variation further increased by 6.40 per cent i.e. 93.00 per cent. Step equation (2) predicted increase/decrease in severity by 1.79 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 0.50 to 3.07 per cent, whereas, 11.55 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in evening vapour pressure if all the other predictors remained constant (95% CI from 7.96 to 15.13%). The contribution of evening vapour pressure and rainfall (step 2) in the predicted equation was 87 and 13 per cent, respectively. In step 3, after adding morning vapour pressure, variation further increased by 3.1 per cent i.e. 96.10 per cent in response variable explained by the cumulative effect of evening vapour pressure, morning vapour pressure and rainfall. Step equation (3) predicted increase/decrease in severity by 5.15 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 0.93 to 9.36 per cent, whereas, 2.20 and 6.38 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in rainfall and evening vapour pressure if all the other predictors remained constant (95% CI from 1.17 to 3.40 and 1.26 to 11.50%, respectively). The contribution of evening vapour pressure, rainfall and morning vapour pressure (step 3) in the predicted equation was 46, 16 and 38 per cent, respectively. In step 4, after adding canopy temperature, variation further increased by 1.60 per cent i.e. 97.70 per cent. Stepwise equation (4) predicted 2.48 per cent increase/decrease in severity per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant having 95 per cent CI from 0.21 to 4.74 per cent, whereas, 5.62, 1.79 and 3.55 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in morning vapour pressure, rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 2.12 to 9.12, 0.77 to 2.82 and -1.39 to 8.50%, respectively). The contribution of evening vapour pressure, rainfall, morning vapour pressure, rainfall and canopy temperature in the predicted equation (step 4) was 26, 13, 42 and 19 per cent, respectively. Further, the data in the Table 6 also revealed that the lower tolerance (<1) and VIF (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 5C) of severity values showed good association (R^2=92.50%). The Table 6 further exhibited that, in PBW 343, the step 1, 2, 3 and 4 were highly significant having F (1, 12) = 31, F (2, 11) = 30, F (3, 10) = 31 and F (4, 9) = 47 at p<0.01, in predicting severity of stripe rust. The step wise regression showed that in the step 1, among the different explanatory variables, evening vapour pressure was highly significant in describing 72.20 per cent variation in the observed severity of stripe rust in PBW 343. Stepwise equation (1) developed for predicting severity revealed that 11.61 per cent increase/decrease in disease severity per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 7.09 to 16.26, per cent. After adding rainfall in the step 2, per cent variation further increased by 12.50 per cent i.e. 84.60 per cent. Step equation (2) predicted increase/decrease in disease severity by 10.71 per cent per week by per unit increase/decrease in evening vapour pressure, if all the other predictors remained constant having 95 per cent CI from 7.05 to 14.36 per cent, whereas, 1.79 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in rainfall if all the other predictors remained constant (95% CI from 0.48 to 3.09%). The contribution of evening vapour pressure and rainfall in the predicted equation (step 2) was 85 and 15 per cent, respectively. In step 3, after adding morning vapour pressure, variation further increased by 5.7 per cent i.e. 90.30 per cent. Stepwise equation (3) predicted increase/decrease in disease severity by 4.86 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 0.37 to 9.36 per cent, whereas, 2.26 and 5.82 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 1.07 to 3.45 and 0.36 to 11.29%, respectively). The contribution of evening vapour pressure, rainfall and morning vapour pressure in the predicted equation was 45, 17 and 38 per cent, respectively. In step 4, after adding canopy temperature, variation further increased by 5.20 per cent i.e. 95.50 per cent. Stepwise equation (4) predicted increase/decrease in severity by 3.04 per cent per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant having 95 per cent CI from 0.89 to 5.18 per cent, whereas, 5.44, 1.65 and 2.35 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in morning vapour pressure, rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 2.13 to 8.67, 0.69 to 2.62 and 2.32 to 7.04%, respectively). The contribution of evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in the predicted equation was 19, 13, 44 and 24 per cent, respectively. Further, the data in the Table 5 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 5D) of disease severity values showed good association (R^2=92.80%).

4.3.3 Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under late sowing conditions

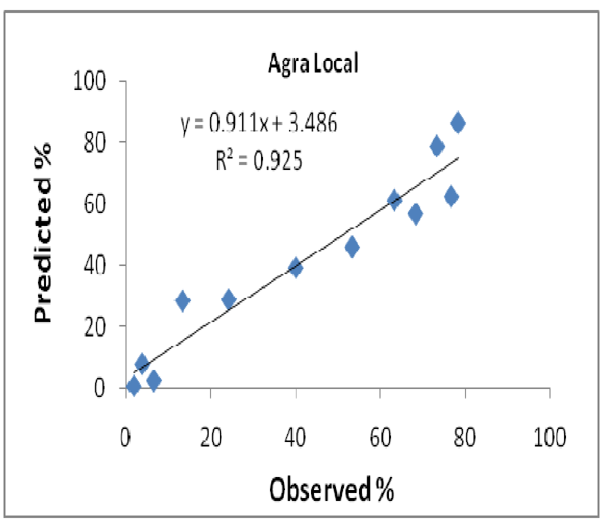
The data in Table 7 depicted that under the late sowing conditions, in RSP 561, the step 1, 2, and 3 were highly significant having F (1, 12) = 29, F (2, 11) = 40 and F (3, 10) = 38 at p<0.01, in predicting severity of stripe rust. The stepwise regression showed that in the step 1, among the different explanatory variables, minimum temperature was highly significant in describing 70.80 per cent variation in the observed severity of stripe rust in RSP 561. Step equation (1) predicted 6.59 per cent increase/decrease in severity per week by per unit (^oC) increase/decrease in minimum temperature, if all the other predictors remained constant with 95



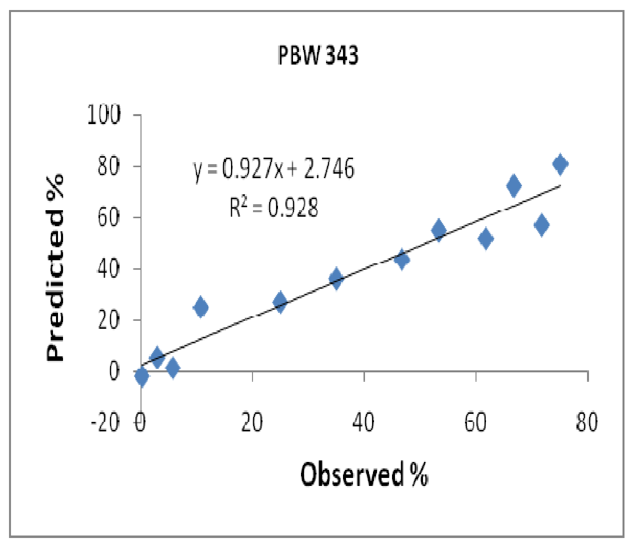
(A)



(B)



(C)



(D)

Figure 5: Comparison between observed and predicted values of the severity of stripe rust of wheat under normal sowing conditions

