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Rice blast modeling and forecasting

Omkar Singh, Jagadeesh Bathula and DK Singh

Abstract

Rice *(Oryza sativa*) is a major food crop, on which two-third of the world population subsists wholly or partially. Several pests and diseases affect the rice crop round the year. Rice blast is one of the major diseases of rice crop which causes 40-70 percent yield loss. It is caused by a fungal pathogen, *Pyricularia oryzae* (telemorph, *Magnaporthe grisea*). Several environmental factors are known to influence sporulation and spore dissemination. Temperature between 19-29 ˚C, particularly in the range of 23-26˚ C, and more than 16 hr of relative humidity above 90 percent are considered to be highly favorable conditions for blast development. Simulation studies using data from tropical and subtropical areas have shown that temperature changes may bring about years that are blast conducive. Forecasting techniques could be used to identify that which years are conducive and whether fungicide application would be cost-effective or risky under those conditions. Rice farmers in most developing countries demand immediate results once disease problems are encountered. For this reason, fungicides are still the preferred control measures against diseases like blast and to counter this, better forecasting schemes for tropical conditions are solely needed. Several rice blast forecasting models have been developed for the prediction of rice blast disease, out of which computer-based prediction models are most important. EPIBLA, BLASTAM, BLASTL, and EPIBLAST are the computerized forecasting systems which has been developed to simulate the incidence and progress of rice blast in the field. A computer-based simulation model was also developed in Kangra district of Himachal Pradesh in 1999 for the prediction of rice blast. Many of the control practices useful in reducing plant diseases are of limited use to control rice blast. Since blast is present in most rice growing areas, and it has such a wide host range, eradication and crop rotation are of little value. Method and rate of nitrogen application highly influence the disease development. Chemicals such as Probenazole, Tricyclazole, Propiconazole, Azoxystrobin and Isoprothiolane were found to be effective against rice blast disease, forecasted weather products and area wise weather networks are becoming prevalent. The use of predictive models can help growers to manage disease in their crops which will increasingly be a part of an overall IPM program.

Keywords: forecast, fungicide, rice blast, IPM, conducive

Introduction

Rice (*Oryza sativa* L.) is one of the most important crop since it is used as the primary energy source by most world continents. Human consumption accounts for 85 percent of the total production of rice, compared with 60 percent for wheat and 25 percent for maize (IRRI, Rice Almanac, 1993) [8]. Rice is the staple food for more than 50 percent world population and 85 percent Indian population. Rice is originated from South East Asia (Indo – Burma region) and belongs to the family, *Poaceae*. More than 90 percent of the world's rice is grown and consumed in Asia where 60 percent of the earth's people live (Kole, 2006) [22]. Globally rice occupies an area of 163 m ha with a production of 719 m t of paddy (FAO, 2014) [6]. India is one of the leading producers of rice. It is cultivated in an area of 44 m ha with a production of 105.28 m t (2013-14 FAO). W.B (14.28 per cent), U.P (13.70 per cent), A.P (10.94 per cent), Punjab (10.81 per cent), Bihar (7.15 percent), Odisha (6.93 per cent) and Chhattisgarh (6.28 per cent) jointly contributes about 70 per cent of the National rice production.

Rice is known to be attacked by many pests and diseases which cause huge losses annually worldwide. Among fungal diseases of rice, rice blast caused by *Magnaporthe oryzae* is of economic importance. It causes about 40-70 percent yield loss annually which is highest among all disease yield losses in rice. Outbreaks of rice blast is a serious and recurrent problem in all rice growing regions of the world. In India, blast was first recorded in 1913 and the first devastating epidemic was reported in 1919 in the Tanjore delta of erstwhile Madras area. A 4 per cent reduction in yield due to blast was estimated for the first time in India. During 1960–1961, the total loss due to blast was 2, 65,000 t. Seven epidemics of blast happened between 1980 and 1987 in the states of Himachal Pradesh, Andhra Pradesh, Tamil Nadu and Haryana resulting in huge yield losses. It is estimated that each year enough of rice is destroyed by rice blast alone to feed 60 million people (Zeigler, Leong, & Teng, 1994) [42, 48]. Rice blast probably the disease known as rice fever disease in China as early as 1637 and then reported in Japan (1704), Italy (1828), USA (1876) and in India (1913). It is a disease of immense importance in temperate, tropical, subtropical Asia, Latin America and Africa and found in approximately 85 countries throughout the world. Blast is known to attack nearly all above ground parts as well as during all growth stages of plant.

Crill *et al.* (1982) [4]. Reported that it is the only rice disease that has ever caused serious problems in Korea. In Japan, an epidemic in 1953 caused yield reduction of about 800,000 tons (Goto, 1965) [7]. In the Philippines, production losses of over 90 per cent were estimated in two provinces during 1962 and 1963 (Villareal, 1979) [46]. In India, large scale epidemics were reported to cause losses of more than 65 per cent in Madras area and in some peninsular regions (Padmanabham, 1965) [32].

Symptoms

It causes disease at seedling and adult stages on the leaves, nodes and panicles. On leaves, lesions are typically spindle-shaped, wide in the center and pointed toward each end. Large lesions usually develop a diamond shape with grayish center and brown margin. Under favorable conditions, lesions on the leaves expand rapidly and tend to coalesce, leading to complete necrosis of infected leaves giving a burnt appearance and can easily be seen from a distance. Hence the name rice blast given to this disease. The node region of the plant is also infected by the pathogen and also infect the panicles affecting the seed formation. Lesions can be found on the panicle branches, spikes and spikelets. There are different stages of rice blast and they are known as leaf blast, collar rot, nodal blast, and panicle blast. The development of the blast pathogen in epidemic proportion is influenced by the presence of inoculum, susceptible stage of the host and period of favourable environmental conditions. Temperature between 19-29 ˚C, particularly in the range 23-26 ˚C, and more than 16 hr of relative humidity above 90 percent are considered to be highly favorable conditions for blast development (Choong *et al*.,1988) [3].

Pathogen description

Rice blast caused by a heterothallic, unitunicateascomycete fungus, *Magnaporthe grisea* (anamorph= *Pyricularia grisea* (Cooke) Sacc.) infecting more than 50 hosts including weeds like *Echinochloa colona, Leptochloa chinensis* etc. The carryover of blast inoculum from one season to the next appear not to be an important factor in the tropics because conidia are present throughout the year in air, but it plays an important role in the disease cycle in temperate regions. In temperate and subtropical regions, the pathogen overwinters as mycelium and conidia on diseased straw and seeds. In hilly areas of India, the fungus overwinters within straw piles or in straws covered with winter snows.

Disease development

The mature conidia becomes airborne and lodge on the surface of rice plants, mainly on leaves and germinates in the presence of a thin film of water by germtube. Water film consisting of rain, dew or guttation drops are essential for germination and formation of appressoria between 10 ˚C and 33 ˚C, optimum being at 25 ˚C to 28 ˚C for germination and between 16˚c and 25 ˚C for appresoria formation. An appressorium formation starts generally 4 hr after absorption of water. The average time for appressoria formation ina population of conidia is 11 hr, optimum being at 24 ˚C.The infection peg produced from appressorium penetrates the cuticle or epidermis or enters leaf tissue through stomata. The presence of dew period plays an important role in penetration and colonization. A minimum period of 6-8 hr at 25 ˚C is sufficient to initiate the infection, whereas at other temperature a longer period is required. The period required to invade the host cells by conidia varies from 10 hr at 32 ˚C to 8 hr at 28 ˚C or 6 hr at 24 ˚C. The initiation of infection occurs from 5-7 hr at 21-27 ˚C and 8 hr at 18 ˚C after deposition of conidia on wet leaves and almost all conidia completes infection at these temperatures within 18 and 24 hr, respectively. The lesion appears in 13-18 days at 9-10 ˚C, lesion becomes twice as long as in 7 days. Conidiophore develop within 2-4 hr and mature within 4-6 hr if placed in water saturated conditions and produce conidia within 40 min. The fungus sporulates in the temperature range of 12 ˚C to 34˚C with an optimum of 28˚C and relative humidity over 89 percent with an optimum of more than 93 per cent. Under the normal conditions spore release which may commence after 4-5 hr and the cycle goes on (Bhatt, 1992) [1].

Rice blast epidemiology in relation to the physical environment

Epidemics of blast disease result from favorable interaction between components of the pathosystem. Given a compatible host-pathogen relationship, crop growth and disease severity rely primarily on the existing ambient and edaphic environmental conditions. As in most air-borne pathogens, the life cycle of *P. grisea* is a series of overlapping monocycles that make up a polycyclic process during the growing season. Each stage in the monocycle is affected by weather conditions either directly or indirectly through plant predisposition either immediately or with some time lag.

