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MOULI SAHA

Department of Botany, Acharya Prafulla Chandra College, New Barrackpore, Kolkata 700131

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Blast disease of rice is generally considered the most important rice disease worldwide for its extensive distribution and also for its destructiveness under favourable environmental conditions. The disease incidence and development in time scale in relation to different parameters can be predicted through epidemiological study. Plant disease forecasting is a management system used to predict the occurrence or change in severity of plant diseases. A field experiment was conducted for three consecutive year in kharif season at two different sampling sites in North 24 Parganas, West Bengal to find out the effect of meteorological factors on severity of blast disease. The aim of the present study is to prepare models for predicting the severity, with the aim of helping to prevent or at least mitigate the spread of blast disease. For forecasting of disease severity, the comparative study of three years meteorological data was made. The congenial weather conditions for the infection of blast disease pathogen viz. *Pyricularia oryzae* was recorded. The crop phases during which rapid development of disease takes place were also recorded. Multiple regression analysis (MRA) of *PDI* values with the age of the plant, respective pathogenic spore concentration and with five meteorological parameters was performed. From step down equation, it was found that if the age of the plant and airborne spore concentration, RH and rain fall are increased, disease severity also increases significantly in both the seasons. From Cumulative logit model the covariates with their odds ratios were determined. From all the findings it can be concluded that among meteorological parameters high relative humidity, rain fall and comparatively low temperature are the common factor for disease incidence and severity.

Key words: Aerobiology, blast disease, Box plot, kharif season, PDI, rice

INTRODUCTION

Rice blast, caused by *Pyricularia oryzae* Cavara, (teleomorph, *Magnaporthe oryzae* Couch.) was named as blast by Metcalf as early as 1906 due to devastating damage caused by the disease. Epidemiology is defined as the study of population of pathogen in the population of host and the resulting disease under the influence of environmental factors. Blast disease epidemics can cause huge losses in yield of crops (Miah *et al*. 2013; Pal and Mondal, 2015), causes 70 to 80% yield loss of Rice (Nasruddin and Amin, 2013). It is stated that nearly 80% of crop was lost due to blast in 1920 in South India. The fungus can attack the rice plant at all the stages on the leaves, nodes and panicles though leaf infection is more common. (Pal *et al.* 2017).

*Correspondence : mouli.saha2008@gmail.com

Rice is the main cereal crop and also a main staple food for the people of India. The state West Bengal ranks 1st in India in rice production, producing 14% of the total production in India (Anjaneyulu, 2015). Nearly 72% of agricultural land in West Bengal is under rice cultivation (Anjaneyulu, 2015). It is grown over 58.30 million ha of land with an average yield of 2,256 kg/ha annually. The North 24 Parganas district is the leading producer of rice in West Bengal, where the total area under rice cultivation is about 273.6 thousand ha and its annual production is 2,628 kg/ha (Aktar, 2015).

Airborne fungal spores have an important role in the spreading of many plant diseases causing serious agricultural loss (Kasprzyk, 2008), with occasional epidemics and have direct impact on our food. An airborne fungus which causes plant disease occurs a few days earlier in the atmosphere than the actual appearance of the disease symptoms. The disease forecasting system has served as an important tool in preventing epidemics and successive crop losses (Savary *et al.* 2012). Disease forecasting is more dependable if the reasons for the particular disease development under certain conditions are known. Therefore, aerobiological studies provide evidence to develop database and predictive modelling in order to identify periods of greatest concentration of the fungal propagules in the air, which poses a risk to the crop. Recently lot of emphasis are given on the meteorology based disease prediction models to save the crop from sudden outbreak of the disease. Keeping all these points in view, the present experiment was carried out to find out the most critical meteorological as well as other host and pathogenic factors responsible for the development of leaf blast in southern West Bengal and also to work out prediction equation for forecasting the disease, which may help to reduce the outbreak of the disease.

MATERIALS AND METHODS

Study area

North 24 Parganas, a district in Southern West Bengal, of Eastern India, was selected for the present study. North 24 Parganas extends in the tropical zone from latitude 22º11'6" N to 23º15'2" N and from longitude 88º20' E to 89º5' E. The study area was situated at an elevation of 9.25 meters above mean sea level (https:// www.calcuttaweb.com). It is bordered to Nadia district by North, to Bangaldesh by North and East, to South 24 Parganas and Kolkata by South and to Kolkata, Howrah and Hoogly by West.