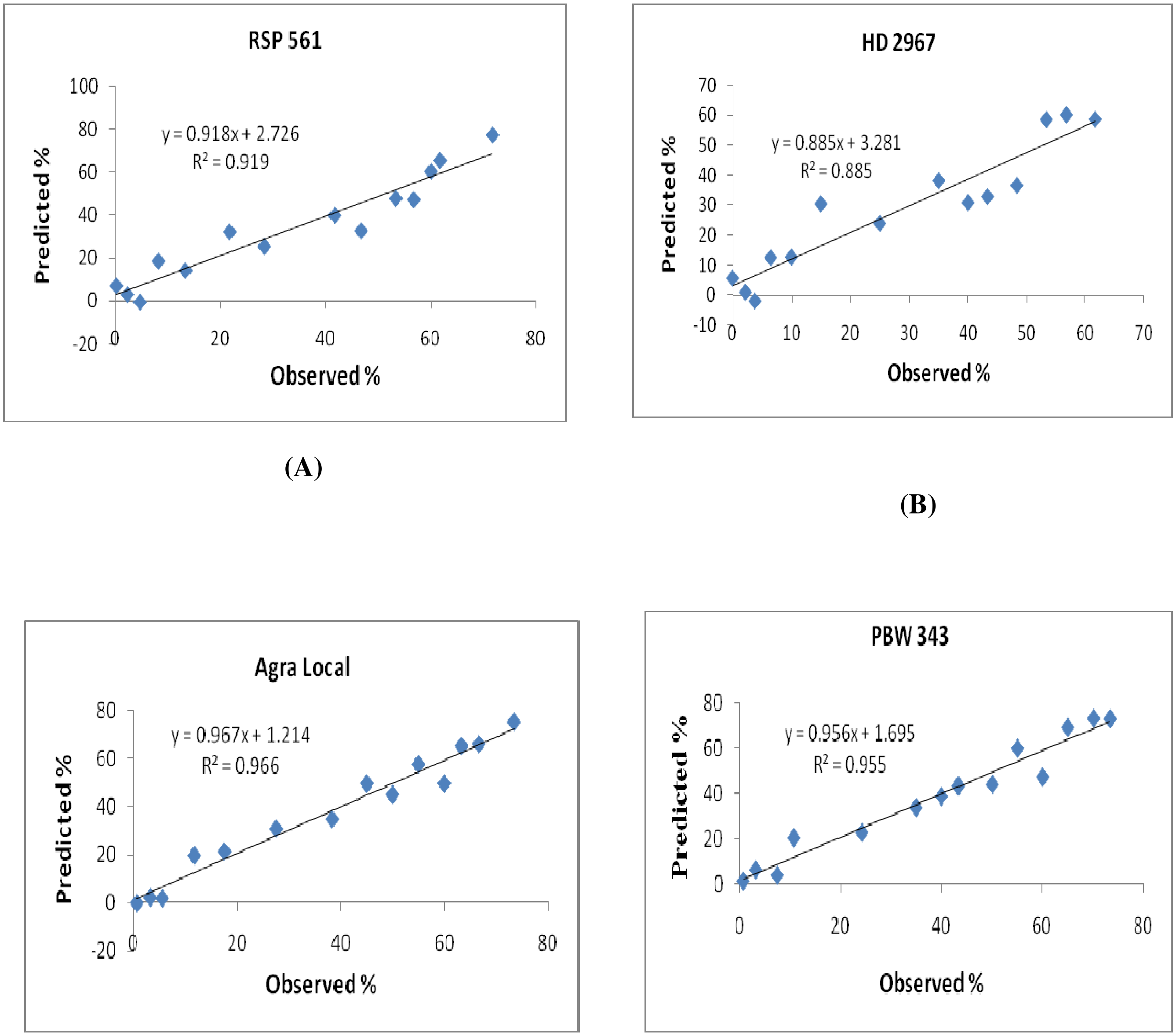
per cent CI from 3.93 to 9.25 per cent. After adding maximum temperature in the step 2, per cent variation further increased by 17.00 per cent i.e. 87.80 per cent. Stepwise equation (2) predicted increase/decrease in severity by 3.12 per cent per week by per unit increase/decrease in maximum temperature, if all the other predictors remained constant having 95 per cent CI from 1.94 to 6.46 per cent, whereas, 4.20 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in minimum temperature if all the other predictors remained constant (95% CI from 1.36 to 4.88%). The contribution of minimum temperature and maximum temperature (step 2) in the predicted equation was 66 and 44 per cent, respectively. In step 3, after addition of rainfall, variation further increased by 4.1 per cent i.e. 91.9 per cent variation was in response variable explained by the cumulative effect of minimum temperature, maximum temperature and rainfall. Step equation (3) predicted increase/decrease in severity by 0.90 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 0.03-1.80 per cent, whereas, 2.77 and 3.82 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in maximum temperature and minimum temperature, if all the other predictors remained constant (95% CI from 1.20 to 4.33 and 1.83 to 5.82%, respectively). The contribution of minimum temperature and maximum temperature and rainfall (step 3) in the predicted equation was 51, 37 and 12 per cent, respectively. Further, the data in the Table 7 also revealed that the lower tolerance (<1) and VIF (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 6A) of disease severity values showed good association (R^2=91.90%). In case of HD 2967, the table depicted that step 1 and 2 were highly significant having F (1, 12) = 30 and F (2, 11) = 42 at p<0.01 in predicting severity of stripe rust. The stepwise regression showed that in step 1, among the different explanatory variables, minimum temperature was highly significant in causing 71.70 per cent variation in the observed severity of stripe rust in HD 2967. Stepwise equation (1) developed for predicting severity revealed that 5.85 per cent increase/decrease in disease severity per week by per unit (^oC) increase/decrease in minimum temperature, if all the other predictors remained constant with 95 per cent CI from 3.54 to 8.17 per cent. After adding maximum temperature in the step 2, per cent variation further increased by 16.80 per cent i.e. 88.50 per cent. Stepwise equation (2) predicted increase in severity by 3.75 per cent per week by per unit increase in minimum temperature, if all the other factors remained constant having 95 per cent CI from 1.81 to 5.68 per cent, whereas, 2.75 per cent increase in disease severity was predicted per week by per unit increase in maximum

Table 7: Multiple (stepwise) regression of epidemiological factors with the severity of stripe rust of wheat under late sowing conditions

Variety	Steps	Stepwise Regression Equation	R^2	F value	95% C I Lower-upper	Tolerance	VIF
RSP 561	1	Y_1= -23.68 +6.59 X_2	.708	29.1	X2= 3.93-9.25	1.000	1.000
	2	Y_1= -67.88 + 4.20 X_2+3.12 X_1	.878	39.5	X_1=1.94-6.46 X_2=1.36-4.88	.646 .646	1.549 1.549
	3	Y_1=-60.51+3.82 X_2+2.77 X_1+.90 X_5	.919	37.6	X_2=1.83-5.82 X_1=1.20-4.33 X_5=.03-1.80	.623 .612 .817	1.605 1.634 1.223
HD 2967	1	Y_2= -22.24+5.85 X_2	.717	30.3	X_2=3.54-8.17	1.000	1.000
	2	Y_2=-61.127+ 3.75X_2 + 2.75X_1	.885	42.40	X_2=1.81-5.68 X_1=1.24-4.25	.646 .646	1.549 1.549
Agra Local	1	Y_3= -88.34+ 9.76 X_6	.716	30.32	X_6= 5.90-13.63	1.000	1.000
	2	Y_3= -83.06+8.87X_6 + 1.64 X_5	.869	36.40	X_6=6.05-11.70 X_5=.63-2.65	.962 .962	1.039 1.039
	3	Y_3= -93.83+ 6.70 X_6 + 1.21 X_5 + 2.22X_4	.916	36.52	X_6=3.55-9.84 X_5=.24-2.15 X_4=.14-4.31	.560 .781 .464	1.787 1.280 2.153
	4	Y_3= -88.80+ 2.73 X_6+1.55 X_5+3.85 X_4+2.33X_3	.967	65.50	X_6=-.49-5.95 X_5=.87-2.23 X_4=.92-3.73 X_3=1.49-6.21	. .242 .701 .463 .316	4.134 1.426 2.158 3.160
PBW 343	1	Y_4= --68.77+ 5.91 X_4	.735	33.35	X_4=3.68-8.15	1.000	1.000
	2	Y_4= -90.50+ 4.68 X_4 +3.98X_3	.876	38.91	X_4 =2.89-6.46 X_3=1.50-6.46	.815 .815	1.227 1.227
	3	Y_4= -82.41+ 3.33X_4 + 4.99X_3 + 1.36X_5	.956	72.53	X_4=2.00-4.66 X_3=3.33-6.64 X_5=.65-2.08	.587 .732 .717	1.703 1.366 1.394

Y_1 = Disease severity of RSP-561, Y_2 = Disease severity of HD-2967, Y_3 = Disease severity of Agra Local, Y_4 = Disease severity of PBW-343
T_{Max}.= (X_1), $T_{Min.}$= (X_2), $Vp_{Morn.}$= (X_3), C_{Tmp}.= (X_4), Rainfall= (X_5), Vp_{Even} = (X_6)

temperature if all the other predictors remained constant (95% CI from 1.24 to 4.25%). The contribution of minimum and maximum temperatures (step 2) in the predicted equation was 43 and 57 per cent, respectively. Further, the data in the Table 6 also revealed that the lower tolerance (<1) and VIF (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 6B) of disease severity values showed good association (R^2= 88.50%). The data in the Table 7 shows that under the late sowing conditions, in Agra Local, the step 1, 2, 3 and 4 were highly significant having F (1, 12) =30, F (2, 11) = 36, F (3, 10) = 37 and F (4, 9) = 66 at p<0.01, in predicting severity of stripe rust. The stepwise regression showed that in the step 1, among the different explanatory variables, evening vapour pressure was highly significant in causing 71.60 per cent variation in the observed severity of stripe rust in Agra Local. Step equation (1) developed for predicting disease severity revealed that 9.76 per cent increase/decrease in disease severity per week by per unit (mmHg) increase/decrease in evening vapour pressure, if all the other predictors remained constant with 95 per cent CI from 5.90 to 13.63 per cent. After adding rainfall in the step 2, per cent variation further increased by 15.30 per cent i.e. 86.90 per cent. Step equation (2) predicted increase/decrease in severity by 8.87 per cent per week by per unit increase/decrease in evening vapour pressure, if all the other predictors remained constant having 95 per cent CI from 6.05 to 11.70 per cent, whereas, 1.64 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in rainfall if all the other predictors remained constant (95% CI from 0.63 to 2.65%). The contribution of evening vapour pressure and rainfall (step 2) in the predicted equation was 84 and 16 per cent, respectively. In step 3, after adding canopy temperature, variation further increased by 4.7 per cent i.e. 91.60 per cent. Step equation (3) predicted increase/decrease in severity by 2.22 per cent per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant having 95 per cent CI from 0.14 to 4.31 per cent, whereas, 1.21 and 6.70 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 0.24 to 2.15 and 3.55 to 9.84%, respectively). The contribution of evening vapour pressure, rainfall and canopy temperature in the predicted equation (step 3) was 65, 12 and 23 per cent, respectively. In step 4, after adding morning vapour pressure, variation further increased by 5.1 per cent i.e. 96.70 per cent. Step equation (4) predicted increase/decrease in severity by 2.33 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 1.49 to 6.21 per cent, whereas, 3.85, 1.55 and 2.73 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in canopy temperature, rainfall and evening vapour pressure, if all the other predictors remained constant (95% CI from 0.92 to 3.73, 0.87 to 2.23 and -0.49 to 5.95%, respectively). The contribution of evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in the predicted equation (step 4) was 26, 15, 37 and 22 per cent, respectively. Further, the data in the Table 7 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 6C) of disease severity values showed good association (R^2=96.60%). Table 7 further depicted that, in PBW 343, the step 1, 2 and 3 were highly significant having $F (1, 12) = 33$, $F (2, 11) = 39$ and $F (3, 10) = 73$ at $p<0.01$, in predicting severity of stripe rust. The stepwise regression showed that in the step 1, among the different explanatory variables, canopy temperature was highly significant in describing 73.50 per cent. Stepwise equation (1) predicted 5.91 per cent increase/decrease in severity per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant with 95 per cent CI from 3.68 to 8.15 per cent. After adding morning vapour pressure in the step 2, per cent variation further increased by 14.1 per cent i.e. 87.60 per cent. Step equation (2) predicted increase/decrease in severity by 3.98 per cent per week by per unit increase/decrease in morning vapour pressure, if all the other predictors remained constant having 95 per cent CI from 1.50 to 6.46 per cent, whereas, 4.68 per cent increase/decrease in severity was predicted per week by per unit increase/decrease in canopy temperature, if all the other predictors remained constant (95% CI from 2.89 to 6.46%). The contribution of morning vapour pressure and canopy temperature (step 2) in the predicted equation was 54 and 46 per cent, respectively. In step 3, after adding rainfall, variation further increased by 8.0 per cent i.e. 95.60 per cent. Step equation (3) predicted increase/decrease in severity by 1.36 per cent per week by per unit increase/decrease in rainfall, if all the other predictors remained constant having 95 per cent CI from 0.65 to 2.08 per cent, whereas, 4.99 and 3.33 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in morning vapour pressure and canopy temperature, if all the other predictors remained constant (95% CI from 3.33 to 6.64 and 2.00 to 4.66%, respectively). The contribution of canopy temperature, morning vapour pressure and rainfall in the predicted equation (step 3) was 34, 52 and 24 per cent, respectively. Further, the data in the Table 7 also revealed that the lower tolerance (<1) and variation inflation factor (<10) showed the least