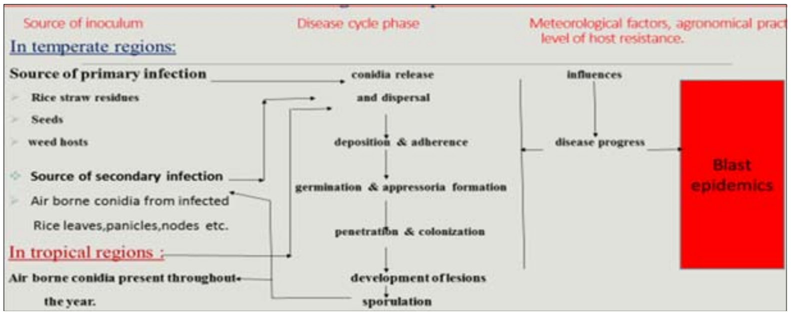


Fig 1: Shows Relationships among inoculum sources, disease cycle phase and disease development leading to blast epidemics.

Initial inoculum survival

The beginning of epidemics depends on the viability of initial inoculum. Blast conidia survive in plant residues, in living tissues or in seeds. Dissemination of *P. grisea* by air is considered the most important means of long-distance transport in triggering outbreaks. Once spores are air-borne, temperature and relative humidity influence survival. In temperate regions, conidia survive in low temperature regimes.

In tropical regions, high temperature during the dry season does not affect *P. grisea* spores because of their ability to withstand temperature beyond 50-60 ˚C (Kapoor and Singh, 1977) [15]. Effect of humidity on survival is not well documented, although some reports have shown that conidia remain viable for a year at 20 per cent relative humidity. In cool temperate rice areas in Japan, conidia and hyphae may survive on nodes of culms of a rice plant for more than a year, under dry indoor conditions, survival may exceed 1,000 days, whereas, viability is lost under moist conditions in soil or compost.

Liberation and dispersal

Several studies shows that liberation of conidia over field and nursery plots have peaks during late night to early morning hours. A study also demonstrated that release of conidia is possible even during noon time under controlled environments. Patterns of spore liberation are affected by several environmental factors. Among these factors, darkness, high relative humidity, wind speed above 3.4 m/s and rainfall over 83 mm/day are most favorable for release.

Temperature, on the other hand, has both direct and indirect effect on liberation due to its contribution to dew formation. Kato (1974) [16, 17]. Reported that a mean temperature of 19 ˚C triggers spore release but Ono and Suzuki (1959) [30]. Believed that release is not temperature-dependent. Other studies have shown that water deposits from dew formation affect spore detachment from conidiophores. *In vivo*, conidia detach readily when water attaches to the junction between spores and conidiophores. Such a mode of liberation is observed even below the optimum microclimatic conditions if spores are mature. Another means of spore liberation is by strong winds and heavy rainfall. Both the immature and mature conidia are released by the shaking of infected leaves and panicles caused by wind velocities of over 3 or 4 m/s or rainfall of more than 83 mm/day.

Successful spore dispersal aided by wind and water (in the form of rainfall or irrigation) has a major impact on the potential of epidemics. Gradients of dispersion for conidia are influenced by dominant wind directions and speed. Both are found important in blast epidemics because of their direct effect on the pattern of spore distribution across crop canopies and across rice fields. The maximum number of spores is observed a few centimeters above ground and tapers-off with increasing canopy height. Similarly, few spores are observed just above the canopy because of wind turbulence. Splash dispersal is the most common form of dissemination by rain or irrigation water. Rainfall or irrigation either increases the build-up of infection due to increased splash dispersion or hinders infection due to washing-off of spores from infected leaves or from spore-laden air. In Korea and Japan the peak of spore dispersion is observed immediately after heavy rainfall. In some blast-prone tropical and sub-tropical areas where continuous rainfall is experienced, heavy downpour may reduce the chance of a disease outbreak. This may be due to washing-off of spores from leaves or to deposition of air-borne spores from rain scrubbing. Kato (1974) [16, 17] and Suzuki (1975) [39]. Reported, that although heavy rainfall causes a decrease in blast occurrence, its contribution to dispersion and to providing moisture for infection significantly influences subsequent epidemic development.

Infection

The infection process consists of three parts: conidial germination, appressorial formation, and penetration. Although these parts require host tissue, the success of completing one stage to the next is also influenced by leaf wetness period, temperature, relative humidity, and soil nutrients. Some simulation models include germination as an on-off function with the presence of free moisture on leaves or panicles as a driving parameter. At 18-38 ˚C, spore germination starts within three hours after spore deposition if host tissues are wet. In *in vitro* studies, germination occurs 4-6 hr after deposition at 12 ˚C and no germination below 5 ˚C. An increase in percent germination is also observed at an optimum temperature range of 20-25 ˚C when spores are incubated in water. Spores that are subjected to dry periods prior to incubation in water have reduced viability.

Appressorial formation occurs 6 hr. after spores are incubated in moist conditions. Studies have shown a variation in range of temperatures required for formation of appressoria. El Refaei (1977) [5]. Examined appressorial formation *in vitro* along with varying relative humidity and found that humidity has no direct relationship to appressorial formation, but a temperature range of 21-30 ˚C is most favorable.

Penetration and colonization of *P. grisea* in host tissues are influenced by both environment and the genetic relationship between host and pathogen. An incompatible relationship can be expressed even under optimum environmental conditions for disease. In most production systems, such incompatibility is broken down as new pathogen races occur among pathogen populations. The impact of environment on infection is obvious once incompatibility is overcome. In general, rate of leaf colonization by the pathogen increases with increasing temperature up to 28 ˚C. The likelihood of panicle colonization, on the other hand, is dictated mostly by a minimum temperature below 21 ˚C. Rainfall differentially affect the success of leaf and panicle infections apparently due to tissue orientation. Heavy rain deposits spores by impaction on panicles which are oriented vertically but it washes off conidia attached on horizontally-oriented leaf surfaces. Panicle infection, however can occur with processes other than impaction which is the reason why a potential simulation model depicting panicle blast patho system should have stochastic processes to explain deposition. Nitrogen fertilization and soil silica content have been shown to influence blast occurrence. Higher nitrogen increases susceptibility of rice to leaf and panicle infections but silica in soil inhibits blast incidence. Lowland fields contain ample amounts of silica due to standing water in the paddy. The physiological mechanism of blast inhibition by silica has been documented but its inclusion in blast simulation models has not been done (Teng *et al*., 1991) [40].

Latency

Latency of infection is affected by the age and degree of susceptibility of the cultivar, temperature, dew duration and soil moisture. Linear and non-linear functions have been generated to show the negative effects of mean temperature on latent period. Teng *et al*. (1991) [40]. Also reported that a decrease in latency of 10 days when temperature increases from 16˚ C to 27˚ C. Latency of blast lesions on rice spikelets appear shorter than those present on panicle axes and neck nodes. At a temperature range of 13-33 ˚C latent periods are 5, 10, and 13 days for spikelet, panicle axes, and neck node lesions, respectively.

Lesion expansion

Rate of lesion expansion is influenced by crop age, lesion age and three environmental factors: temperature, relative humidity, and dew period. Chiba *et al*. (1972) [2]. examined lesion growth at different temperatures and found out that exposure of plants to constant temperature of 25 ˚C and 32 ˚C and variable temperature of 32/20 ˚C or 32/25 ˚C in a 12-hour thermal period caused lesions to expand rapidly for the first 8 days and fall off shortly thereafter. At 16 ˚C and 20/16 ˚C, the rate of lesion expansion was observed to be slow and constant over the 20-day period. Lesions expanded more slowly at 20˚ C and 25/16 ˚C than at higher temperature regimes.

Spore production: During epidemic development, temperature, relative humidity, and light influence the sporulation potential of lesions on both leaves and panicles. However, large numbers of spores are produced by 10 to 15-day old leaf lesions on plants at seedling12 stage regardless of environmental conditions. High sporulation potential is possible at 20 ˚C.

A subsequent decrease in spore production is seen with increasing temperature at 15 ˚C and above 29 ˚C, the amount of spores produced by lesions is the same. Optimum sporulation was found at maximum-minimum temperature combinations of 25/20 ˚C and 25/16 ˚C (Kato and Kozaka, 1974). Suzuki (1975) [39]. reported also that sporulation does not occur below 9 ˚C or over 35 ˚C and that the optimum is 25-28˚ C. Likewise, production is rapid and occurs in shorter periods at 28 ˚C than at 20-25 ˚C. High relative humidity favors sporulation.