Two sites were chosen in North 24 Parganas district for the present study, one site at Barasat and another at Basirhat. The Basirhat site is situated about 42 km South East from the Barasat site.

Rice field in Barasat was situated in the Ganges - Brahmaputra delta region between 22°43' 0" North and 88°31'0" East (https:// www.calcuttaweb.com). The sampling site was more or less square in size which measured 0.053 hectors with an average altitude of 11 meters. The Bangladesh border at Petropole is situated about 80 km from the city. The average altitude is 11 meters. No notable river flows was there. The nearest one is Ganges itself about 15 km to the west. The selected rice field was in the proximity to the Gangetic plain.

Rice field in Basirhat was located on the bank of Ichhamati River (the longer part flows from the Mathabhanga River) between 22°39'26" North, 88°53'39" East (https:// www.calcuttaweb.com). The sampling plot was rectangular in size measured 0.066 hectors.

Sampling technique

Extensive aeromycological survey over the rice fields in North 24 Parganas district of West Bengal was carried out for a period of three consecutive years 2017-2019 to assess the aeromycoflora. Air sampling was carried out in kharif season from July to December at weekly interval in three successive sampling periods during sowing, growing and harvesting periods of rice cultivation in two sampling sites viz. Barasat and Basirhat.

Two volumetric air samplers namely, a Burkard personal one day sampler (Burkard Manufacturing Co. Ltd., England) and an Andersen two stage sampler (Andersen, 1958) were used for trapping *P. oryzae* spores following the methods of the British Aerobiology Federation (The British Aerobiology Federation, 1975).

Collection of meteorological data

For forecasting of blast disease, most commonly used weather variables are maximum and minimum temperature, relative humidity, rainfall and wind speed (Katsantonis *et al*. 2017; Castejon-Munoz, 2008). For Barasat site, weekly records of total rainfall (mm), maximum and minimum temperature (^{0}C), relative humidity (%) and wind speed (mph) were collected from Dum Dum Airport Meteorological Centre which is about 5 km away from the sampling site. For Basirhat site, the meteorological data were obtained from Office of Assistant Director of Agriculture, Administration of Basirhat, 1 km away from the study site.

The climate of the district is tropical and is divided into four seasons viz. winter (December-February), Summer (March - May), Monsoon (June -September) and pre monsoon (October-November).

Observation for disease severity

The disease severity was measured at every subsequent 7 days interval before harvesting of crop. The standard evaluation scale (0-9) of International Rice Research Institute (IRRI), Manila, Philippines (Anonymous 2002) was used (Table1). Evaluation was done on randomly selected plants in each replicated block (total 16 hills/block). Among the total population of the field, sixteen plants were selected as hills (H1- H16) from four corners. Each corner had four plants. The hills were marked by field tag at the beginning of transplantation and marked as H1, H2, H3, H4 to H16.

The following data were collected at 7 days interval from sixteen hills.

1. Number of infected plants in hills.
2. Percentage of infected area on each leaf.
3. Sizes of infection spots.

Disease forecasting

Forecasting is the scientific way of prediction of possible appearance of the disease. It is a component of epidemiology of plant disease. Based on epidemiological knowledge, disease forecasting helps to predict the possible outbreaks or increase of intensity of disease and therefore, allows the farmers to determine whether, when, where and what type of management practice should be undertaken. The comparative study of three years meteorological data was made. The congenial weather conditions for the infection of *P. oryzae* was recorded. The crop phases during which rapid development of infection takes place were also recorded.

Computation of disease severity

The calculation of disease severity was done as percent disease index (PDI). The 10 plants from the replicated hills were randomly selected and PDI per replication was calculated by using the following formula (Wheeler, 1969).

$$\text{Percent Disease Index (PDI)} = \frac{\text{Sum of all numerical ratings}}{\text{Total number of leaf obseved} \times \text{maximum rating}} \times 100$$

The disease severity records were averaged over the four replications and disease progress curves were plotted.