(A) **(B)**

(C) **(D)**

Figure 6: Comparison between observed and predicted values of the severity of stripe rust of wheat under late sowing conditions

multicollinearity (intercorrelated) effect. Observed versus prediction plotting (Fig. 6D) of severity values showed good association (R^2=95.50%).

4.4 Comparative prediction of disease severity of stripe rust of wheat by Logistic and Gompertz models

The observed disease severity of stripe rust in four wheat varieties, RSP 561, HD 2967, Agra Local and PBW 343, during rabi seasons of 2013-14 and 2014-15 were analyzed using Logistic and Gompertz models for the prediction of disease severity. Data presented in Table 8 depict that under early sowing condition (Fig. 7A), in case of RSP-561, predicted estimate by Logistic model (2.41 to 15.11%) was very close to the observed values (2.33 to 14.17%) from 1st to 4th SMW (disease appearance) as compared to predicted estimate (0.29 to 11.07%) by Gompertz model. Whereas, from 5th SMW onwards (disease progress), Gompertz predicted severity was more precise with an accuracy of approx. 97 per cent i.e. 19.19 to 86.75 per cent as compared to observed values (18.33 to 86.67%). In case of HD 2967, the Logistic transformation values of severity showed an accuracy of 96.50 per cent in predicting the disease severity, from 1st to 4th SMW (2.07 to 9.32%) as compare to observed severity (1.67 to 6.67%), while, from 5th to 14th SMW, predicted value by Gompertz model was better from 14.01 to 81.80 per cent as compared with observed severity of 12.50 to 81.67 per cent. Further, using Logistic model, the predicted severity values in Agra Local and PBW 343 during 1st SMW (2.47 and 2.48) and 2nd SMW (4.30 and 4.32) was very close to the observed severity of 2.00 and 1.83 and 3.33 and 3.00 per cent, respectively. Whereas, from 5th to 14th SMW, Gompertz model predicted better with 19.73 to 84.66 per cent in Agra Local and 19.80 to 85.77 per cent in PBW 343 which was close to the observed values of 15.42 to 90.00 and 13.96 to 86.67 per cent, respectively, with an accuracy of approximately 98 per cent. Indicated that Gompertz transformation model was best fitted and had higher accuracy in predicting the stripe rust severity in four selected wheat varieties. Table 8 also shows that under normal sowing condition, in case of RSP-561, predicted estimate by Gompertz model was very close to the observed values from 1st to 14th SMW (disease appearance to terminal) having 0.27 to 83.92 per cent with an accuracy of approximately 99 per cent as compared to observed values (0.33 to 83.33%). In case of HD 2967, the Logistic transformation values of severity showed an accuracy of 99.00 per cent in predicting the disease severity of 5.35 and 10.90 per cent in 3rd and 4th SMW, to the observed severity of 5.33 and 10.83 per cent, respectively, while, from 5th to 14th SMW, Gompertz model predicted better with the values of 18.19 to74.98 per cent to the observed severity (17.50 to 73.33 per cent). Further, in case of Agra Local from 7th to 14th SMW (disease progress to terminal stage) Gompertz model predicted the disease severity of 56.90 to 85.68 per cent as compared to observed severity of 56.67 to 86.67 per cent, having an accuracy of approximately 99 per cent. The disease severity of PBW 343 was predicted better by Gompertz model with an accuracy of approximately 99 per cent in 1st (disease appearance), 4th to 12th (disease progress) and in 14th SMW (terminal) with the values of 0.28, 9.70 to 77.42 and 81.83 per cent compared to the observed severity of 0.33, 10.00 to 73.33 and 81.67 per cent, respectively (Fig. 7B). The data in Table 8 further depicted that during late sowing conditions, Gompertz model predicted the disease severity of RSP 561, HD 2967 and Agra Local, better than Logistic model with an accuracy of 99, 99 and 100 per cent, from 1st to 14th SMW (disease appearance to terminal stage) with values of 0.71 to72.23, 0.63 to 62.24 and 0.58 to 72.50 per cent as compared to observed severity of 0.17 to 71.67, 0.00 to 61.67 and 0.58 to 73.50 per cent, respectively, whereas, in case of PBW

Table 8: Comparative prediction of disease severity of stripe rust of wheat by Logistic and Gompertz models

SMW		Disease Severity (%)											
		Early sowing conditions				Normal Sowing conditions				Late Sowing conditions			
		RSP 561	HD 2967	Agra Local	PBW 343	RSP 561	HD 2967	Agra Local	PBW 343	RSP 561	HD 2967	Agra Local	PBW 343
1st	Obs.	2.33	1.67	2.33	1.00	0.33	0.17	1.83	0.33	0.17	0.00	0.58	0.67
	Logi.	2.41	2.07	2.47	2.48	2.41	0.24	2.65	2.48	2.73	2.41	0.67	2.97
	Gompz.	0.29	0.27	0.29	0.29	0.27	0.27	0.30	0.28	0.71	0.63	0.58	2.89
2nd	Obs.	4.00	2.67	5.00	2.83	3.00	2.33	3.83	3.00	2.33	2.17	3.17	3.17
	Log.	4.20	3.10	4.30	4.32	4.23	4.32	4.65	4.36	4.39	3.88	4.67	4.77
	Gompz.	1.48	1.40	1.52	1.52	1.49	1.40	1.65	1.54	2.26	1.99	2.64	2.46
3rd	Obs.	7.33	4.17	11.17	6.50	4.17	5.33	6.50	5.83	4.67	3.83	5.50	7.50
	Log.	7.40	4.78	7.37	7.40	7.29	5.35	8.02	7.51	6.94	6.14	8.33	7.55
	Gompz.	4.78	4.51	4.90	4.90	4.91	4.51	5.40	5.06	4.36	3.73	5.15	5.84
4th	Obs.	14.17	6.67	15.83	10.83	6.33	10.83	13.33	10.83	8.17	6.50	11.67	10.83
	Log.	15.11	9.32	12.31	12.36	12.2	10.90	13.42	12.57	10.74	9.49	18.33	11.68
	Gompz.	11.07	6.43	10.34	8.34	6.35	10.43	11.50	9.70	7.30	5.07	11.38	10.21
5th	Obs.	18.33	12.50	21.67	20.00	12.50	17.50	24.17	25.00	13.33	10.00	17.50	24.17
	Log.	19.26	19.02	20.68	20.68	20.51	19.02	29.58	21.15	16.83	14.83	26.67	28.33
	Gompz.	19.19	14.01	19.73	19.80	19.52	18.19	28.48	20.91	16.07	14.25	18.02	19.47
6th	Obs.	28.33	20.83	32.50	26.67	22.50	25.83	40.00	35.00	21.67	15.00	27.50	35.00
	Log.	31.06	29.27	31.82	31.82	31.15	29.27	34.30	32.12	24.38	21.48	40.00	36.98
	Gompz.	29.12	25.04	29.84	29.95	29.31	27.63	32.24	31.95	22.97	20.30	24.33	36.54
7th	Obs.	45.00	31.67	50.00	46.67	35.00	36.67	53.33	46.67	28.33	25.00	38.33	40.00
	Log.	46.31	39.86	43.35	43.35	41.84	39.86	57.12	43.15	32.22	28.40	46.67	41.79
	Gompz.	45.90	36.55	41.90	40.06	40.65	37.11	56.90	41.87	31.07	27.46	39.90	40.08
8th	Obs.	55.00	45.00	56.67	63.33	48.33	46.67	63.33	53.33	41.67	35.00	45.00	43.33
	Log.	56.80	49.75	54.22	54.43	51.82	49.75	64.50	53.37	42.51	37.92	50.00	42.97
	Gompz.	55.80	48.89	54.10	54.10	51.54	47.71	64.05	53.14	41.76	35.04	46.85	43.29

