

# Stempedia: a weather-based model to explore and manage the risk of lentil *Stemphylium* blight disease

Moin U. Salam<sup>1</sup> · Tapan K. Day<sup>2</sup> · Ashraf U. Ahmed<sup>2</sup> · Bodrun Nessa<sup>3</sup> ·  
A. H. M. Mahfuzul Haque<sup>2,4</sup> · Subash Subedi<sup>5</sup> · Al Imran Malik<sup>6</sup> · M. Matiur Rahman<sup>7</sup> ·  
William Erskine<sup>6</sup>

Received: 12 March 2016 / Accepted: 26 July 2016 / Published online: 3 August 2016  
© Australasian Plant Pathology Society Inc. 2016

**Abstract** Lentil *Stemphylium* blight is a fungal disease threatening sustainable lentil-based cropping in South Asia including Bangladesh. A weather-based model Stempedia was developed to understand the risk of the disease. Daily maximum temperature and sunshine hours are the two most important parameters of the model. When tested with field data from Bangladesh and Nepal, the model simulated the disease severity well both without ( $R^2 = 0.89$ ,  $n = 17$ ) and with ( $R^2 = 0.80$ ,  $n = 18$ ) fungicide application scenarios. As a result, Stempedia was subjected to experimentation to explore the risk and risk management options related to the disease under Bangladesh conditions. Taking Gazipur - a central regional district - as an example, the model identified that,

predominantly, gradual reductions in sunshine hours (or, increased cloudiness) during the early part of the ‘disease susceptible window’ had increased the disease severity over the last 30 years. The model simulated Ishurdi, a north-western regional district, as more disease prone than Gazipur and Jessore, a south-eastern regional district. Stempedia simulated seasonal variability of the disease and predicted reduced severity with delayed sowing, the magnitude of which differed between regions. Stempedia also predicted financial returns with three foliar applications of an effective fungicide but this depended on the timing of application. The best financial return occurred with an early fungicide application, as soon as the disease appeared during initiation of flowering, followed by further application(s) if a disease-producing environment was expected. We conclude that the model has potential to assess regional and seasonal risks of this disease and to determine risk aversion by manipulating sowing time. This model can further be used to formulate the principle of foliar fungicide application to achieve financial gain.

**Electronic supplementary material** The online version of this article (doi:10.1007/s13313-016-0434-3) contains supplementary material, which is available to authorized users.

✉ Moin U. Salam  
moinsalam1@gmail.com

- <sup>1</sup> Department of Agriculture and Food Western Australia, 3 Baron-Hay Court, South Perth, WA 6151, Australia
- <sup>2</sup> Bangladesh Agricultural Research Institute (BARI), Gazipur 1701, Bangladesh
- <sup>3</sup> Bangladesh Rice Research Institute (BRRI), Gazipur 1701, Bangladesh
- <sup>4</sup> Sylhet Agricultural University, Tilagor, Sylhet 3100, Bangladesh
- <sup>5</sup> Grain Legumes Research Program (GLRP), Rampur, Chitwan, Nepal
- <sup>6</sup> Institute of Agriculture/Centre for Plant Genetics and Breeding, School of Plant Biology, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia
- <sup>7</sup> International Rice Research Institute (IRRI), House 9, Road 2/2, Chairmanbari, Banani, Dhaka 1213, Bangladesh

**Keywords** Disease risk · Disease severity · Lentil · Model · Stempedia · *Stemphylium* blight · Weather-based model

## Introduction

Lentil (*Lens culinaris*) is affected by a wide range of pathogens with fungal diseases being the most important. Among them, *Stemphylium* blight, caused by *Stemphylium botryosum*, is a serious threat to lentil industry in many countries (Mwikutuya and Banniza 2010). The disease has been reported on lentil in Bangladesh, Canada, Egypt, Syria and the USA (Bayaa and Erskine 1998; Mwikutuya and Banniza 2010). It is a serious disease in South Asia where yield loss is frequent (Bakr and Ahmed 1992; Huq and Khan 2008).

The symptoms of the disease as reported by Bakr (1991) in Bangladesh include the appearance of small pin-headed light brown to tan colored spots on the leaflets. These spots rapidly enlarge and cover the leaf surface within 2 to 3 days. A blighted dull yellow appearance is observed with infected foliage and branches. Defoliation occurs rapidly, leaving the branches with terminal leaves. The stems and branches also bend down, dry up and gradually turn ashy white, but the pods remain green. White mycelial growth can also be observed on the infected stems. Significant leaf drop, loss in biomass and a reduction in seed size contribute to yield loss (Mwakutuya and Banniza 2010). Mwakutuya (2006), through reviewing the disease, highlights that *S. botryosum* is pathogenic to lentil, spinach, onion, tomato, alfalfa and clover. The same review has emphasized the importance of plant debris as the primary source of inoculum. Infected seed is an important mean of transmission of the disease from region to region and also serve as a source of initial inoculum early in the season (Agarwal and Sinclair 1996). The conidia and ascospores produced on crop debris are responsible for the spread of the disease (Mwakutuya 2006). The secondary spread occurs by airborne conidia that develop in successive generations on distinct conidiophores on the leaf surface (Mwakutuya and Banniza 2010).