Statistical Modelling

Prediction of disease development based on PDI values along with their respective spore concentration, age of the plant and meteorological parameters was expressed by linear prediction equation. By starting with a full model and eliminating variables that do not significantly enter the regression equation, step down equation was established. For forecasting of disease severity, the correlation matrix is based on PDI or disease scale considering host factor (age of the plant), environmental factors and pathogen concentration. Another approach, cumulative logit models were used for forecasting of the disease which relate

Table 1: Scale for Blast disease of rice 0-9

Scale	Affected leaf area
0	No lesions observed
1	small brown speaks of pin point size
2	small roundish to slightly elongated about 1 -2 mm in diameter
3	same as in scale 2, but on upper leaves also
4	less than 4%
5	4-10%
6	11-25%
7	26-50%
8	51-75 %
9	more than 75%

the disease severity to age of the plant, weather variables and airborne conidia density.

RESULTS AND DISCUSSION

The growth stages of rice can be divided broadly into three phases namely, Nursery stage, Vegetative stage, and Reproductive stage.

Concentration of pathogen

The progress of a disease in a field is an important issue which needs some attention (Brown and Hovmoller, 2002). It is of interest to see how the infection rate of susceptible units at a given time depends on meteorological variables along with number of spores in air (Uddin, 2004). Age of the host plant plays an important role to increase the infection rate. In two different sampling sites, the concentration of *P. oryzae* spores in air gradually increased with increase in age of the crop. The optimum spore concentration of *P. oryzae* in Barasat ranged between 5.19-6.02%, while in Basirhat, it was between 5.34-5.93**%** (Table 2).

Disease scale

According to the degree of infection by *P. oryzae,* the leaves were graded into 10 scales (0-9) as indicated in Table 1 following the standard evaluation system (SES) for rice of International Rice Research Institute (IRRI), Manila, Phillipines (Anonymous 2002). Blast disease symptoms on rice leaves have been presented in Fig. 1.

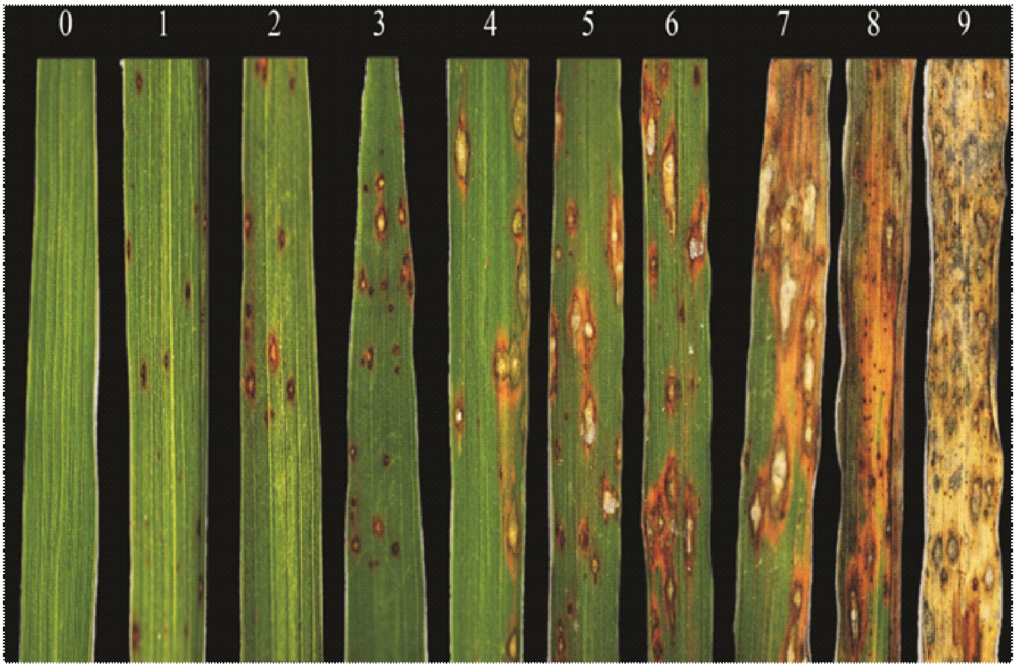

Fig. 1. 0-9 disease scales for blast disease of rice. [0 = no lesion, 1 = small brown speaks of pin point size, 2 = small roundish to slightly elongated about 1 - 2 mm in diameter, 3 = same as in scale 2, but on upper leaves only, 4 = less than 4 %, 5 = 4-10 %, 6 = 11-25 %, 7 = 26-50 %, 8 = 51-75 %, 9 = more than 75 %]