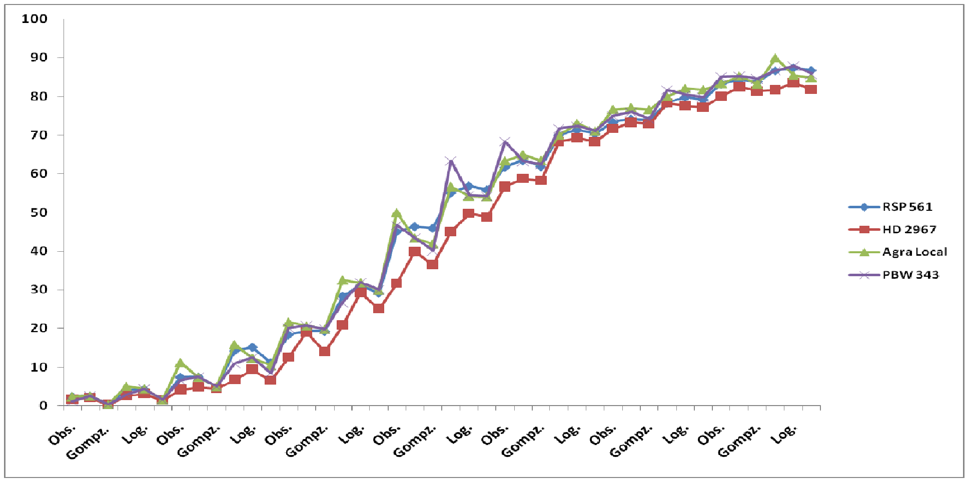
9th	**Obs.**	61.67	56.67	63.33	68.33	55.00	53.33	68.33	61.67	46.67	40.00	50.00	50.00
	Log.	63.40	58.76	64.95	63.20	61.17	58.31	69.29	63.01	47.31	41.81	56.67	51.45
	Gompz.	61.89	58.31	63.41	62.41	59.71	54.96	68.75	61.57	46.95	41.06	50.11	50.72
10th	**Obs.**	70.00	68.33	70.00	71.67	68.33	56.67	73.33	66.67	53.33	43.33	55.00	55.00
	Log.	71.34	69.24	73.08	72.36	69.72	65.34	74.81	70.05	53.74	47.50	60.00	58.45
	Gompz.	70.35	68.34	71.06	71.06	69.25	58.76	73.95	68.31	53.50	46.26	56.92	57.15
11th	**Obs.**	73.33	71.67	76.67	75.00	75.00	61.67	76.67	71.67	56.67	48.33	60.00	60.00
	Log.	74.14	73.33	77.10	75.92	76.52	70.90	79.77	74.70	58.57	51.76	66.67	63.70
	Gompz.	73.85	72.90	76.62	74.10	75.29	63.23	78.50	73.51	57.44	50.62	62.03	62.53
12th	**Obs.**	78.33	78.34	80.00	81.67	78.33	63.33	78.33	75.00	60.00	53.33	63.33	65.00
	Log.	79.79	77.55	82.11	80.42	81.30	75.18	82.83	77.56	61.94	54.74	70.00	67.37
	Gompz.	79.15	77.18	81.75	79.75	79.09	66.59	82.68	77.42	61.47	54.17	65.60	66.92
13th	**Obs.**	83.33	80.00	83.33	85.00	81.67	68.33	83.33	81.67	61.67	56.67	66.67	70.00
	Log.	84.20	82.48	85.25	85.25	84.24	78.40	85.76	80.31	67.18	57.01	73.33	70.43
	Gompz.	83.85	81.40	83.21	84.53	83.00	69.98	84.64	79.25	66.69	56.73	67.98	69.81
14th	**Obs.**	86.67	81.67	90.00	86.67	83.33	73.33	86.67	83.33	71.67	61.67	73.50	73.33
	Log.	87.40	83.61	85.44	87.86	84.89	80.80	88.01	82.41	75.62	68.30	76.67	71.37
	Gompz.	86.75	81.80	84.86	85.77	83.92	74.89	85.68	81.83	72.23	62.24	72.50	73.19

Obs. = Observed **Log. =Logstic** **Gomperz. = Gompertz**

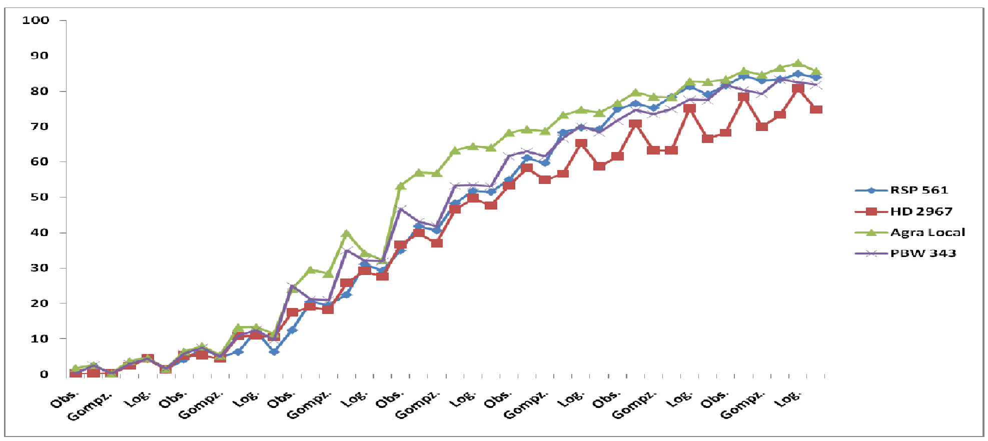
343, Gompertz model predicted better in 1st, 2nd and from 4th to 12th SMW by 2.89, 2.46 and 10.21 to 66.92 per cent, respectively, compared to observed severity of 0.67, 3.17 and 10.83 to 65.00 per cent, respectively (Fig. 7C) with overall indicated that Gompertz transformation model was best fitted for predicting the stripe rust severity in four selected wheat varieties during rabi season of 2013-14 and 2014-15.

4.5 Principal component analysis of epidemiological factors of stripe rust of wheat

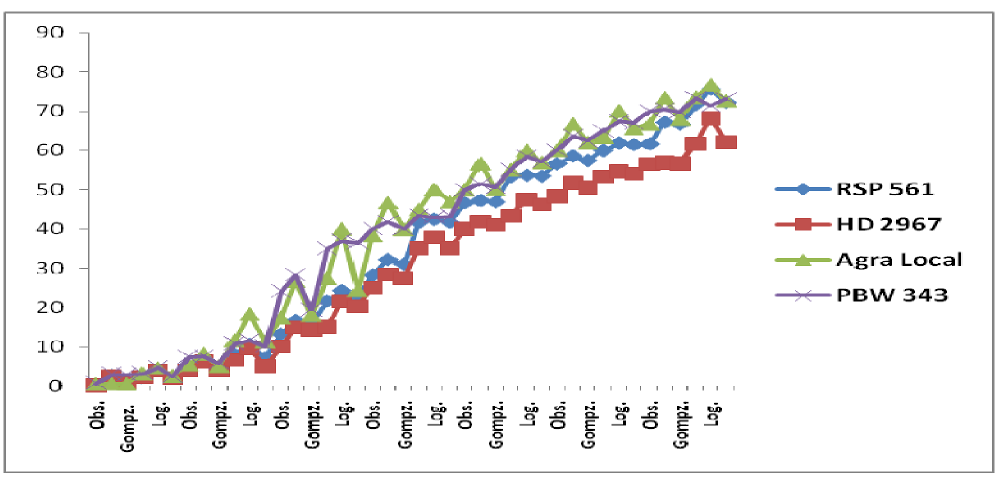
The average data of environmental factors and severity of stripe rust of wheat in four varieties of wheat (RSP 561, HD 2967, Agra Local and PBW 343) during rabi seasons of 2013-14 and 2014-15 were subjected to Principal Component Analysis to reduce the larger data set of variables to the smaller ones. Perusal of the data in the Table 9 indicated that under normal sowing conditions, three principal components (Pc_1, Pc_2 and Pc_3) based on the eigenvalues ≥1 (Fig. 8A) were generated by PCA, in which RSP 561, HD 2967, Agra Local PBW 343, maximum temperature, minimum temperature, morning vapour pressure , evening vapour pressure , evaporation, canopy temperature, soil temperature and age of the crop contributed heavily in loading of principal component one (Pc_1) having coefficient values of 0.912, 0.896, 0.908, 0.926, 0.801, 0.864, 0.902, 0.911, 0.695, 0.693, 0.859 and 0.886, followed by minimum relative humidity, sunshine, morning cloud cover and evening cloud cover in Pc_2 having coefficient of -0.785, 0.917, -0.807 and -0.882, while, maximum relative humidity, mean wind velocity and rainfall contributed in loading of Pc_3 having coefficient of -0.611, 0.834 and 0.742, respectively (Fig. 8D). The extraction values ranging from 0.661 to 0.985 for the epidemiological factors explained their proportion contribution in the formation of all three principal components. Among the 85.32 per cent cumulative variance explained by epidemiological factors, Pc_1, accounted for 59.49 per cent, followed by 16. 55 and 9.28 per cent variance by Pc_2 and Pc_3, respectively. Under normal sowing conditions, again three principal components (Pc_1, Pc_2 and Pc_3) based on the eigenvalues ≥1 (Fig. 8B) were generated by PCA, in which RSP-561, HD 2967, Agra Local PBW 343, maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure, evaporation, canopy temperature, soil temperature and crop age contributed heavily in loading of principal component one (Pc_1,) having coefficient values of 0.897, 0.914, 0.927, 0.920, 0.800, 0.863, 0.901, 0.912, 0.691, 0.686, 0.855 and 0.885, followed by minimum relative humidity, sunshine, morning cloud cover and evening cloud cover in Pc_2 having coefficient of -0.785, 0.917, -0.807 and -0.882, while, maximum relative humidity, mean wind velocity and rainfall in loading of Pc_3 having coefficient of -0.609, 0.837 and 0.739, respectively (FIG. 8E). The extraction values range from