In Bangladesh, at least 15 pathogens causing 17 diseases of lentil have been recorded (Ahmed 1986). Among the disease, Stemphylium blight is major, which was first reported in 1986 (Bakr and Zahid 1986). Since then it has gained importance due to its increased severity, with reports of more than 80 % crop loss in some situations (Bakr and Ahmed 1992). Without sufficient resistant varieties, farmers of Bangladesh, depending on circumstances, may adopt cultural and/or chemical options for managing the disease in order to sustain lentil production (Shahiduzzaman et al. 2015).

In Bangladesh, and other countries in South Asia, lentil is traditionally sown after harvest of late monsoonal rice (Transplant *Aman*). This rice is harvested, depending to transplanting time and variety use, during mid-October to mid-December. Apparently, the sowing window of lentil in Bangladesh is wide ranging from early-November to mid-December. However, intensive rice cultivation over the last two decades in Bangladesh has created a tight window (November to February) for lentil cropping between late monsoonal rice and either late transplanted irrigated winter rice (*Boro*) or an early-monsoonal (*Aus*) rice. In order to fit lentil into this cropping system, it needs to be planted early (by the third week of November), but disease severity is reportedly higher with early plantings (RARS 1988). Intensive cropping systems in Bangladesh have also resulted in limited scope for management of the disease without chemical intervention, commonly with application of an effective fungicide (Bakr 1991). The severity of the disease varies between locations within a season and between seasons within a location (Haque et al. 2013) making it difficult for farmers to properly

formulate financially-viable fungicide-based disease control measures. Regional and seasonal risks of this disease need to be assessed; weather-based models are useful for determining and understanding such risks and for formulating disease management options (Salam et al. 2003, 2011). To the best of our knowledge, no such model exists for lentil Stemphylium blight disease.

We developed a simple model to predict the severity of Stemphylium blight in lentil based on weather, and to study the financial implications of the timing and frequency of foliar fungicide application for disease control. In this paper, we present the model and test its validity and apply it for assessing the disease risk and managing the disease.

## Materials and methods

### Description of the model

The Stempedia model simulates the severity of Stemphylium blight disease on a lentil crop based on sowing date, first flowering date and daily weather. Disease severity is predicted in the presence or absence of any fungicide application. The model further estimates the financial gain/loss with or without disease control (by fungicide application) scenarios taking into account of crop loss, lentil seed price and costs of the fungicide and its application.

The model calculates disease severity on a weekly basis for six consecutive weeks starting one week prior to onset of flowering. This six-week period is known as the disease susceptible window.

$$DS_{wi} = SAI \times InfInd \quad (1)$$

Where  $DS_{wi}$  is the disease severity index in week  $i$  and  $i = 1, 2, \dots, 5, 6$ . SAI is the spore availability index and  $InfInd$  is the infection index. The value of SAI and  $InfInd$  vary between 0 and 1.

$$SAI = ADSW/PSW \quad (2)$$

Where PSW, a parameter of the model, is the total number of days per week under calculation that will result in the maximum SAI value of 1. ADSW is the actual number of days per week when spores are available to potentially cause infection.

$$ADSW = \sum FDDI \quad (3)$$

Where FDDI is the total number of favourable days per week when spores are released. A day is designated as favourable for spore release when daily maximum temperature meets the threshold ( $MaxT_{threshold}$ ) and sunshine hours are equal to or less than the threshold

(SSHthreshold). MaxTthreshold and SSHthreshold are parameters of the model.

Infection takes place within two days following the availability of spores, defined as the potential disease establishment window (DEW). InfInd is the ratio of the total number of favourable days for infection per week to DEW. A day was designated as favourable for infection if it exceeded the threshold of relative humidity (RHthreshold), a parameter of the model.

In the case of fungicide application, DS<sub>swi</sub> declines by a factor of fungicide protection efficacy (FPE). FPE is an input of the model quantifying what percentage of the disease is suppressed by one application of foliar fungicide.

In the field, the disease severity (DS) is calculated on a 0 to 5 scale: 0 = no infection, 1 = a few scattered leaf infections but no twig blighted, 2 = 5–10 % leaflet infection and/or few scattered twigs blighted, 3 = 11–20 % leaflet infection and/or 1–5 % twigs blighted, 4 = 21–50 % leaflet infected and/or 6–10 % twigs blighted, and 5 = above 51 % leaflet infected and/or more than 10 % twigs blighted (Bakr and Ahmed 1992). The model used this scale as follows:

$$DS = \text{AvgDS}_{\text{swi}} \times 5 \quad (4)$$

Where AvgDS<sub>swi</sub> is the weighted average of DS<sub>swi</sub> during the ‘disease susceptible window’, where higher weights were designated for the first three weeks.