Table 2:Variation in the concentration and contribution (%) of pathogen

Sampling sites	Crop season's total spore/m^3 of air and their percentage contribution to total airspore (%)					
	2017		2018		2019	
	No of spores	%	No of spores	%	No of spores	%
Barasat	529	6.02	505	5.19	479	5.27
Basirhat	534	5.93	495	5.84	486	5.34

Statistical modelling

Disease forecasting system for the rice crop was reported by many workers based on the meteorological parameters and growth phases of the rice crop (Malicdemand Fernandez , 2015). But no aerobiological data has so far been provided for forecasting of diseases of rice crop. Thus, aerobiological studies have to be taken into consideration for disease forecasting system of air borne pathogens. The quantitative assessment of pathogens in airspora, their seasonal variations and the meteorological parameters are closely co-related (Muralidharan, 2006). It has been observed that inoculum responsible for initiating disease in the crop occurred in the air over crop canopy 15-22 days in advance. Thus, it provides a clue for the onset of a particular disease.

In the present study, all the data were analysed to multiple regression analysis (MRA) and correlation matrix were worked out under three different diseases with respective crop seasons.

Correlation matrix

While using Percent Disease Index (PDI) data, which is continuous in nature, fitted a linear regression model:

$$\text{PDI} = Intercept + \beta_1 * Age + \beta_2 * Spore + \beta_3 * maxT + \beta_4 * minT + \beta_5 * RH + \beta_6 * Rain + \beta_7 * Wind.$$

Disease severity in terms of PDI value is positively significant with age of the plant, *Pyricularia oryzae* spore concentration, RH and rainfall but is negatively significant with maxT. That means as the age (0.85), spore concentration (0.58), RH (0.41) and rainfall (0.3) increase the PDI values also increase significantly, but as the maxT (-0.51), minT (0.73) increase the PDI value decrease significantly (Table 3). Correlation of determination (R^2) value between disease severity and seven groups of independent variables are 0.85 (Table-3). This finding bout the role of maxT and minT on disease severity has similarities with the findings of Irabanta and Munanthoi (2000) and Neetam *et al.* (2014). Shafaullah *et al*. (2011) also revealed that blast disease severity increases with the decrease of temperature. According to Kim *et al.* (2017) specific rice varieties have considerable assistance to rice blast researchers, especially in comparison with conventional rice blast predictions.

From the step down equation it can be concluded that only age is positively and significantly correlated with disease severity and it is revealed that with an increase in age by one unit there may be an increase in disease severity (PDI value) by 0.67516 unit (Table 4). It is further confirmed by high R^2 value (0.82) indicating that 82% change in disease severity is due to positive influence of age. The step down equation is

$$\text{PDI} = 5.311 + 0.67516 * Age$$

Proportional – odds cumulative logit model

Ordered logistic regression or Proportional-odds cumulative logit model is a regression model for ordinal dependent variables, first used by McCullagh (1980) and is found to be the most popular model for ordinal data. This model uses cumulative probabilities upto a threshold, thereby making the whole range of ordinal categories binary at that threshold. Let the response be

Table 3: Correlation matrix of blast disease severity with host factor, pathogen concentration and environmental factors

	PDI	Age	Spore	maxT	minT	RH	Rain	Wind
PDI	1	0.85*	0.58*	-0.51*	-0.73*	0.41*	0.3*	0.25
Age		1	0.71*	-0.57	-0.81	0.42	-0.35	-0.33
Spore			1	0.26	0.38	0.14	0.25*	-0.31
maxT				1	0.65	0.15	0.03	0.01
minT					1	0.58	0.27	0.19
RH						1	0.3*	0.09
Rain							1	0.12
Wind								1