The most favorable humidity level is over 93 per cent, but ample spore production is also possible at 85 per cent. In panicle blast, sporulation of lesions is not as affected by relative humidity and spores are produced at 65 per cent. Not much attention has been given to the effect of light on conidial formation. Suzuki (1975) [39] reviewed the effect of light intensity on sporulation. From the review, light indirectly affects sporulation by directly affecting plant resistance. During cloudy days, assimilation of carbon decreases while soluble nitrogen accumulation in tissues increases. When this occurs, physiological activity and resistance of the host are reduced, making plants more vulnerable to pathogen attack. An earlier study by Yoshino and Yamaguchi (1974) [47]. Supports this argument. They reported that shaded plants have a tendency to undergo 'temporary susceptibility' and become infected. Unpublished laboratory studies at the Division of Entomology and Plant Pathology at the International Rice Research Institute (IRRI), however, revealed that sporulation among *P. grisea* isolates grown *in vitro* is enhanced by exposing cultures to continuous fluorescent light for 5-7 days. This practice of enhancing spore production should be explored further to unravel the real effects of solar radiation and sunshine duration on blast incidence.

Disease forecasting

Forecasting is a set of formula's, rules, tables, or algorithms patterned after the biology of a specific pathogen. Models are driven by observed or forecasted weather conditions for each location. Forecasting of plant diseases means predicting for the occurrence of plant disease in a specified area ahead of time, so that suitable control measures can be undertaken in advance to avoid losses. Disease forecasts are predictions of probable outbreaks or increase in intensity of disease. It involves well organized team work and expenditure of time, energy and money. It is used as an aid to the timely application of chemicals and is done on the basis of (a) air temperature(b)relative humidity(c) leaf wetness (dew) (d) precipitationande) others.

General information needed for disease forecasting

Forecasting diseases is a part of applied epidemiology. Hence, knowledge of epidemiology (development of disease under the influence of factors associated with the host, pathogen) is necessary for accurate forecasting. The factors of epidemic and its components should be known in advance before forecasting is done.

The information required for forecasting are:

1. Host Factors: it includes (a) prevalence of susceptible varieties in the given locality (b) response of host at different stages of the growth to the activity of pathogen e.g. some diseases are found during seedling stages while others attack grown up plants and (c) density and distribution of the host in a given locality. Dense populations of susceptible, variety invite quick spread of an epidemic. Growing susceptible varieties in scattered locations and that too in a limited area are less prone to epiphytotic.

2. **Pathogen factor:** which includes (a) amount of primary (initial) inoculum in the air, soil or planting material (b) dispersal of inoculum (c) spore germination (d) infection (e) incubation period (f) sporulation on the infected host (g) re-dispersal / dissemination of spores (h) perennating stages and (i) inoculum potential and density in the seed, soil and air

3. **Environmental factors:** includes (a) temperature (b) humidity (c) light intensity and (d) wind velocity.

Uses of forecasting models: (a) It can be alternative to calendar spray programs (b) enhance timing of fungicide sprays based on disease development (c) spray reduction may be possible (d) economic benefits and (e) environmental benefits

Stages of a model: There are different stages in the establishment of a model which includes (a) development where assumptions & monitoring of variables takes place (b) validation which includes, testing the assumptions and (c) implementation which includes grower trials, release to public.

Model development

Models typically are developed from a combination of laboratory and field studies. The goal is to predict the risk of disease and/or development of inoculum and need to identify key environmental and host variables like air temperature, relative humidity, hours of free moisture (dew), precipitation, host growth stages, etc. Based on management options and goals, action thresholds can be incorporated into the model to provide advice on fungicide applications.

Validation of models

Descriptive models must be validated across a variety of microclimates over a number of years, as pilot studies (multiple locations), multiple seasons (hot, cold, wet, dry weather), sensor placement (canopy, field edge). Models developed in one area are frequently validated by researchers in other areas, may need region-specific modifications. Plants treated according to the model are compared to disease levels managed by traditional spray schedules as well as unsprayed plots.

Model implementation

Predictive models require local weather input. Initial implementation efforts are supported by industry, university researchers and extension agents through field days, demonstrations and on-farm trials. Growers and pest control advisors can use it for enhanced crop management.

Rice blast forecasting

Simulation studies using data from tropical and subtropical areas have shown that temperature changes may bring about years that are blast conducive (Teng *et al*., 1993)[41]. Forecasting techniques could be used to identify that which years are conducive and whether fungicide application would be cost-effective or risky under those conditions. Rice farmers in most developing countries demand immediate results once disease problems are encountered. For this reason, fungicides are still the preferred control measure against diseases like blast (Ou, 1980) and to counter this, better forecasting schemes for tropical conditions are solely needed. Several rice blast forecasting models have been developed for the prediction of rice blast disease, out of which computer-based prediction models are most important. EPIBLA, BLASTAM, BLASTL and EPIBLAST are the computerized forecasting system which has been developed to stimulate the incidence and progress of rice blast in the field.

Epibla

EPIBLA (EPIdemiology of BLAst) is a computerized forecasting system developed to stimulate the incidence and progress of rice leaf blast in the field. A stepwise regression analysis was used to evaluate the model for best fit in predicting atmospheric spores and disease progress on rice cultivars IR50 and IR20.Three equations were used to estimate the number of blast spores and to predict disease incidence. Estimated values were close to observed values. The partial regression coefficient suggest that temperature and relative humidity influence spore dispersal significantly, number of spores, relative humidity (73-100 percent), temperature (14-25 ˚C) and amount of dew significantly affect disease incidence. This model is developed in India by K. Manibhushanrao and P. Krishan in 1991[25]. It is a stepwise regression analysis used to evaluate the model for best fit in predicting atmospheric spores and disease progress. It made 7-day forecasts of disease progression in tropical rice areas in India. EPIBLA was developed following the multiple regression equation.

$$Y = \alpha + \beta_1 x_1 + \beta_2 X_2 + \ldots\ldots\ldots + \beta_n X_n$$

Where, Y, is either the number of spores/m^3 of air or disease incidence, α, the intercept, β, the partial regression coefficients, and X, the predictor variables. In predicting the number of spores in the air, daily values of maximum temperature and maximum relative humidity served as predictors in the equations. The predicted spore amount and the minimum temperature and amount of dew, summed and averaged, respectively over a 7-day period preceding disease onset were used to estimate disease incidence. It has following modeling system,

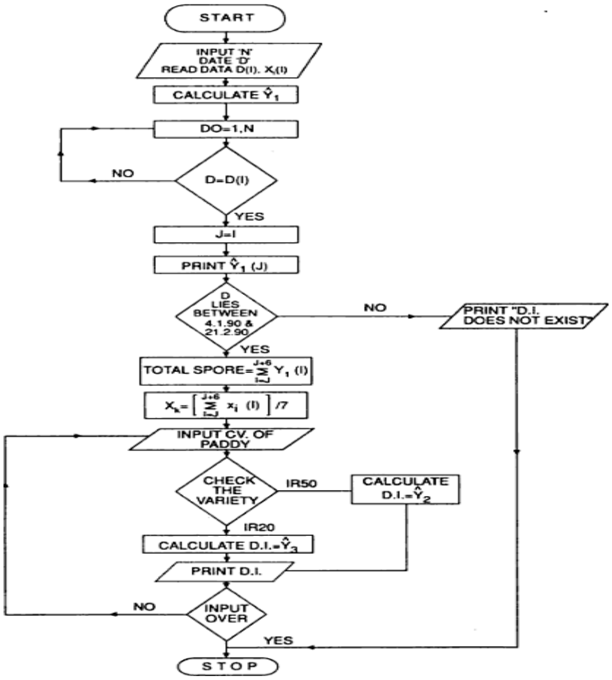


Fig 2: Epibla model for rice blast forecasting

Blastam

In Japan, a computer model was developed by Uehara and co-workers in 1988 [44]. To forecast the occurrence of *P. grisea* in relation to prevailing weather (meteorological) conditions. The model named BLASTAM, estimated leaf blast occurrence and development at the Hiroshima Prefecture from daily weather data supplied by the Automated Meteorological Data Acquisition System (AMeDAS). Leaf blast predictions were found to be nearly accurate but further improvements to estimate panicle blast development are needed. Other forecasting systems in Japan employ not only a deterministic approach but also stochastic functions to accurately predict leaf and panicle blast epidemics (Ishiguro, 1991; Ishiguro and Hashimoto, 1988, 1989) [9, 10,11]. Using the meteorological factors, through AMeDAS, they concluded that precipitation (> 1mm/hr), wet period (10hr) including night, temperature (>16˚c), sunshine duration, wind force are important factors and indicates that when favorable conditions for infection will appear. According to them general epidemics of leaf blast starts about 10 d after first appearance of favorable condition for infection.