(A): Under early sowing conditions



(B): Under normal sowing conditions



(C): under late sowing conditions

(Log = Logistic, Gpmperz = Gompertz, Obs = Observed)

Figure 7: Comparative prediction of disease severity of stripe rust of wheat by Logistic and Gompertz models under three different sowing conditions

0.656 to 0.984 for all the epidemiological factors. Cumulative variance of 85.40 percent among all epidemiological factors in which Pc_1, accounted for 59.49 per cent followed by 16.55 and 9.28 per cent variance by Pc_2 and Pc_3. Perusal of the data in the Table 9 further indicated that under late sowing conditions, again three principal components (Pc_1, Pc_2 and Pc_3) based on the eigenvalues ≥1 (Fig. 18C) were generated by PCA, in which RSP 561, HD 2967, Agra Local PBW 343, maximum temperature, minimum temperature, morning vapour pressure , evening vapour pressure , evaporation, canopy temperature, soil temperature and age contributed heavily in loading of principal component one (Pc_1) having coefficient values of 0.898, 0.902, 0.914, 0.914, 0.807, 0.871, 0.893, 0.912, 0.707, 0.722, 0.868 and 0.891 followed by minimum relative humidity, sunshine, morning cloud cover and evening cloud cover in Pc_2 having coefficient of -0.785, 0.916, -0.808 and -0.879, while, maximum relative humidity, mean wind velocity and rainfall in loading of Pc_3 having coefficient of -0.598, 0.837 and 0.735, respectively (Fig. 8F). The extraction values range from 0.653 to 0.980 for epidemiological factors. Whereas, Pc_1, accounted for 60.02 percent variation followed by 16.43 and 9.28 per cent variance by Pc_2 and Pc_3.

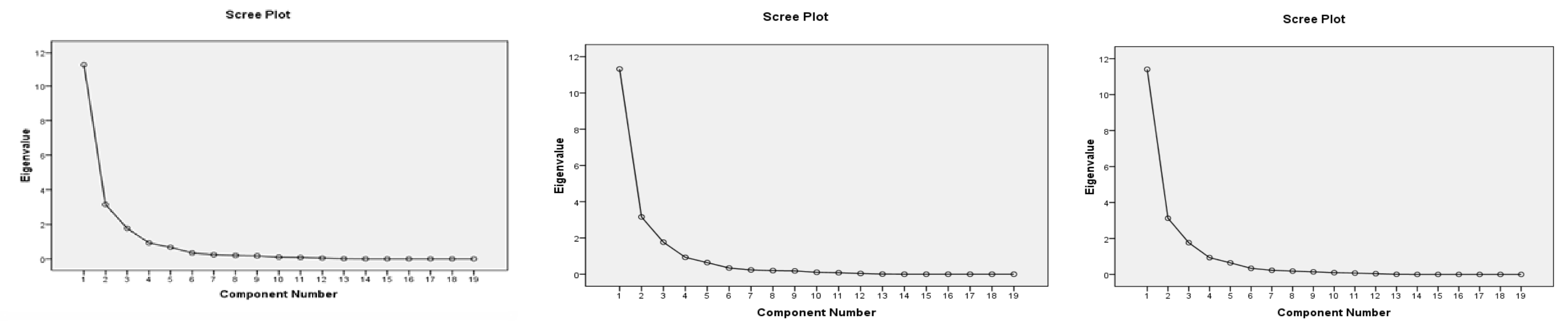
4.6 Effect of leaf wetness duration on the severity of stripe rust of wheat

Data in the Table 10 reveal that after 12 hour of leaf wetness period, symptoms appeared only in Agra Local with latent period of 10 days, maximum pustule size of 0.9 mm and disease severity of 47.50 per cent. Increasing leaf wetness duration from 12 to 24 hour, resulted in the appearance of symptoms in all the four varieties *viz.,* RSP 561, HD 2967, Agra Local and PBW 343 with latent period of 7.5, 11.25, 8 and 7.5 days, with pustule size and disease severity of 9.55, 9.25, 9.95 and 9.38 mm and 47.50, 22.50, 52.50, 47.50 per cent, respectively. With further increase in leaf wetness duration (24 to 36 hour), the latent period of rust decreased in all four wheat varieties to 7.25, 9.50, 7.5 and 7.25 days in RSP 561, HD 2967, Agra local and PBW 343, respectively, whereas, pustule size increased with maximum of 10.03, 9.38, 11.05 and 10.98 mm, respectively. The disease severity was also increased with maximum of 57.50, 30.00, 60.00 and 54.34 per cent in RSP-561, HD-2967, Agra Local and PBW-343, respectively.

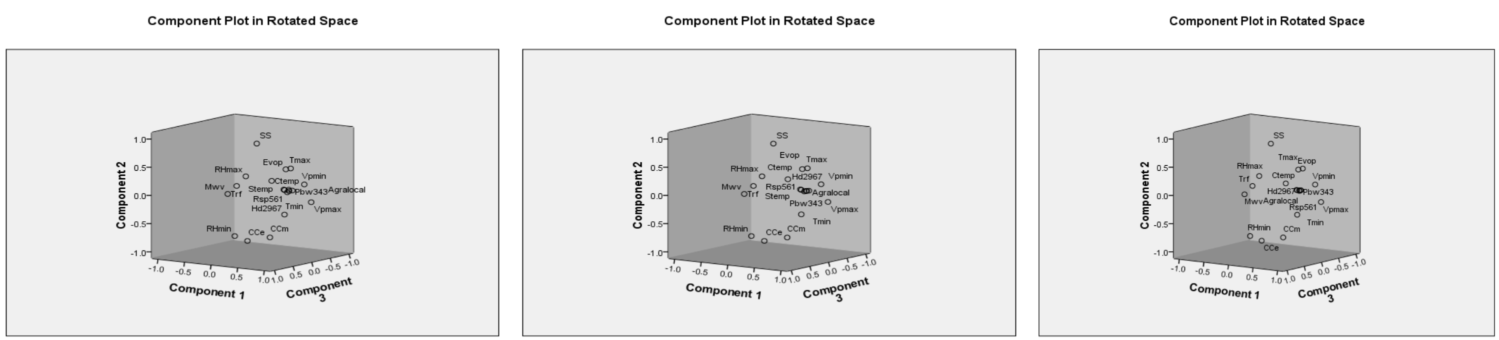
Table 9: Principal component analysis of epidemiological factors of stripe rust of wheat

Epidemiological factor	Early Sowing conditions				Normal Sowing conditions				Late Sowing conditions			
	Communities	Pc_1	Pc_2	Pc_3	Communities	Pc_1	Pc_2	Pc_3	Communities	Pc_1	Pc_2	Pc_3
RSP 561	.962	.912	.168	.319	.946	.897	.163	.340	.956	.898	.183	.340
HD 2967	.944	.896	.148	.346	.963	.914	.168	.317	.958	.902	.171	.338
Agra Local	.964	.908	.192	.322	.955	.927	.166	.260	.966	.914	.182	.314
PBW 343	.952	.926	.169	.256	.968	.920	.170	.304	.975	.914	.184	.324
$T_{Max.}$ (^{0}C)	.934	.801	.528	.117	.935	.800	.531	.117	.938	.807	.525	.106
$T_{Min.}$ (^{0}C)	.946	.864	-.246	.374	.944	.863	-.243	.373	.951	.871	-.251	.359
$RH_{Max.}$ (%)	.701	-.554	.146	-.611	.708	-.562	.147	-.609	.709	-.572	.152	-.598
$RH_{Min.}$ (%)	.701	-.278	-.785	.079	.702	-.280	-.785	.080	.703	-.282	-.785	.082
$M_{Wvv.}$ (km/hr)	.721	.117	.110	.834	.727	.116	.111	.837	.730	.134	.106	.837
$Vp_{Morn.}$ (mmHg)	.911	.902	-.119	-.289	.909	.901	-.115	-.291	.903	.893	-.119	-.304
$Vp_{Evn.}$ (mmHg)	.889	.911	.225	-.092	.892	.912	.229	-.091	.892	.912	.222	-.105
SS (hr)	.912	.202	.917	.174	.912	.201	.917	.176	.915	.209	.916	.177
Rainfall (mm)	.661	.221	.250	.742	.656	.220	.248	.739	.653	.225	.249	.735
Evop. (mm)	.742	.695	.499	.097	.740	.691	.503	.099	.752	.707	.495	.090
$C_{Temp.}$ (^{0}C)	.825	.693	.349	.473	.844	.686	.378	.480	.843	.722	.307	.477
$CC_{M orn.}$ (okta)	.730	.173	-.807	-.221	.733	.184	-.807	-.220	.735	.177	-.808	-.225
$CC_{E vn.}$ (okta)	.807	-.151	-.882	-.080	.808	-.151	-.882	-.083	.806	-.161	-.879	-.082
$S_{Temp.}$ (^{0}C)	.927	.859	.198	.386	.922	.855	.202	.387	.929	.868	.192	.373
Age (days)	.985	.886	.194	.402	.984	.885	.197	.402	.980	.891	.190	.388
Variance (%)	--	59.49	16.55	9.28	--	59.58	16.63	9.29	--	60.02	16.43	9.28
Cumulative (%)	--	--	76.04	85.32	--	--	76.21	85.4	--	--	76.4	85.6