$Y = 1,2, \ldots, J$ where the ordering is natural. The associated probabilities are $\{\pi_1, \pi_2, \ldots, \pi_J\}$ and a cumulative probability of a response less than equal to k is:

$$P(Y \leq k) = \pi_1 + \pi_2 + \cdots . + \pi_k$$

Then a cumulative logit is defined as

$$\log(\frac{P(Y \leq k)}{P(Y > k)}) = \log(\frac{P(Y \leq k)}{1 - P(Y \leq k)}) = \log\frac{\pi_1 + \pi_2 + \cdots . + \pi_k}{\pi_{k+1} + \pi_{k+2} + \cdots . + \pi_J}$$

This explains the log-odds of two cumulative probabilities, one less-than and the other greater-than type which quantifies how likely the response is to be in category k or below versus in a category higher than κ

The sequence of cumulative logits may be defined as:

$$L_1 = \log\frac{\pi_1}{\pi_2 + \pi_3 + \cdots . + \pi_J}$$

$$L_2 = \log\frac{\pi_1 + \pi_2}{\pi_3 + \pi_4 + \cdots . + \pi_J}$$ and so on

In this notation, Lκ is the log-odds of falling into or below category κ versus falling above it. Suppose we incorporate covariates into the model, like this:

$$L1 = \alpha_1 + \beta_1 X_1 + \beta_2 \times 2 + \ldots . \beta_p \times p$$

$$L2 = \alpha_2 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p$$ and so on

In this model, intercept ακ is the log-odds of falling into or below category *j* when . A single parameter βκ describes the effect of Xκ on Y such that βκ is the increase in log-odds of falling into or below any category associated with a one-unit increase in Xκ, holding all the other X-variables constant. Therefore, a positive slope indicates a tendency for the response level to decrease as the variable decreases.

This model is called the proportional-odds cumulative logit model. One of the assumptions underlying ordinal logistic regression is that the relationship between each pair of outcome groups is the same. It describes a linear relationship of the logit of the odds ratio of the response being below/above a particular category with explanatory variates. It is found to be the extension of the common logistic model having only two possible outcomes (i.e., diseased or healthy). Hence, cumulative logit models are actually a class of generalized linear models, taking for granted that the errors follow a binomial distribution. This model satisfies

$$log\{\frac{P(Y \leq j|x\_1)/P(Y > j|x\_1)}{P(Y \leq j|x\_2)/P(Y > j|x\_2)}\} = \beta(x1 - x2)$$

For all j (i.e., proportional odds property, hence it is also known as proportional odds model). Thus, β estimates the change in the cumulative odds ratio for one unit increase in the explanatory variate x. A fter estimation of variables involved in cumulative logit model, it can be revealed that age, spore, Rh are positively associated, while maxT is negatively associated with the disease severity (Table 5). In one unit increase in age or *Pyricularia oryzae* spore concentration or RH, there is 0.0113 unit or 0.0381 unit or 0.035 unit increase in the expected value of disease severity in log odds scale. With increase in *Pyricularia oryzae* spore concentration by one unit, 0.0381 unit, there is increase in the expected value of disease severity in log odds scale, in one unit increase in RH, 0.035 unit increase in the expected value of disease severity in log odds scale keeping all other variables as constant (Table 5). On the other hand, when maxT is decreased by one unit, there will be 0.207 unit increase in the expected value of disease severity respectively in log odds scale, Pal *et al*. (2017) also indicated that Maximum RH exhibited significant positive effect on disease severity but maximum temperature increment caused significant negative contribution towards the disease. Asibi *et al.* (2019) reported with long periods of rainy and cloudy conditions, both growth of rice and its resistance to rice blast are weakened. According to some workers (Greer and Webster, 2001; Kapoor *et al*. 2004; Neupane and Bhusal, 2021), the most suitable conditions for the outbreak of blast fungus are cloudy weather, high relative humidity (93-99 percent), low night temperatures between 15-20°C.

BOX - whiskers plot

From all the findings it can be concluded that spore is the common factor for all these three rice disease incidence and severity. Hence, Box - whisker plot analysis has been done where spore concentration is only taken into consideration with disease severity.

The disease severity in terms of disease scale 0-9 is converted to five disease grades viz. 'Absent', 'Low', 'Moderate', 'High' and 'severe'. Box-whisker

Table 4: Step down formulation for disease severity of rice crop in terms of PDI values

Significant cofactor	Estimate	R^2 for the whole model	Step down equation	R^2 for the step down model
Age	6.7516	0.85	*PDI* = 5.311 + 0.67516**Age*	0.82

Table 5:Estimate of parameters involved in cumulative logit model along with their odds ratio.