Blastl

Developed in Japan by Hashimoto *et.al,* in1984.It is a simulator of leaf blast epidemics and is a systems analytic model originally written in FORTRAN and later rewritten in N88BASIC. The model simulates the pathosystem of leaf blast. The essence of the component is based on a large number of information accumulated earlier. Information on spore penetration and spore formation are the most valuable. Input to the model are several meteorological parameters. Meteorological data used in BLASTL are air temperature precipitation, wind force, duration of sunshine and duration of wet period. Wet period is measures by dew balance whereas other meteorological factors are collected from AMeDAS. BLASTAM, suggests when and where general epidemic will stars. BLASTL shows not only the beginning of a general epidemic, but also how the disease will progressor how susceptible the leaves are. BLASTAM and BLASTL tells the onset of leaf blast epidemics.

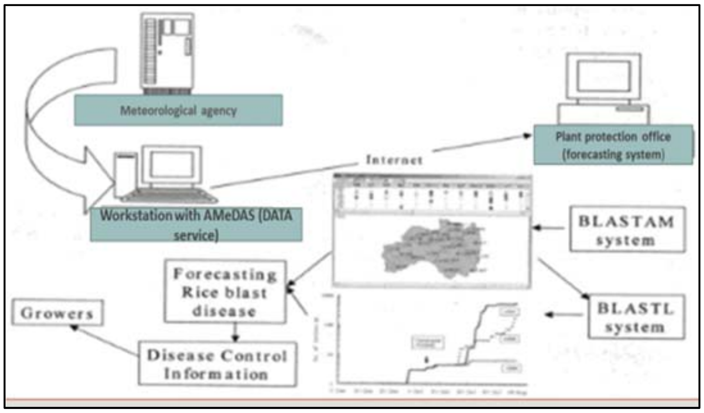


Fig 3: Computer system for public forecasting service for rice blast disease

Epiblast

EPIBLAST was developed in Korea by Chang Kyu Kim and Choong Hoe Kim in 1991 [21]. They experimented and collected field data of the blast fungus to study epidemiology and developed a leaf blast simulation model EPIBLAST. It is devised for quantitative forecasting of the incidence of leaf blast disease. In EPIBLAST, temperature, relative humidity, rainfall, dew period, and wind velocity were taken as meteorological input variables. Healthy, diseased and dead leaf area were plant physiological state variables. Inoculum potential, sporulation, conidia release and dispersal, penetration, and incubation period were by epidemiological processes. The accuracy of EPIBLAST predictions was field tested during the 1991 cropping season and EPIBLAST predicts peak of the leaf blast epidemic in middle of July where it meets with favourable condition for the disease development. It can also predict similar disease progress patterns with direct observation, but some fluctuations were observed due to sensitivity of EPIBLAST to minute weather changes.

In Korea, Kim *et al*. (1988) [20]. Developed a computerized forecasting system based on microclimatic events and then tested it in upland and lowland rice fields. A two-battery-operated microcomputer unit regularly monitored air temperature, leaf wetness, and relative humidity, which were used to predict blast development from estimates of blast units of severity (BUS). BUS were calculated based on algorithms employing logical functions that correlate disease to meteorological variables. The cumulative BUS were then used to predict disease progression.

In another situation, Lee *et al*. (1989) used spore traps to investigate blast outbreaks at Icheon and Suweon, South Korea in relation to temperature, relative humidity, rainfall, sunshine hours, and leaf wetness duration in the field. The amount of spores trapped in samplers was used to predict leaf severity and panicle blast incidence. Differences in disease trends were found between the two sites and were attributed to differences in leaf wetness periods at the sites.

Managing rice blast using forecasting

Forecasting of rice blast in Kangra district of Himachal Pradesh

A.S. Kapoor, R. Prasad and G.K. Sood of department of plant pathology, CSK HPKV Palampur conducted an experiment and found that the overall rice blast severity during 1997, 1998 and 1999 in Kangra district, Himachal Pradesh was mild to moderate. Rainfall amount and distribution varied greatly within the rice growing season. In all the three years, temperature (18-28 °C) and RH (>90 per cent for more than 9 hr.) during crop season were within the optimum range required for disease development. Analyses of 13 years (1984-1996) weather data revealed that the number of days with RH of >90 percent (47 and 27 days) during July to September, number of rainy days in a week and cloudiness were most critical factors in the development of rice blast epidemics during blast years of 1984 and 1992. Moderate to high (10-30 per cent) leaf blast severity in trap nurseries are sown at 15 days interval starting from 1st June or 5-10 per cent leaf blast incidence on trap plants, continued high humidity > 80 per cent, prevalence of low temperature (16-19 ˚C) and maximum temperature (< 28 ˚C) for 6-8 days or cloudy weather and 5-6 rainy days in a week were identified as rice leaf blast rules for predicting blast disease development. Though the quantitative predictive equations developed were not very encouraging some variables *viz*., temperature, hours RH > 90 per cent, wetness duration, rainy days and rainfall amount in different combinations were found to be useful in the prediction of rice blast. Validation of rice blast rules during 1999 revealed 50 per cent reduction in rice blast in managed plots after forecasting and grain yields improved by 30 to 40 per cent. Field trials were conducted during 1998 to 1999 at four locations i.e., Palampur, Malan, Gurkari (Kangra) and Mahakal (Baijnath) and in 1997 at two locations in district Kangra. Blast trap nursery was sown in plot size 1x $0.5m^2$ with susceptible rice cultivars (Himalaya 741, Himalaya 2216, T-23 and HR 12) at 15 days interval starting from June 1 to July 1 at Palampur and Malan for monitoring blast development. The weather data for preceding week from the date of disease appearance were collected. For trap plant method, seeds of two most susceptible rice varieties (Himalaya 741 and T-23) were sown regularly in plastic pots (9 cm dia.) from 1st week of June. Three pots of each variety with 5 seedlings / pot were periodically exposed to field before and after seeding/transplanting of rice. After 3 days exposure, pots were brought back to growth chamber for observation of rice blast infection. Weather data for preceding week of disease appearance and severity level in trap plants were analyzed and critical weather variables were compared for the prediction of rice leaf blast. Weather data of thirteen years (1984-1996) of Palampur location were analysed and compared with the weather of blast epidemic years (1984 and 1992). For the development of prediction models rice blast disease progress was observed in four selected sites of Kangra district. Experiments were laid out with two varieties, Himalaya 741 and Himalaya 2216 at Palampur and Himalaya 741 and T-23 at Malan. Each variety was planted in an area of 100 m^2 with the recommended package of practices i.e. 90 kg N and 40 kg P_2O_5 with 40 K_2O. Two farmer's field were also selected after transplanting of rice at Mahakal and Gurkari. After the appearance of disease, 100 to 200 plants were randomly selected and tagged for recording severity of rice leaf blast at 5/7 days interval. Number of lesions was recorded and mean number of lesions/hill was used for analysis. Neck blast was recorded randomly at 10 spots as percentage of tillers having neck blast in 1 m^2 quadrate area. Only panicles with lesion covering complete around neck or lower part of panicle axis were taken into account for analysis. Grain yield of each plot was recorded after excluding the border rows. Meteorological data were collected from thermo hygrographs fixed in farmer's field and experimental plots at Palampur and Malan. The leaf wetness duration was measured by installing leaf wetness counter fabricated by ICRISAT. The dryness or relative wetness gave zero count whereas rain or dew deposits on the sensor element of the counter gave numerical counts. Each count was taken to represent 6 minutes duration for leaf wetness. So leaf wetness was calculated in hours from the counts. Data on blast and on meteorological conditions were subjected to linear regression analysis. The rainfall and distribution varied significantly within growing seasons during 1979-1999. The average monthly temperature (18-28°C) and RH (> 90 per cent) for more than 9h was within the optimum range for disease development. The overall rice blast incidence was mild (10-20 per cent) to moderate (21-30 per cent) during three years period. The progress of leaf blast was plotted against time at four locations based on data in farmer's field. At all the locations, disease progress curves were mostly sigmoid and invariably reached peak values during 2nd to 3rd week of August during 1997, 1998 and 1999 This indicated that the favourable weather for rice blast development occurs from the second fortnight of August to first fortnight of September. These rules were used for predicting leaf blast at three locations. The data revealed that both phases of blast were reduced by about 50 per cent with suitable measures.