C_{Temp} = Canopy temperature, T_{Max}= Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max..}$= Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity,. $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn..}$=Evening vapour pressure, SS = Sunshine, Evop. . = Evaporation, $CC_{Morn.}$= Morning cloud cover, $CC_{Evn.}$= Evening cloud cover, $S_{Temp.}$ = Soil temperature



(A) (B) (C)



(D) (E) (F)

Early Sowing **Normal Sowing** **Late sowing**

Figure 8: Principal Component Analysis of epidemiological factors of stripe rust of wheat

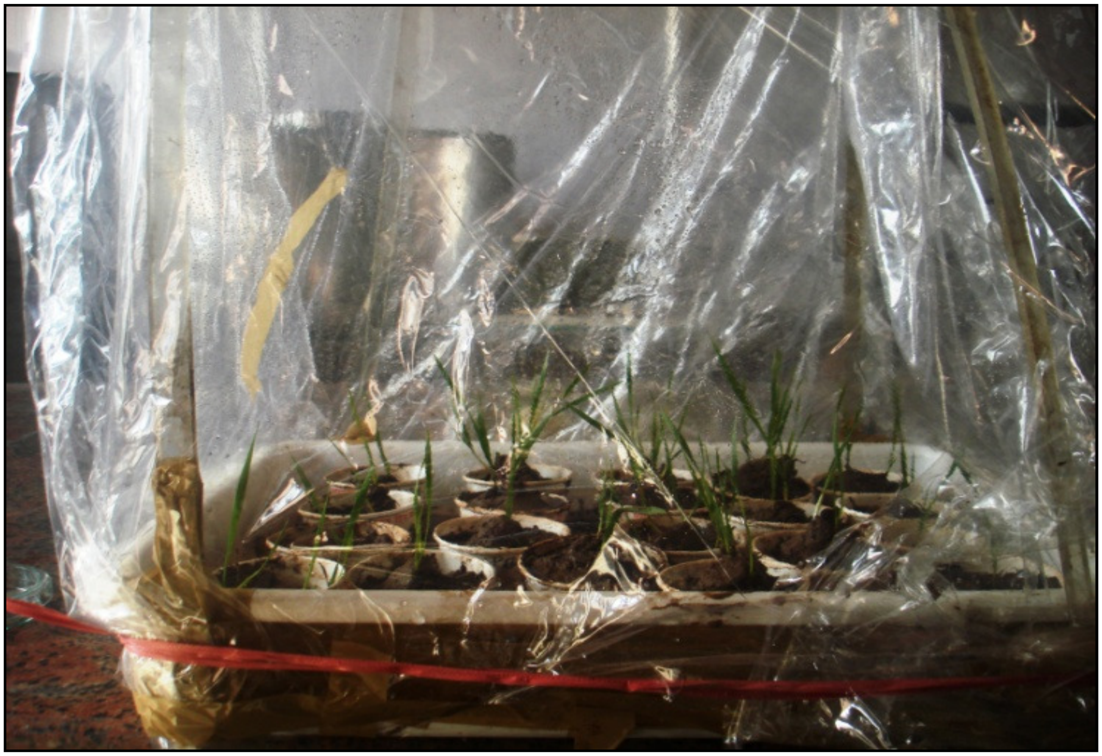


Plate 3: Moisture chamber for leaf wetness studies

Plate 4: Appearance of stripe rust pustule

Table 10: Effect of leaf wetness duration on the severity of stripe rust of wheat

Duration	Varieties	Latent period (days)				Pustule size (mm)				Severity (%)			
		Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation	Min.	Max.	Mean	Std. Deviation	Min.	Max.
12 h	RSP 561	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	HD 2967	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Agra Local	10	0.0	10	10	0.47	0.30	0.1	0.9	18.83	18.43	2.5	47.5
	PBW 343	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24 h	RSP 561	7.5	0.0	7.5	7.5	5.03	3.43	0.75	9.55	20.08	17.47	1.75	47.5
	HD 2967	11.25	0.0	11.25	11.25	4.95	3.37	0.73	9.25	10.25	8.45	1.25	22.5
	Agra Local	8.0	0.0	8.0	8.08.0	5.29	3.53	0.8	9.95	22.75	20.6	3.0	52.5
	PBW 343	7.5	0.0	7.5	7.5	4.93	3.36	0.85	9.38	20.54	18.49	2.5	47.5
36 h	RSP 561	7.25	0.0	7.25	7.25	5.26	3.58	0.98	10.03	26.04	21.91	2.75	57.5
	HD 2967	9.5	0.0	9.5	9.5	5.11	3.42	0.8	9.38	12.88	10.86	1.75	30
	Agra Local	7.5	0.0	7.5	7.5	5.51	3.78	1.05	11.05	26.13	22.5	4.5	60
	PBW 343	7.25	0.0	7.25	7.25	5.34	3.77	1.05	10.98	24.6	9.68	3.5	54.34

CHAPTER -5

DISCUSSION

Field experiments were carried out for consecutive two rabi seasons of 2013-14 and 2014-15 to evaluate the effect of various epidemiological factors (abiotic and biological) on the initiation and severity of stripe rust in four wheat varieties, RSP 561, HD 2967, Agra Local and PBW 343, for three sowing conditions (early, normal and late sowing). The results revealed that the disease appeared during 1st standard meteorological week (SMW) in all the varieties under three sowing conditions tested. Whereas, under early sowing conditions, the severity of 2.33 per cent each was recorded in RSP 561 and Agra Local, followed by 1.67 per cent in HD 2967 and 1.0 per cent in PBW 343, at jointing stage (73 days after sowing), whereas, under normal sowing conditions, disease appeared at stem elongation stage (53 DAS) with severity of 1.83 per cent in Agra Local, 0.33 per cent each in RSP 561 and PBW 343 and 0.17 per cent in HD 2967. However, under late sowing conditions, the severity was 0.17, 0.58 and 0.67 per cent in RSP 561, Agra Local and PBW 343, respectively, at tillering stage (29 DAS), the corresponding weather conditions during the period remained as maximum temperature of 17.5^{0}C, minimum temperature of 5^{0}C, maximum RH of 92.5 per cent, minimum RH 59 of per cent, mean wind velocity of 1.6 km/h, morning vapour pressure of 8.2 mmHg, evening vapour pressure of 9.9 mmHg, sunshine of 2.9 h/day, evaporation of 1.1 mm, morning cloud cover of 3.5 okta, evening cloud cover of 6.0 okta and soil temperature of 11.4^{0}C. However, the result of canopy temperature for three sowing dates was of 11.7, 12.3 and 12.9^{0}C, respectively. Prevalence of conducive environmental conditions *viz*., low temperatures (average 11.25^{0}C), high maximum RH (92.50%), with continuous cloud cover (5.0 okta) along with phenological vulnerable stages of host (jointing, stem elongation and tillering) were found favourable for the initiation of primary infection of stripe rust of wheat, which was found to be in confirmation with the findings of Stubbs (1967) and Chen *et al.,* (2014) who reported that stripe rust frequently occurred in the areas having cool and moist conditions with low temperature of 7 to 12^{0}C. Dew formation takes place when the average temperature is at or near the minimum temperature, which provides more hours of free moisture in plain areas that is needed for *Puccinia striiformis* for its establishment on host. Since the minimum temperature in the early part of the growing season of the crop (tillering to stem elongation stage) remained below the optimum temperature (7^{0}C), thus facilitating stripe rust development in the season. A sharp increase in severity of 48, 53 and 49 per in RSP 561 per cent, 54, 45 and 57 per cent HD 2967, 43, 37 and 39 per cent in Agra Local and 58, 34 and 54 per cent in PBW 343 were recorded under early, normal and late sowing conditions, respectively, which may be attributed due to rainfall of 5.0 mm during the previous fortnight which had resulted in decreasing in minimum temperature from 10.2 to 8.8^{0}C, mean wind velocity from 3.3 to 1.2 km/h, rise in RH from 82 to 96 per cent, morning vapour pressure from 11.0 to 14.5 mmHg along with sunshine from 3.8 to 6.9 h/day, during 6th to 8th SMW. The minimum temperature of 11.7^{0}C with maximum temperature of 27.7^{0}C coupled with 8.2 hours of bright sunshine per day were found favourable for faster development of stripe rust of wheat (Singh and Tiwari, 2001). Thereafter, disease progressed gradually and showed maximum severity of 90.00, 86.67 and 73.50 per cent in Agra local, 86.67, 83.33 and 73.33 per cent in PBW 343, 86.67, 83.33 and 71.67 per cent in RSP 561 and 81.67, 73.33 and 61.67 per cent in HD 2967 in 14th SMW under early, normal and late sowing conditions, respectively, with the rise in canopy temperature, soil temperature, sunshine hours, and decrease in relative humidity. Activities of *P. striformiis*, such as germination, penetration and development were hindered due to the rise in temperature during April which prevented further disease development as a result of heat and dryness (Dadrezaei and Torabi, 2001; Salman *et al.,*2006; Lal *et al.,*2008).