Significant cofactors	Value	Standard error	p value	Odds ratio
Age	0.0113	0.0009	0.02	1.0114
Spore	0.0381	0.0108	0.0004	1.0388
RH	0.035	0.0164	0.0312	0.9652
maxT	-0.207	0.084	0.0142	0.8133

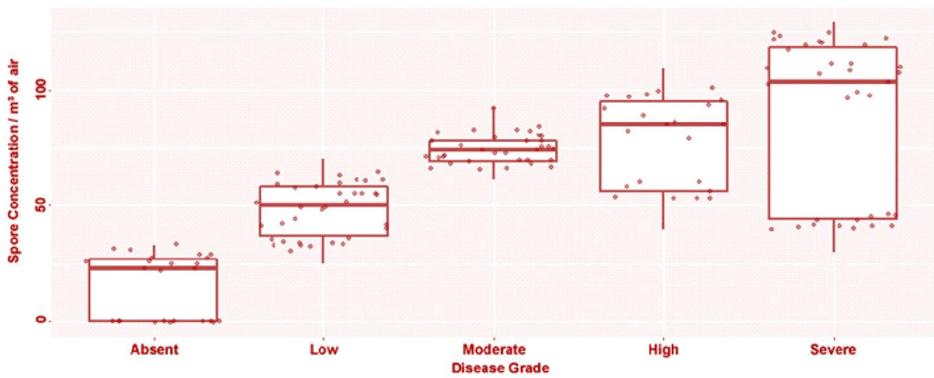

Fig.2:Box-whisker plots showing the blast disease severity

plots show the disease grade along with spore concentration of the respective causal organism at different times of crop development for both the seasons.

For 'Severe' grade the interquartile range is higher nearly 100 which was followed by 'High', 'Abesnt' 'low' and 'Moderate' disease grade. With the increase in median values of spore concentration/ m^3 of air, disease grade also changes from lower grade to higher grade. Here except 'Moderate' diseases grade all other disease grades shows the distributions are skewed right (Fig. 2).

The present investigation confirms a correlation between concentration of *P. oryzae* spores over rice fields, age of the crop and meteorological parameters along with disease incidence vis-a-vis severity of blast disease. It is observed that inocula responsible for initiating diseases in the crop occurred in the air over rice field 2-3 weeks in advance. Among meteorological parameters RH and rainfall exhibited significant positive effect but maximum temperature have negative contribution towards the disease severity. Although this study was based on data from West Bengal, the findings and developed system will be helpful for the various regions in which rice is grown.

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REFERENCES

Aktar, N. 2015. Agricultural productivity and productivity regions in West Bengal. *North- Eastern Hill Univ. J.***13**: 49-61.

Andersen, A.A. 1958. New sampler for the collection, sizing and enumeration of viable airborne particles. *J. Bacteriol.* **76**: 471-484.

Anjaneyulu, M. 2015. Economic analysis of area, production and productivity levels of paddy in India. *EPRA Inter. J. Econ. Business Rev*. **12**:127-132.

Anonymous, 2002. Standard evaluation system for rice. International Rice Research Institute (IRRI), Manila, Philippines.

Asibi, A.E., Chai, Q., Jeffrey A. C.2019. Rice Blast: A Disease with Implications for Global Food Security. *Agronomy*. **9**: 1-14.

British Aerobiology Federation. 1975. *Pollens and spores – A guide to trapping and counting*. 1st ed. – Kimberley Clark Ltd.Lakefield, Aylesford UK.

Brown, J.K.M., Hovmoller, M. S. 2002. Aerial dispersal of pathogens on the global and continental scales and its impact on plant disease. *Science***297**: 537-541.

Castejon-Munoz, M. 2008. The effect of temperature and relative humidity on the airborne concentration of *Pyricularia oryzae* spores and the development of rice blast in Southern Spain. *Span. J. Agric. Res*. **6**: 61-69.

Greer, C. A., Webster, R. K. 2001. Ocurrence, distribution, epidemiology, cultivar reaction, and management of rice blast disease in California. *Plant Dis*. **85**: 1096-1102.