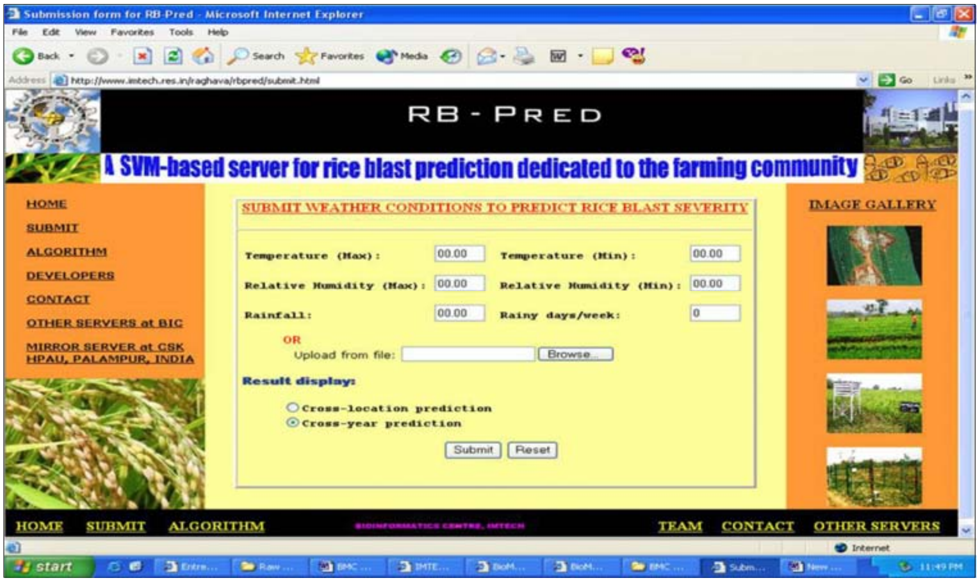
Rice blast management on forecasting system

Location	variety	Leafblast12	Neckblast12	Yield(q/ha.)12	Increase in theyield (%)
Palampur	Himalaya741	36.518.3	19.410.8	15.025.0	40
	Himalaya2216	28.018.2	25.713.5	15.621.2	26.4
Gurkari	Parmal location	40.519.2	25.312.1	10.215.5	34.0
Mahakal	Parmal location	51.512.4	45.225.5	11.516.5	30.0

1= unmaged

2= managed (spray of Carbendazim @0.1% after forecasting)

A new prediction model was introduced which is based on Support Vector Machine (SVM) for developing weather-based prediction models for rice blast which is first of its kind and freely accessible to the farmers at http://www.imtech.res.in/raghava/rbpred/link by Raghava and his co-workers in 2006 [36]. A web-based server, RB-Pred was developed to predict the severity percent of leaf blast. RB-Pred is beautifully designed and is a user-friendly and easy-to-use web server. Users just have to feed the recorded weather variables prevailing in their areas *viz*. temperature (maximum/minimum), relative humidity (maximum/ minimum), rainfall and rainy days/ week data in the 'submit' form of the server. Based on the maximum correlation coefficient and least percent mean absolute error, when the user feed the weather variables, the server classifies them according to these model files and generates the predicted leaf blast severity (per cent) separately for cross-location as well as cross-year predictions. As the cross-year correlation was observed more than the cross-location validation, the predicted blast severity seems to be more accurate for 'cross-year' predictions as compared to the 'cross-location' predictions and thus, the default submit parameter was set on 'cross-year' models.



SUBMIT WEATHER CONDITIONS TO PREDICT RICE BLAST SEVERITY

Temperature (Max): 00.00
Temperature (Min): 00.00
Relative Humidity (Max): 00.00
Relative Humidity (Min): 00.00
Rainfall: 00.00
Rainy days/week: 0

OR

Upload from file:

Result display:

○ Cross-location prediction
● Cross-year prediction

Fig 4: web-based server, RB-Pred.

Rice blast management

Many of the control practices useful in reducing plant diseases are of limited use to control rice blast. Since blast is present in most rice growing areas and it has such a wide host range, eradication and crop rotation are of little value. Although exclusion may appear to be a useless concern, one should keep in mind that pathogen is quite variable and that virulence factors present in one population may not be present in another geographically isolated one. It is probably worth to make sure that rice material moved from one area to another is healthy. Lot of work on developing effective rice blast management strategies has been done over a century. The control measures found effective and utilized in the fields which can be broadly classified as (a)cultural control (b) chemical control(c) host resistance and (d)biological control.

Among these the chemical control is most effective and after forecasting only chemical measures are available and most reliable source to reduce the effect of pathogens but as precaution is better than cure so some of the practices can also be applied prior to disease occurrence to avoid the disease at some extent.

Cultural control

When there were no methods of disease management in the past, cultivation practices were the only mean to control the diseases. These include nutrient management, water management, time of planting, spacing etc. Nutrient Management In case of rice blast, two nutrients *viz*. Nitrogen and Silicon have been found to affect the disease occurrence and development significantly. Since long time back, studies have shown that high N supply always induces heavy incidence of rice blast. Delayed or large top dressings are often responsible for severe disease

A limit of 15 kg N/ha is recommended for upland rice in Brazil, specifically to reduce vulnerability to blast. Plant receiving large amount of N are found to have fewer silicate epidermal cells and thus have lower resistance (Miyake & Ikeda, 1932) [26]. The correlation between silica content and disease incidence was also studied on different cultivars of rice and it was observed that plants with high silica content or large number of silicate epidermal cells had slight damage from blast disease (Onodera, 1917) [29]. So it is suggested that resistance of rice to blast can be increased by applying silica slag in the field (Kawashima, 1927) [19]. Studies conducted at University of Florida USA, showed that reduction in the rice blast with the application of silica (calcium silicate slag) was comparable to that of fungicide (Benomyl) and now silicon fertilization has become a routine practice in Florida rice production. Singh & Singh (1980) [38] reported that application of water hyacinth compost to soil reduces the rice blast disease.

Water Management

The availability of water also affects the susceptibility of host plant to *P. oryzae*. Rice grown under upland conditions is more susceptible than rice grown in flooded soil (Kahn & Libby, 1958) [13]. Under upland conditions, susceptibility is increased further with increasing drought stress. Hence flooding the field in upland rice can reduce the severity of blast.

Time of Planting

Planting time also has a marked effect on the development of blast within a rice crop. For rice blast control early planting is recommended. In tropical upland rice, crops sown early during the rainy season generally have a higher probability of escaping blast infection than late-sown crops, which are often blasted severely. In upland areas of Brazil, farmers are advised to sow early to escape inoculum produced on neighbouring farms (Prabhu & Morais, 1986) [35].

Effect of nitrogen fertilization on disease progress of rice blast on susceptible and resistant cultivars