The analysis of the relationship between epidemiological factors with severity of stripe rust in different wheat varieties during the rabi seasons of 2013-14 and 2014-15 revealed that under early, normal and late sowing conditions, at three dates of sowing the severity in RSP 561 had significant and positive correlation with maximum temperature (‘R’= 0.833, 0.825 and 0.833, respectively), minimum temperature (‘R’= 0.840, 0.835 and 0.842, respectively), morning vapour pressure (‘R’= 0.723, 0.710 and 0.690, respectively) evening vapour pressure (‘R’= 0.838, 0.806 and 0.836, respectively), evaporation (‘R’= 0.683, 0.673 and 0.687, respectively), canopy temperature (‘R’= 0.805, 0.783 and 0.809, respectively), soil temperature (‘R’= 0.916, 0.916 and 0.917, respectively) and age of the crop (‘R’= 0.986, 0.981 and 0.988, respectively), followed by maximum RH which was significantly and negatively correlated (‘R’= -0.630, -0.649 and -0.651, respectively), whereas, rainfall was moderately and positively correlated (‘R’= 0.546, 0.561 and 0.582, respectively). In case of HD 2967, the disease severity had significantly positive correlation with maximum temperature (‘R’= 0.813, 0.831 and 0.834, respectively), minimum temperature (‘R’= 0.841, 0.842 and 0.847, respectively), morning vapour pressure (‘R’= 0.709, 0.719 and 0.695, respectively) evening vapour pressure (‘R’= 0.798, 0.853 and

0.830, respectively), evaporation (‘R’= 0.668, 0.679 and 0.698, respectively), canopy temperature (‘R’= 0.770, 0.811 and 0.809, respectively), soil temperature (‘R’= 0.912, 0.916 and 0.934, respectively) and age of the crop (‘R’= 0.979, 0.988 and 0.988, respectively) under three sowing conditions (early, normal and late sowing conditions), respectively, followed by maximum RH which was significantly negatively correlated (‘R’= -0.648, -0.643 and -0.639, respectively), respectively, whereas, rainfall was positively moderately correlated (‘R’= 0.562, 0.542 and 0.558, respectively), Also, maximum temperature (‘R’= 0.840, 0.833 and 0.846, respectively), minimum temperature (‘R’= 0.830, 0.829 and 0.841, respectively), morning vapour pressure (‘R’= 0.710, 0.749 and 0.708, respectively) evening vapour pressure (‘R’= 0.844, 0.869 and 0.850, respectively), evaporation (‘R’= 0.695, 0.677 and 0.700), canopy temperature (‘R’= 0.820, 0.797 and 0.831, respectively), soil temperature (‘R’= 0.915, 0.884 and 0.920, respectively) and age (‘R’= 0.989, 0.974 and 0.991, respectively) were significantly positively correlated with severity in Agra Local under early, normal and late sowing conditions, respectively, followed by maximum RH which was significantly negatively correlated (‘R’= -0.637, -0.626 and -0.654, respectively), whereas, rainfall was positively moderately correlated (‘R’= 0.543, 0.501 and 0.547, respectively). Similarly, in PBW 343, the severity had significantly positive correlation with maximum temperature (‘R’= 0.830, 0.841 and 0.854, respectively), minimum temperature (‘R’= 0.828, 0.838 and 0.844, respectively), morning vapour pressure (‘R’= 0.754, 0.730 and 0.708, respectively) evening vapour pressure (‘R’= 0.867, 0.852 and 0.845, respectively), evaporation (‘R’= 0.678, 0.685 and 0.710, respectively), canopy temperature (‘R’= 0.779, 0.824 and 0.858, respectively), soil temperature (‘R’= 0.899, 0.908 and 0.921, respectively) and age of the crop (‘R’= 0.976, 0.987 and 0.991, respectively), followed by maximum RH was significantly negatively correlated (‘R’= -0.586, -0.655 and -0.690, respectively), whereas, rainfall was the only epidemiological factor that was positively moderately correlated (‘R’= 0.502, 0.514 and 0.517, respectively) under early, normal and late sowing conditions, respectively, which was in confirmation to the findings of Ahmed *et al.* (2010), who observed that stripe rust severity had strong correlation with maximum temperature, minimum temperature and sunshine radiation having ‘R’ value of 0.453, 0.299 and 0.465, respectively. Christensen *et al.* (1993) also recorded that temperature in January and February was significantly correlated with severity of stripe rust of wheat. Moisture enhances germination and infection, but availability of free water also inhibits infection by reducing the viability and survival of the pathogen (Chen, 2005). Hyde (1982) reported that air temperature not only affected survival, latent period, growth, infectious period of leaf rust pathogen but also the age and relative susceptibility of host.

The predictive models developed through stepwise multiple regressions of the significant epidemiological variables of two rabi seasons of 2013-14 and 2014-15 depicted that under early sowing conditions, in RSP 561 and HD 2967, maximum and minimum temperature contributed 87.70 and 85.80 per cent variation in the observed disease severity of stripe rust, whereas, in Agra Local, evening vapour pressure, rainfall, morning vapour pressure and canopy temperature contributed 97.40 per cent variation, followed by PBW 343 in which evening vapour pressure, morning vapour pressure and rainfall contributed 92.60 per cent variation. Under normal sowing conditions, maximum temperature and minimum temperature caused 86.30 per cent variation in the severity of RSP 561. While, in case of HD 2967, evening vapour pressure, rainfall, morning vapour pressure and canopy temperature caused 95.60 per cent variation in disease severity. Similarly, in case of Agra Local, evening vapour pressure, rainfall, morning vapour pressure and canopy temperature contributed 97.70 per cent variation, whereas, evening vapour pressure, rainfall, morning vapour pressure and canopy temperature caused 95.50 per cent variation in disease severity of PBW 343. During late sowing conditions, maximum temperature and minimum temperature caused 91.90 and 88.50 per cent variation in the disease severity of RSP 561 and HD 2967, respectively, followed by contribution of 96.70 per cent by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in causing the disease severity of Agra Local. In case of PBW 343, rainfall, morning vapour pressure and canopy temperature contributed 95.60 per cent in disease severity variation. In different prediction equation, the variation (85 to 97%) was caused by thermic (maximum and minimum temperature, canopy temperature) and hydric (rainfall) variables. Urediniospore germination, infection, latent period, sporulation and survival were greatly affected by the temperature. Optimum temperature of 7^0C is reported to be required for germination of urediniospores, 11^oC for infection and 10 to 12^0C for sporulation (Burleigh, 1965; Line, 2002). Thermal and harydic variables were responsible for 94 to 99 per cent and 91 to 98 per cent variation in causing disease severity of leaf rust in wheat (Khan, 1997; Jamshed *et al.,* 2008). Since, environment is a complex system, it is influenced by many variables, where change in one leads to the change in another. Precipitation (rainfall) washes inoculum from the air, reduces light intensity, lowers temperatures and increases the probability of dew formation for several succeeding days, which favours disease development and spread (Eversmeyer and Burleigh, 1969).

Comparison between the observed and predicted values of per cent stripe rust severity of generated through Logistic and Gompertz models, revealed that under different sowing conditions (early, normal and late), Logistic model predicted better with an accuracy of 95 per cent then Gompertz model for primary infection, but gradually the Gompertz model had better prediction with an accuracy of 99 per cent (secondary infection), in all selected wheat varieties. It may be due to the fact that the prediction of severity values by Logistic model allowed misinterpretation of epidemic rates when low disease proportions were encountered, weather they were real differences or errors in disease estimation. Such slight differences in disease proportion at low severities are interpreted correctly by Gompertz transformation (Berger and Luke, 1979). Although the Logistic model (van der Plank, 1963) has been widely used for comparison of the rate of disease progress in several plant pathosystems, but Gompertz model has been proved more appropriate for analysis of the progress of epidemics (Berger, 1981). Similarly, Gompertz model was reported best fitted in various pathosystems especially in polycyclic diseases such as wheat leaf rust, apple scab and groundnut rust (Hau and Kranz, 1977; Analytis, 1979; Das and Raj, 2000).

Three principal components, Pc_1, Pc_2 and Pc_3 having eigenvalues >1were generated through Principal Component Analysis. Among different epidemiological factors, thermic (temperature, canopy temperature, soil temperature) along with biological variables (disease severity in RSP 561, HD 2967, Agra Local and RSP 561 and age of crop) contributed for 59.49, 59.58 and 60.02 per cent variance in Pc_1 having coefficients in range of 0.693 to 0.992, 0.686 to 0.927 and 0.707 to 0.914, respectively, whereas, the light variables (sunshine and cloud cover) were responsible for 16.55, 16.63 and 16.43 per cent variance for Pc_2 having coefficient in range of -0.807 to 0.917, -0.807 to 0.917 and -0.808 to 0.916, however, hydric variables (maximum RH and rainfall) contributed 9.28, 9.29 and 9.28 per cent variance in Pc_3 with coefficient in range of -0.611 to 0.834, -.0.609 to 0.739 and -0.598 to 0.735, under early, normal and late sowing conditions, respectively, which was in confirmation with the findings of who reported that temperature, moisture and light have major role in uredinial infection process and spread of the disease (Rapilly and Foucault, 1976; Welling *et al.,*1988; Wang *et al.*, 2009; Chen *et al.,*2014).