Lost yield due to disease (LYD, kg ha<sup>-1</sup>) is calculated as follows:

$$LYD = PY \times (\text{PYRDS}/100) \times (\text{DYL}/100) \quad (5)$$

Where PY is potential yield (kg ha<sup>-1</sup>), an input of the model; PYRDS is the percentage of PY reduced due to delayed sowing after 1 November, and DYL is the percentage of yield lost due to the disease. PYRDS was derived from experimental data (Fig. 1) using the following equation:

$$\text{PYRDS} = 615.6 - 1.676 \times \text{JDS} \quad (6)$$

Where JDS is the Julian day of sowing.

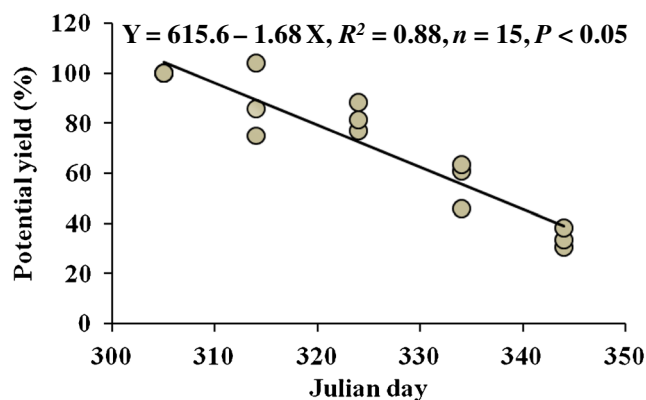
DYL was also derived from experimental data (Fig. 2) as follows:

$$\text{DYL} = -10 + 13.88 \times \text{DS} \quad (6)$$

Where DS is disease severity, an output of the model (Eq. 4). This equation implies a maximum DYL of 59.4 % at the highest DS of 5 and zero DYL when DS ≤ 0.72.

A financial estimate of the cost of the disease (CoD) is derived from the following equation:

$$\text{CoD} = LYD \times LP + (\text{FAC} \times \text{NFA}) \quad (7)$$

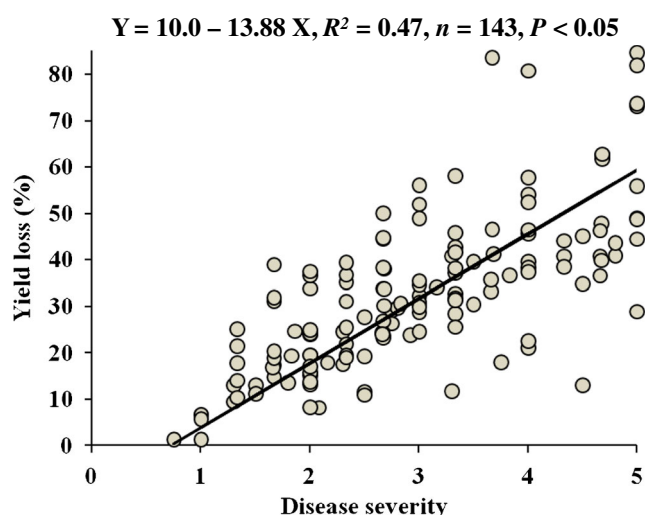


**Fig. 1** The relationship between sowing time of lentil (Julian day) and potential yield. The circles represent observed experimental data and the straight line is the linear regression

Where CoD is expressed in Bangladesh currency (BDT ha<sup>-1</sup>), LP is the price of lentil (BDT kg<sup>-1</sup>), FAC is the cost of one application of foliar fungicide (BDT ha<sup>-1</sup>) and NFA is the number of foliar applications used. LP, FAC and NFA are inputs of the model.