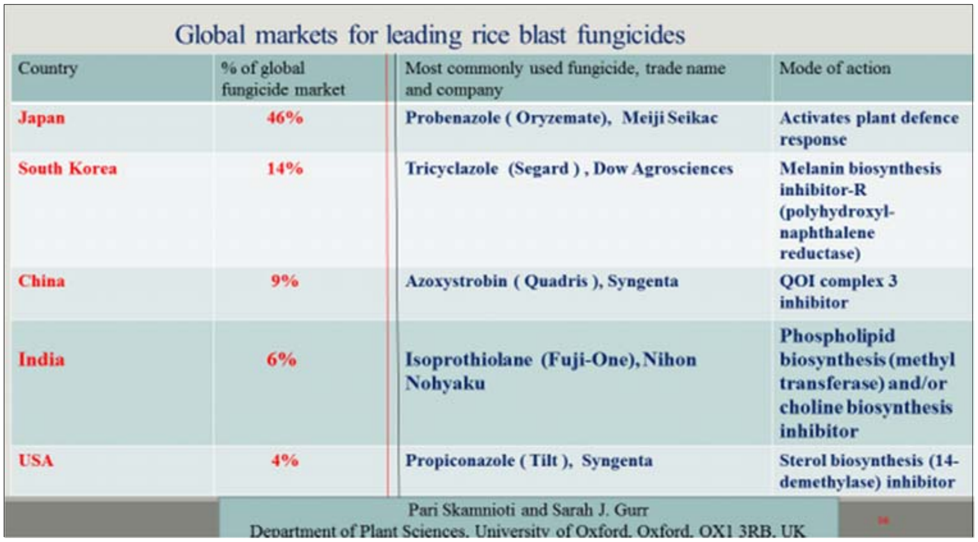
The effects of three nitrogen fertilization treatments on the development of rice blast were studied on eight cultivars under field conditions in Arkansas in 1995 and 1996 by D. H. Long. The eight cultivars (Kaybonnet, Cypress, Lacassine, Mars, Adair, Alan, Newbonnet and RT7015) ranged from resistant to susceptible to blast according to previous field observations. The recommended nitrogen levels for the eight cultivars varied from 123 to 168 kg/ha/year. Three treatments, consisting of different rates and timing of nitrogen applications were tested over 2 years at one location. The first treatment consisted of a single nitrogen (N) application applied to plots at the recommended rate at pre flood during the mid tillering stage. The second treatment consisted of applying nitrogen as a single preflood application but at 1.5 times the recommended N rate used in treatment one. The third treatment (control) consisted of applying the recommended amount of nitrogen fertilizer used in treatment one, but in a three-way-split application with 56 to 100 kg/ha N applied approximately 10 and 20 days after the panicle differentiation (PD) growth stage. Inoculated spreader plots were used to initiate rice blast epidemics in the test plots. The results indicate that the disease progress for rice blast, regardless of N treatments followed a unimodal curve whereby disease incidence and total lesion area per plant reached a maximum near midseason (PD growth stage) and then gradually declined. This decline in disease was attributed to adult resistance, leaf senescence and the formation of new leaves (non infected). Application of nitrogen above the recommended rate for any given cultivar significantly increased disease incidence and total lesion area per plant on all cultivars except Kay bonnet, a highly resistant cultivar. Furthermore, a differential cultivar response to nitrogen was observed when measuring both disease incidence and total lesion area per plant. Leaf blast was significantly more severe on the susceptible and very susceptible cultivars when N fertilizer was applied as a single application at preflood than in the split application treatment. Nitrogen treatments did not significantly affect the incidence of collar rot or neck blast. Eight rice cultivars commonly grown in Arkansas, selected to represent diverse genotypes, maturities and degree of susceptibility to *P. grisea* were grown in replicated field trials at the Pine Tree Branch Experiment Station, Colt, Arkansas, during 1995 and 1996. Experimental plots were planted on 19 April, 1995 and 3 May, 1996. The sites were precision leveled for optimum water management and were bordered by trees on the east and north. The eight cultivars received nitrogen at the recommended rates of 123 to 168 kg/ha/year depending on the recommendation for each cultivar. Three nitrogen (as urea) treatments were tested in a randomized block design (RBD), with four replications of each treatment per cultivar. Plots were drill-seeded at 125 kg/ha in 1.5 × 4.6 m plots of nine rows spaced 17.5 cm apart. The first treatment (Normal-N) consisted of nitrogen (N) fertilizer applied at the recommended rate as a single preflood application (initial tillering stage). The second treatment (High-N) consisted of 1.5 times the recommended rate of N fertilizer, also applied as a single preflood application. The third nitrogen treatment

(Split- N), the standard for the last 10 years in Arkansas, consisted of the recommended amount of N fertilizer applied in three separate applications with 56 to 100 kg/ha (depending on cultivar) of the N fertilizer applied at preflood and the remaining 67 kg/ha of N fertilizer applied 10 and 20 days after PD stage in two equal applications of 34 kg/ha. Inoculation of spreader plots. Rice blast often occurs naturally at the experimental site; nevertheless, artificial inoculation of susceptible "spreader" cultivars (a mixture of M201, M203, and L203) was used to increase disease likelihood. Spreader plots were planted at a seeding rate of 125 kg/ha in 1.5 × 4.8 m plots of nine rows with 17.5 cm between rows. Spreader plots bordered all sides of each plot so that plots would be equally exposed to secondary inoculum. Spreader plants were inoculated with *P. grisea* races IB49 and IC17 at the midtillering stage of rice development, approximately 4 weeks after planting. Seven cultivars used in these studies were susceptible to these two races of *P. grisea*. Conidia of each race were harvested separately from 7 to 10-day-old cultures grown on potato dextrose agar (PDA, Difco Laboratories, Detroit, MI) incubated under continuous light at 25°C. Conidial suspensions of each race were adjusted to 5×10^5 conidia per ml and combined in equal volumes prior to inoculation. Xanthan gum (0.4 g/liter) and Silwet L77 (0.2 ml/liter) were added to the spore suspensions just before inoculation. Two inoculations, 4 days apart, were made on 19 and 23 May, 1995 and 27 and 31 May, 1996 at the midtillering stage within the spreader plots. Inoculations were made between 2200 and 2400 hrs using a compressed air sprayer. The following morning plots were covered with a shade cloth at approximately 0600 hrs to prolong leaf wetness within the canopy. The cloth was removed approximately 30 to 32 h after inoculation. Flood irrigation was employed 1 day after the inoculation of *P. grisea* and was maintained at a depth of 10 to 15 cm throughout the season, as recommended for commercial production. However, since draining rice fields can increase the incidence and severity of rice blast, the plots were drained two times (26 May and 7 June 1995 and 4 and 16 June 1996) for approximately 5 to 7 days prior to the PD growth stage. The incidence and severity of leaf blast, collar rot, and neck blast symptoms were assessed at 7-day intervals beginning 1 week after inoculation of the spreader plots. All leaves on 12 arbitrarily selected plants in each plot were examined to determine the number and size of the leaf blast lesions. Disease incidence was calculated as the percentage of plants that had at least one lesion. Disease incidence of flag leaf collar rot and neck blast was determined at the end of each season by examining 50 arbitrarily collected panicles in each plot. The total lesion area per plant also was determined by counting the total number of lesions per plant and measuring each lesion length and width. The summation of these measurements was reported as total lesion area per plant. The effect of the three nitrogen treatments on leaf blast development was determined over the assessment period by calculating the area under the disease progress curve (AUDPC). Statistical analyses of AUDPCs were calculated for both disease incidence and total lesion area per plant data. AUDPC values were subjected to analysis of variance (AOV) with the GLM and protected LSD procedures in SAS (1990, SAS Institute, Cary, NC). Furthermore, the effect of the three nitrogen treatments on leaf blast development was assessed when leaf blast was at a maximum (17 July 1995 and 8 August 1996) and at the end of each season (prior to panicle emergence). These two sampling dates represent potentially important rice growth stages during leaf blast development that may be important in subsequent neck blast infections and yield loss Data taken at these two sampling points were analyzed as described Symptoms of blast were observed on seven of the cultivars examined for all three N treatments in both 1995 and 1996. No disease was observed on the resistant cultivar, Kaybonnet, during the 2 years. Disease incidence was considerably higher in 1996 (average disease incidence at PD growth stage on the control treatment was 68 per cent) than in 1995 (average disease incidence at PD growth stage on the control treatment was 19 per cent). These differences in disease incidence were attributed to higher temperatures and less rainfall observed in 1995 compared with 1996. Although foliar disease incidence differed among the cultivars and N treatments for both years, the disease progress curves generally followed a unimodal pattern. Disease incidence increased early in the season, consistently reached a maximum near midseason at the PD growth stage, and then generally declined toward the end of the season. This unimodal pattern was observed on the majority of the cultivars regardless of N treatment. Furthermore, not only did the disease incidence (the percentage of plants with at least one lesion) decline after PD growth stage, but there was also a decline in the total lesion area per plant observed following PD growth stage to panicle emergence Significant differences in disease development were observed among the eight cultivars examined. Based on the lack of rice blast development on Kaybonnet, this cultivar was considered immune. Kaybonnet was omitted from further consideration, since no disease was observed for the specified N treatments during the course of the studies.