The selected wheat varieties (RSP 561, HD 2967, Agra Local and PBW 343) when subjected to three different leaf wetness duration (12, 24 and 36 hours) under laboratory conditions, 24 hours of leaf wetness duration showed the successful infection of stripe rust with latent period of 7.5 days in both RSP 561 and PBW 343, 8 days in Agra Local and 11.25 days in HD 2967, having maximum pustule size of 9.95 mm each in Agra Local and RSP 561, followed by 9.38 mm in PBW and 9.25 in HD 2967, with severity of 47.50, 22.50, 52.50 and 47.50 in RSP 561, HD 2967, Agra Local and PBW 343, respectively. Whereas, in 36 hours of leaf wetness duration, least latent period of 7.25 days in both RSP 561 and PBW 343, 7.5 days in Agra Local and 9.5 days in HD 2967, having maximum pustule size of 1.05 mm in Agra Local and PBW 343, followed by 0.98 mm in RSP 561 and 0.80 mm in HD 2967 and maximum disease severity of 60 per cent in Agra Local, 57.5 per cent in RSP 561, 54.34 per cent in PBW 343 and 30 per cent HD 2967. The rate of epidemic development is largely influenced by the length of latent period, which determines the number of potential infection cycles that can be completed during a growing season (de Vallavielle-Pope *et al*., 2000). The duration of leaf wetness period determines amount of spore germination and successful infection (Lalancette *et al*., 1988; Madden and Ellis, 1988). Shorter the latent period, more reproduction cycles can occur during the season, which depends on inoculum and lesion density (Gumpert *et al*., 1987). Disease appeared within 12 hours of leaf wetness duration only in Agra Local, which had the latent period of 10 days with pustule size of 0.9 mm and severity of 47.50 per cent. As the latent period also vary with the level of host susceptibility and host growth stages, therefore it is important to studying the pathogen and host dynamics in plant disease epidemiology is of great importance (van Manen and Xu, 2003).

CHAPTER-6

SUMMARY AND CONCLUSION

The present study was conducted to evaluate the effect of epidemiology factors (abiotic and biological) on the disease severity of stripe rust caused by *Puccinia striiformis* in four wheat varieties, RSP 561, HD 2967, Agra Local and PBW 343, under three different sowing conditions (early, normal and late) for two rabi seasons of 2013-14 and 2014-15. The study revealed that during both the rabi seasons, the disease appeared in 1st SMW in all the selected wheat varieties and under all three sowing conditions when the crop was of 73 days after sowing (jointing stage), 53 DAS (stem elongation stage) and 29 DAS (tillering stage) under early, normal and late sowing conditions, respectively, with disease severity of 2.33 per cent each in RSP 561 and Agra Local, 1.67 per cent in HD 2967 and 1.0 per cent in PBW 343. The corresponding weather conditions remained as maximum temperature of 17.5^{0}C, minimum temperature of 5^{0}C, maximum RH of 92.5 per cent, minimum RH 59 of per cent, mean wind velocity of 1.6 km/h, morning vapour pressure of 8.2 mmHg, evening vapour pressure of 9.9 mmHg, sunshine of 2.9 h/day, evaporation of 1.1 mm, morning cloud cover of 3.5 okta, evening cloud cover of 6.0 okta and soil temperature of 11.4^{0}C with canopy temperature of 11.7, 12.3 and 12.9^{0}C, respectively. Sharp increase in disease severity was recorded from 6th to 8th SMW which attributed due to the weather conditions that prevailed during previous fortnight. Maximum disease severity of 90.00, 86.67 and 73.50 per cent in Agra local, 86.67, 83.33 and 73.33 per cent in PBW 343, 86.67, 83.33 and 71.67 per cent in RSP 561 and 81.67, 73.33 and 61.67 per cent in HD 2967 was recorded in 14th SMW under early, normal and late sowing conditions, respectively.

The correlation analysis between epidemiological factors with severity of stripe rust in different wheat varieties during the rabi seasons of 2013-14 and 2014-15 revealed that under all three sowing conditions the severity of disease in RSP 561, HD 2967, Agra Local and PBW 343 had significant positive correlation with maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure, evaporation, canopy temperature, soil temperature, and age of the crop, whereas, maximum RH which was significantly and negatively correlation, however, rainfall was moderately and positively correlated, thereby establishing that these epidemiological factors having correlation coefficient, contributed maximum in initiating and spread of stripe rust.

The predictive models generated through stepwise multiple regressions analysis of the significant epidemiological variables of two rabi seasons of 2013-14 and 2014-15 depicted that under early sowing conditions, maximum and minimum temperature contributed 87.70 and 85.80 per cent variance, respectively, in observed disease severity of RSP 561 and HD 2967, 97.40 per cent by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in Agra local followed by 92.60 per cent variance contributed by evening vapour pressure, morning vapour pressure and rainfall in PBW 343. Under normal sowing conditions, maximum temperature and minimum temperature caused 86.30 per cent variation in the severity of RSP 561, 95.60 per cent variation by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in case of HD 2967, 97.70 per cent contributed by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature caused in disease severity of Agra Local, whereas, 95.50 per cent variation was caused by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in disease severity of PBW 343.Similarly, under late sowing conditions, 91.90 and 88.50 per cent variation in the disease severity of RSP 561 and HD 2967 was contributed by maximum temperature and minimum temperature, respectively, 96.70 per cent by evening vapour pressure, rainfall, morning vapour pressure and canopy temperature in Agra Local and 95.60 per cent variation in PBW 343 was caused by rainfall, morning vapour pressure and canopy temperature. The thermic (maximum and minimum temperature, canopy temperature) and hydric (rainfall) variables were found to cause approximately 85 to 97 per cent variation in the different prediction equations generated through multiple (stepwise) regression.

Logistic models predicted the disease severity better with an accuracy of 95 per cent for primary infection then the Gompertz models which had better prediction accuracy of 99 per cent for secondary infection in all four wheat varieties and under all three sowing conditions, when compared with the observed disease severity of stripe rust. This variation in prediction of disease severity was attributed to the reason that at low disease proportion, Logistic model allowed misinterpretation of epidemic rates, which, otherwise were correctly interpreted by Gompertz models. Overall, Gompertz model was observed to be best fitted in predicting the disease severity of stripe rust in all four wheat varieties and under all three sowing conditions.

Principal component analysis of epidemiological factors revealed that variance in Pc_1 was heavily contributed by thermic (temperature, canopy temperature, soil temperature) and biological variables (disease severity in RSP 561, HD 2967, Agra Local and RSP 561 and age of crop) by 59.49, 59.58 and 60.02 per cent and having coefficients in range of 0.693 to 0.992, 0.686 to 0.927 and 0.707 to 0.914, under early, normal and late sowing conditions, respectively. Whereas, the light variables (sunshine and cloud cover) caused 16.55, 16.63 and 16.43 per cent of variance in Pc_2 having coefficient in range of -0.807 to 0.917, -0.807 to 0.917 and -0.808 to 0.916, respectively, followed by hydric variables (maximum RH and rainfall) which contributed for 9.28, 9.29 and 9.28 per cent variance in Pc_3 with coefficient in range of -0.611 to 0.834, -.0.609 to 0.739 and -0.598 to 0.735, respectively, indicating that temperature, moisture and light are most contributing epidemiological factors for infection process and disease spread.

Under laboratory conditions, the leaf wetness duration of at least 24 hours was found crucial for causing infection, in all four selected wheat varieties (RSP 561, HD 2967, Agra Local and PBW 343), among the three different leaf wetness durations of 12, 24 and 36 hours. Whereas, increase in pustule size from 9.55 to 10.03 mm, 9.25 to 9.38 mm, 9.95 to 11.05 mm and 9.38 to 10.98 mm, disease severity from 47.50 to 57.50 per cent, 22.50 to 30.00 per cent, 52.50 to 60.00 per cent and 47.50 to 54.34 per cent and reduction in latent period from 7.5 to 7.25 days, 11.25 to 9.5 days, 8.0 to 7.50 days and from 7.50 to 7.25 days was observed in RSP 561, HD 2967, Agra Local and PBW 343, respectively, when the selected wheat varieties were subjected to 36 hours of leaf wetness duration.

To sum up, following conclusions were drawn from the present studies:

- The disease appeared in 1st standard meteorological week in all four wheat varieties selected under three different sowing conditions (early, normal and late), when the crop was of 73, 53 and 29 days after sowing, respectively, with maximum disease severity of 2.33 per cent each in RSP 561 and Agra Local, 1.67 per cent in HD 2967 and 1.0 per cent in PBW 343 under early sowing conditions.
- The disease severity of all selected wheat varieties had significant positive correlation with maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure, evaporation, canopy temperature, soil temperature and age of the crop, whereas, maximum RH was significantly negatively correlated, followed by rainfall, that had moderate positive correlation with the disease severity under different sowing conditions.
- Thermic (maximum and minimum temperature, canopy temperature) and hydric (rainfall) variables were found to cause approximately 85 to 97 per cent variation in the observed disease severity in different prediction equations generated through multiple (stepwise) regression.
- Gompertz model having an accuracy of 99 percent was found to be best fitted then Logistic model in predicting the severity of stripe rust.
- The thermic and biological variables were the significant epidemiological variables that contributed for 59.49, 59.58 and 60.02 per cent variance in Pc_{1}, followed by light variables that contributed for 16.55, 16.63 and 16.43 per cent variance in Pc_2 and hydric

variables that contributed for 9.28, 9.29 and 9.28 per cent variance in Pc_3 under three different sowing conditions, respectively.

- Under laboratory conditions, at least 24 hours of leaf wetness duration was required for the appearance of stripe rust disease in all four selected wheat varieties. The latent period decreased, while the pustule size and disease severity increased with the increased in leaf wetness duration (36 hours).

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