Irabanta Singh, N., Munanthoi Singh, N. 2000. Aerobiology and Epidemiology of rice blast disease in Imphal, Manipur. *Proc. Intl Conf. on Plant disease management for sustainable Agriculture. Publ.IPS, New Delhi*: 1010-1011

Kapoor, A. S., Prasad, R., Sood, G.K. 2004. Forecasting of rice blast in Kayra district of Himachal Pradesh, *Indian Phytopathol.* **57**: 440-445

Kasprzyk, I. 2008. Aeromycology-main research field of interest during the last twenty five years. Ann. *Agric. Environ. Med*. **15**: 1-7.

Katsantonis, D.; Kadoglidou, K., Dramalis, C., Puigdollers, P. 2017.Rice blast forecasting models and their practical value: A review. *Phytopathol. Mediterr*. **56**: 187–216

Kim, Y.; Go, J.; Kang, I.J.; Shim, H.-W.; Shin, D.B.; Heu, S.; Roh, J.-H. 2016 Distribution of rice blast disease and pathotype analysis in 2014 and 2015 in Korea. *Res. Plant Dis*. **22**, 264–268.

Malicdem, A. R., Fernandez, P.L. 2015 Rice Blast Disease Forecasting for Northern Philippines. *Wseas Trans. Inform. Sci.Applic.* **12**: 120-129.

McCullagh, P. 1980. Regression models for ordinal data. *J. Royal Statist. Soc*. : series B (Methodological). **42**: 109-142.

Metcalf, H. 1906. A preliminary report on blast of rice, with notes on other rice diseases. *Bulletin* South Carolina Agricultural *Experiment* Station. **121**:43.

Miah, G., Rafii, M.Y., Ismail, M.R., Puteh, A.B., Rahim, H.A., Asfaliza, R., 2013. Blast resistance in rice: a review of conventional breeding to molecular approaches. *Mol. Biol. Rep*. **40:** 2369-2388.

Munoz, M.C. 2008. The effect of temperature and relative humidity on the airbone concentration of *Pyricularia oryzae* spores and the development of rice blast in southern Spain. *Span. J. Agric*. **6**: 61-69.

Muralidharan, K. 2006. Variability, the weapon in the combat between plant and pathogen as illustrated with rice and blast. In: *Plant Protection in New Millennium, Vol. 1* (Ashok V Gadewar and BP Singh eds.), Satish Serial Publishing House, New Delhi. Pp 69-108.

Nasruddin, A., Amin, N., 2013. Effects of cultivar, planting period and fungicide usage on rice blast infection levels and crop yield. *J.Agril. Sci*. **5**: 160-167.

Neetam, R.S., Tiwari, R.K.S., Bahadur, A.N., Singh, D.P., Patel, D.P. 2014. Effect of sowing dates and meteorological factors on the development of blast disease in finger millet crop. *Amer. Inter. J. Res. Formal, Appl.Natur. Sci.***5**: 1-5.

Neupane, N., Bhusal K. 2021. A Review of Blast Disease of Rice in Nepal. *J. Plant Pathol.Microbiol*. **12**: 1-5

Pal, R., Mandal, D. 2015. New fungicides for the management of leaf blast disease of rice. *Indian J. PlantProt*.**43**: 389-391.

Pal, R., Mandal, D., Sen Naik, B. 2017. Effect of different meteorological parameters on the development and progression of rice leaf blast disease in western Odisha. *Inter.J. Plant Protect*. **10:** 52-57.

Savary, S., Nelson, A., Willocquet, L., Pangga. I., Aunario. J. 2012. Modelling and mapping potential epidemics of rice diseases globally. *Crop Protect*. **34**: 6-17.

Shafaullah Khan, M.A., Khan, N.A., Mahmood, Y. 2011. Effect of epidemiological factors on the incidence of paddy blast (*Pyricularia oryzae*) disease. *Pak. J. Phytopathol.***23**: 108-111.

Uddin, N. 2004. Air spora studies over a rice (high yielding variety) field in rabi season in the state of West Bengal,Iindia. *Aerobiologia*. **20**: 127-134.

Wheeler, B. E. J., 1969. *An introduction of plant disease*. John Wiley and Sons Limited, London : 301.