Chemical control

Chemicals, mainly fungicides are the most frequently and widely used method of plant disease management worldwide. For rice blast most aggressive and successful chemical control program in world has been shown by Japan. The copper fungicides were first effectively used in Japan shortly after the turn of the century and continued to be used until the Second World War (Thurston, 1998) [43] but as they are highly phytotoxic, a more attractive alternative was sought. Subsequently, copper fungicides were used in mixture with phenyl mercuric acetate (PMA) which was more effective than copper alone in rice blast control and were less toxic to the rice plant. Later, discovery was made by Ogawa (1953) [28] that a mixture of PMA and slaked lime provides much more effective control of rice blast and was less toxic and cheap, hence used extensively. However these fungicides are toxic to mammals and are severe environmental pollutants, so banned by Japanese Government in mid-1968. Then the Organophosphorus fungicides were introduced to control blast in Japan but in the late 1970's the reports of resistance in *P. oryzae* to these compounds started emerging. Further studies revealed that resistance to one organophosphorus fungicide did not necessarily confer resistance to other specific fungicides. So it was suggested that rotating the use of fungicides or mixing them, rather than continuously relying on single compound, greatly reduces the risk of developing highly resistant populations. At the same time development and implication of new systemic fungicides was also on progress. The phosphonothioate fungicides, including iprobenfos and edifenphos, were introduced in Japan as rice blast fungicides in 1963. Iprobenfos and isoprothiolane have systemic action and are used mainly as granules for application on the surface of paddy water (soil application). Copper fungicides were found effective for rice blast control in India as well, but it was seen that high yielding varieties (HYVs) were copper-shy, hence the emphasis was shifted to another group of fungicides *viz*., Dithiocarbamate and Edifenphos but they were having shorter residual activity. So in 1974-75, the first generation systemic fungicides, Benomyl, Carbendazim and others were evaluated and found effective. Following these, many systemic fungicides with different mode of action, like anti-mitotic compounds, melanin inhibitors, ergosterol biosynthesis inhibitor (EBI) and other organic compounds were discovered for rice blast control (Siddiq, 1996) [37]. In a chemical scheduling trial Bavistin 1g/L spray at tillering + Hinosan 1g/L at heading and after flowering provided the best yield increase. Tricyclazole and Pyroquilon fungicides as seed dressers have been found effective to provide protection to seed upto 8 weeks after sowing. Some of the recently developed chemicals for blast control are: (a)Carpropamid (1999, melanin biosynthesis inhibitor) (b)Fenoxanil (2002, melanin biosynthesis inhibitor) and (c)Tiadinil (2004, plant activator)

In the most recent field evaluation of commercial fungicidal formulations, Rabicide (tetrachlorophthalide), Nativo (tebuconazole + trifloxystobin) and Score (difenoconazole) are found most effective (Usman, Wakil, Sahi, &Saleem, 2009) [45]. The site-specific fungicides are recommended to be used in mixture or in rotation due to the development of resistance in the pathogen. The non-fungicidal agents are supposedly specific to the target organism and are less likely to lead to resistance problems.



Global markets for leading rice blast fungicides

Country	% of global fungicide market	Most commonly used fungicide, trade name and company	Mode of action
Japan	46%	Probenazole (Oryzemate), Meiji Seikac	Activates plant defence response
South Korea	14%	Tricyclazole (Segard) , Dow Agrosciences	Melanin biosynthesis inhibitor-R (polyhydroxyl-naphthalene reductase)
China	9%	Azoxystrobin (Quadris), Syngenta	QOI complex 3 inhibitor
India	6%	Isoprothiolane (Fuji-One), Nihon Nohyaku	Phospholipid biosynthesis (methyl transferase) and/or choline biosynthesis inhibitor
USA	4%	Propiconazole (Tilt), Syngenta	Sterol biosynthesis (14-demethylase) inhibitor

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Fig 5: Global market for leading rice blast fungicides

Filia is the combi. Product which contains – Tricyclazole (a market leader in controlling blast.) and Propiconazole (which can protect against other plant diseases and also offers crop enhancement properties, ensuring that the rice neck remains strong until harvest time.)

Integrated management

The studies conducted by V. Jaiganesh and A. Eswaran to investigate the efficient usage of bio-control agent *Serratia marcescens*, Nicotinic Acid (NA) and Panchakavya (PK - organic product) for the successful integrated management of rice blast. Combined application of SMS (seed treatment with *S. marcescens* @ 10 g/kg of IR 50 rice seed), NA1 (foliar application of NA @ 0.1 per cent 15 days after transplanting (DAT)) and PK2 (foliar application of PK @ 5 per cent on 30 DAT) significantly reduced the rice blast disease incidence and increased biometrics and yield parameters in both pot and field trials. All the pot trials were conducted at department of plant pathology, faculty of agriculture, Annamalai University, Annamalai Nagar, Cuddalore district, Tamil Nadu, India during 2012-13.The effective treatments observed in different experiments under pot culture experiments (integrated pot culture treatment) were pooled together and a new schedule of treatments for the effective management of blast was evaluated. The treatment details are given below;

T1- *Serratia marcescens* @ 10 g/kg of seed + Two sprays with *S. marcescens* @ 2.5 kg/ha on 15 and 30 DAT. T2- *S. marcescens* @ 10 g/kg of seed + Two sprays with Nicotinic acid @ 0.1 % on 15 and 30 DAT. T3- *S. marcescens* @ 10 g/kg of seed + Two sprays with Panchakavya @ 5 % on 15 and 30 DAT.T4- *S. marcescens* @ 10 g/kg of seed + First spray with *S. marcescens* @ 2.5 kg/ha on 15 DAT + Second spray with Nicotinic acid @ 0.1 % on 30 DAT. T5- *S. marcescens* @ 10 g/kg of seed + First spray with Nicotinic acid @ 0.1 on 15 DAT + Second spray with *S. marcescens* @ 2.5 kg/ha on 30 DAT. T6- *S. marcescens* @ 10 g/kg of seed + First spray with Nicotinic acid @ 0.1 % on 15 DAT + Second spray with Panchakavya @ 5 % on 30 DAT. T7- *S. marcescens* @ 10 g/kg of seed + First spray with Panchakavya @ 5 % on 15 DAT + Second spray with Nicotinic acid @ 0.1% on 30 DAT. T8- *S. marcescens* @ 10 g/kg of seed + First spray with Panchakavya @ 5 % on 15 DAT + Second spray withs *S. marcescens* @ 2.5 kg/ha on 30 DAT.T9- *S .marcescens* @ 10 g/kg of seed + First spray with *S. marcescens* @ 2.5 kg/ha on 15 DAT + Second spray with Panchakavya @ 5 % on 30 DAT.T10 – Un treated control. DAT – Days after transplanting. The datashowed that the disease incidence was minimum in plots sprayed thrice at 15, 30 and 45 DAT (23.6 per cent), followed by plots receiving two sprays at disease initiation (15 DAT) and maximum tillering (30 DAT) stages (24.2 per cent). This was followed by plots received two sprays at 15 DAT and 45 DAT which recorded lower disease incidence (27.4 per cent). The maximum disease incidence was recorded in control plots (68.4 per cent). In their study they found that, Panchakavya spray not only checked the disease incidence but also significantly influenced the grain yield at the harvesting time and also act as plant growth promoter. The earlier report of

Pathak and Ram (2002) [33] clearly showed that Panchakavya influenced the growth and yield characters. The macro and micronutrients present in Panchakavya might be attributed to the positive influence of the treatments in controlling the disease. For this reason, Panchakavya was one of the ingredient which was used by them for their research. The study showed that, the blast incidence was effectively controlled by the combined application of SMS plus foliar application of Nicotinic acid (at 15 DAT) and Panchakavya (at 30 DAT). The disease incidence recorded in T6 was 6.82 per cent. The percent blast incidence was found higher in untreated control. The effect of different treatments on the height of rice crop was also recorded. Among the treatments, the maximum plant height (85.40 cm) was observed in combined application of antagonist and chemicals (T6) and control recorded the least plant height (78.70 cm). Also, all the treated plants had significantly higher number of panicles per clump, when compared to control. However, the treatment T6 recorded maximum number of tillers / clump (15.67) followed by T7 (15.24). Control recorded the lesser number of productive tillers / clump (8.86). All the treatments had increased the panicle length when compared to control. The maximum panicle length (19.56 cm) was observed with T6. The maximum filled grain percentage (86.0 per cent) and maximum thousand grain weight of 19.36 g was observed with T6. The positive influence of various treatments on the grain and straw yield of paddy was well established in the investigation. All the treatments recorded significant increase in grain and straw yield, when compared to control. Of which T6 recorded the maximum grain yield of 7.21 t/ha and straw yield of 9.66 t/ha, respectively.

Future prospects

The highly destructive and variable nature of rice blast has made it a disease of immense importance for the whole of the world. Rice blast forecasting has become important in the present day situation particularly in India and other agricultural advance countries due to a large scale adoption of the strategies which are increasing the food production, as the modern agriculture is cost oriented so by forecasting one can take the suitable management practices ahead of the disease development. The use of predictive models can help growers to manage disease in their crops which will increasingly be a part of an overall IPM program.

Forecasting is very important and is need of today's life, so for this agriculture sectors should be collaborated with the information technology sector to get the maximum benefit. Most of the forecasting system is developed by the developed countries and very few by the developing countries because of the utilization of information technology sectors in agricultural field by the developed ones, as well as there is need of development of more reliable models which are users friendly and easily in the reach of farmers and valid for multiple locations.

Reference

1. Bhatt JC, Singh RA. Blast of rice. In: Singh, U.S., Mukhopadhyay AN, Kumar J, Chaube HS, eds. Plant Diseases of International Importance, vol. I, Diseases of Cereals and Pulses. New Jersey: Prentice Hall,1992, 80-115
2. Chiba S, Chiba J, Shimada K, Kagawa H. Epidemiological studies on rice blast disease: An estimation of infection rate in the field and the influence of some factors on it. Annals of the Phytopathological Society of Japan.1972; 38:15-21
3. Choong D, MacKenzie S, Rush MC. Field testing a computerized forecasting system for rice blast disease. Phytopathology. 1988; 78(7):931-934
4. Crill P, Ham Y, Beachell H. The rice blast disease in Korea and its control with race prediction and gene rotation. In Evolution of the gene rotation concept for rice blast control, Int. Rice Res. Inst., Los Baños, Philippines, 1982, 123-130
5. El Refaei MJ. Epidemiology of rice blast disease in the tropics with special reference to leaf wetness in relation to disease development. Ph.D. thesis. India: Faculty of the Post-graduate School of Indian Agricultural Research Institute, 1977, 195
6. Food and Agriculture Organization (FAO). Food and Agricultural organization of United Nations, 2014. Website: http://FAOSTAT.fao.org.
7. Goto K. Estimating losses from rice blast in Japan. In: The Rice Blast Disease. Baltimore, Md: John Hopkins Press, 1965, 195-202
8. IRRI Rice Ilmanac. International Rice Research Institute, Manila, Philippines, 1993.
9. Ishiguro K. Studies on the forecast of rice blast disease. Annals of the Phytopathological Society of Japan. 1991; 57:298
10. Ishiguro K, Hashimoto A. Development of a simulation model for rice panicle blast epidemics. 1. Composition of the basic model. Bulletin of the Fukushima Prefecture Agricultural Research Station. 1988; 27:1-19
11. Ishiguro K, Hashimoto A. Recent advances in forecasting of rice blast epidemics using computers in Japan. Tropical Agriculture Research Series, 1989; 22:153-162
12. Jaiganesh V, Eswaran A. Integrated management of blast of rice. JPl. Dis. Sci. 2013; 8(1):52-58
13. Kahn RP, Libby JL. The effect of environmental factors and plant age on the infection of rice by the blast fungus, Pyricularia oryzae. Phytopathology.1958; 48:25-30
14. Kapoor AS, Prasad R, Sood GK. Forecasting of rice blast in Kangra district of Himanchal Pradesh. Indian Phytopathology. 2004; 57(4):440-445
15. Kapoor AS, Singh BM. Overwintering of *Pyricularia oryzae* in Himachal Pradesh. Indian Phytopathology, 1977; 30:213
16. Kato H. Epidemiology of rice blast disease. Review of Plant Protection Research. 1974; 7:1-20.
17. Kato H, Kozaka T. Effect of temperature on lesion enlargement and sporulation of *Pyricularia oryzae* on rice leaves. Phytopathology.1974; 64:828-840.
18. Kaundal R, Kapoor AS, Raghava GP. Machine learning techniques in disease forecasting: a case study on rice blast prediction. BMC bioinformatics. 2006; 7(1):485. PM id: 17083731 http://dx.doi.org/10.1186/1471-2105-7-485.
19. Kawashima R. Influence of silica on rice blast disease. Japanese Journal of Soil Science and Plant Nutrition. 1927; 1:86-91
20. Kim CH, MacKenzie DR, Rush MC. Field testing a computerized forecasting system for rice blast disease. Phytopathology. 1988; 78:931-934
21. Kim CK, Kim CH. Predicting rice blast outbreaks in Korea. In: Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea. Manila, Philippines: International Rice Research Institute, 1991, 53-68

22. Kole C. Cereals and millets: Springer, 2006, 1. http://dx.doi.org/10.1007/978-3-540-34389-9
23. Lee JT, Yun SH, Kim CK, Im JN, Jung YS. Forecasting model of rice leaf blast (*Pyricularia oryzae*) by meteorological data. Research Reports of the Rural Development Administration, Crop Protection. 1989; 31:9-16
24. Long DH, Lee FN, Tebeest DO. Effect of Nitrogen fertilizer on disease progress of rice blast on susceptible and resistant cultivars. Plant Disease. 2000; 84(4):403-409
25. Manibhushanrao K, Krishan K. Epidemiology of blast (EBIPLA): a simulation model and forecasting system for tropical rice in India. In: Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea. Manila, Philippines: International Rice Research Institute, 1991, 31-38
26. Miyake K, Ikeda M. Influence of silica application on rice blast. Japanese Journal of Soil Science and Plant Nutrition. 1932; 6:53-76
27. Muralidharan K, Venkatarao G. A simple method for forecasting rice blast disease. Indian Phytopathology. 1980; 33:560-564
28. Ogawa M. Studies on blast control of Ceresin lime Ohugoku-Shikoku Agricultural Research. 1953; 3:1-5
29. Onodera I. Chemical studies on rice blast (*Dactyl ariaparasitance* Cavara). Journal of Scientific Agricultural Society. 1917; 180:606-617
30. Ono K, Suzuki H. (Abstract). Spore formation of blast fungus on water surface. I. Dropped conidia. Annals of the Phytopathological Society of Japan,1959; 24:3-4
31. Ou, S.H. 1980. A look at worldwide rice blast disease control. *Plant Disease.* 64: 439-445
32. Padmanabham SY. Breeding for blast resistance in India. Proceeding Indian Academy Science.1965; 49:349-362
33. Pathak RK, Ram RA. Approaches for organic production of vegetable in India, 2002.
34. Report Central Institute for sub-tropical Horticulture, Lucknow.1-13
35. Prabhu A, Morais O. Blast disease management in upland rice in Brazil. In Proceedings of Symposium on Progress in Upland Rice Research, International Rice Research Institute, Manila, Philippines, 1986.
36. Raghava GP, Kaundal R, Kapoor AS. Machine learning techniques in disease forecasting: a case study on rice blast prediction. BMC bioinformatics. 2006; 7(1):485
37. Siddiq EA. Rice. In: 50 Years of Crop Science Research in India (R. S. Paroda and K. L. Chadha, eds.). ICAR (Indian Council of Agricultural Research), (India),1996.
38. Singh N, Singh RS. Lysis of Fusarium *Oxysporium* f. *udum* caused by soil amended with organic matter. Journal of Mycology and Plant Pathology.1980; 10:146-150.
39. Suzuki H. Meteorological factors in the epidemiology of rice blast. Annual Review of Phytopathology. 1975; 13:239-256
40. Teng P, Klein-Gebbinck HW, Pinnschmidt H. An analysis of the blast pathosystem to guide modeling and forecasting. In: Rice Blast Modeling and Forecasting: Proceedings of the International Rice Research Conference, Suweon, Korea. Manila, Philippines: International Rice Research Institute, 1991, 1-30
41. Teng PS. The epidemiological basis for blast management. In: Proceedings of the Wisconsin Blast Symposium, August 1993. Madison: University of Wisconsin, 1993.
42. Teng P, Zeigler RS, Leong SA. Rice blast disease: International Rice Research Institute, Manila, Philippines,1994; 87:626
43. Thurston HD. Tropical plant diseases: American Phytopathological Society (APS Press), 1998.
44. Uehara Y, Imoto M, Sakai Y. Studies on the forecasting of the rice blast development using weather data from AMeDAS. Bulletin of the Hiroshima Prefecture Agricultural Experiment Station. 1988; 51:1-15
45. Usman GM, Wakil W, Sahi ST, Saleemil Y. Influence of various fungicides on the management of rice blast disease. Mycopathology. 2009; 7(1):29-34
46. Villareal RL. The slow leaf blast infection in rice (*Oryza sativa* L.). Ph.D. thesis. University Park, Pa: Pennsylvania State University, 1979, 114
47. Yoshino R, Yamaguchi T. Influence of sunshine and shade conditions on the occurrence of rice blast caused by *Pyricularia oryzae* Cavara. Bull. Hokuriku Agric. Exp. SIn.1974; 16:61-119.
48. Zeigler RS, Leong SA, Teng P. Rice blast disease: International Rice Research Institute, Manila, Philippines, 1994.