#### Datasets used in the study

Thirty-seven datasets were used in the model’s calibration and validation (Table 1) which were built through consulting the Australian Centre for International Agricultural Research (ACIAR) (CIM-2009-038) Project Reports. The sowing-date-related potential yield data (15 datapoints) used in Fig. 1 were derived from the ACIAR (CIM-2009-038) Project (Professor W. Erskine, The University of Western Australia). The disease-related yield loss data (143 datapoints)



**Fig. 2** The relationship between severity of *Stemphylium* blight in lentil and yield loss. The severity is represented on a 0 to 5 scale, defined by Bakr and Ahmed (1992), and yield loss as percentage. The circles denote for observed experimental data and the straight line is the linear regression

**Table 1** List of datasets used in the calibration and validation of the model Stempedia. Bangladesh data were sourced through ACIAR (CIM-2009-038) Project (W. Erskine, The University of Western Australia), whereas Nepalese data were supplied by the co-author (SS)

Code	Year	Location	Used for
D1	2011–12	Gazipur, Bangladesh	Calibration
D2	2012–13	Ishurdi, Bangladesh	Calibration
D3, D4	2010–11	Gazipur, Bangladesh	Validation (– fungicide)
D5	2013–14	Gazipur, Bangladesh	Validation (– fungicide)
D6, D7, D8	2014–15	Gazipur, Bangladesh	Validation (– fungicide)
D9	2014–15	Ishurdi, Bangladesh	Validation (– fungicide)
D10, D11, D12	2011–12	Jessore, Bangladesh	Validation (– fungicide)
D13	2012–13	Jessore, Bangladesh	Validation (– fungicide)
D14, D15, D16	2012–13	Rampur, Nepal	Validation (– fungicide)
D17, D18, D19	2013–14	Rampur, Nepal	Validation (– fungicide)
D20, D21, D22	2011–12	Gazipur, Bangladesh	Validation (+ fungicide)
D23, D24, D25	2014–15	Gazipur, Bangladesh	Validation (+ fungicide)
D26, D27, D28			
D29, D30, D31	2014–15	Ishurdi, Bangladesh	Validation (+ fungicide)
D32, D33, D34			
D35, D36, D37	2011–12	Jessore, Bangladesh	Validation (+ fungicide)

used in Fig. 2 were taken from unpublished experimental data collected from 1989–90 to 1996–97 by the Plant Pathology Division of the Bangladesh Agricultural Research Institute (BARI, Bangladesh) and from 2011–12 to 2014–15 by the ACIAR (CIM-2009-038) Project (Professor W. Erskine, The University of Western Australia).

The weather data used for analysis and model runs in Bangladeshi locations were gathered from the Bangladesh Meteorological Department (BMD) and that of Nepal were supplied by the co-author (SS).

### Calibration of the model and parameter estimation

Two datasets belonging to two agro-ecological regions and growing seasons were used to calibrate the model (Table 1). To do so, three parameters of the model were considered: MaxTthreshold-lower, MaxTthreshold-upper and SSHthreshold. The model was run using the inputs (Supplementary Table 1) with 27 combinations or sets of three levels of the three parameters [ $3 \times 3 \times 3$ ] (MaxTthreshold-lower: 20, 21 and 22 °C; MaxTthreshold-upper: 26, 27 and 28 °C; SSHthreshold: 5, 6 and 7 h). The range of parameter values was considered based on the literature (Bakr 1991; Huq and Khan 2008; Mwakutuya and Banniza 2010). The values of these three parameters were determined through statistical analysis, described in ‘Statistical analysis’ sub-section. The value for RHthreshold was taken from the literature (Sinha and Singh 1993) while DEW and PSW were estimated by consulting field pathologists at the Bangladesh Agricultural Research Institute (BARI, Bangladesh) who had been working on the epidemiology of the disease. The six parameters of the model and their values are listed in Table 2.

### Validation of the model

The model was validated under two scenarios, without and with fungicide control. For the ‘without fungicide control’ scenario, 17 datapoints were used: six, one and four from Gazipur, Ishurdi and Jessore in Bangladesh, respectively, and six from Rampur, Nepal. For the ‘with fungicide control’ scenario, 18 datapoints were used: nine, six and three from Gazipur, Ishurdi and Jessore in Bangladesh, respectively (Table 1). The model was run with respective weather data using sowing date, days to 50 % flowering, and the number and timing of sprays, where applicable (Supplementary Table 1). Disease severity predicted by the model for the respective datasets were compared with observations in the validation study.

### Experimentation with the model

#### *Long-term scenario in disease pattern*

The historical change in disease severity was simulated by running the model for 30 years from 1985–86 in Gazipur, Bangladesh, using the single sowing date of 10 November and days to 50 % flowering as 60. The outputs were averaged over a ten-year period. The daily maximum temperature and sunshine hour for 30 years were summarised for the same ten-year period on a weekly basis from the third week of December to the second week of February.

#### *Regional, seasonal and time of sowing related disease pattern*

The model was run in combination with three locations (Gazipur, Ishurdi and Jessore in Bangladesh), five

**Table 2** List of parameters of the model Stempedia and their values

Parameter	Description	Unit	Value
DEW	Potential disease establishment window	d	2
MaxTthreshold-lower	Lower range of daily maximum temperature favourable for spore release	°C	20
MaxTthreshold-upper	Upper range of daily maximum temperature favourable for spore release	°C	28
PSW	Number of days of a week of susceptible window releasing spores to produce the maximum SAI <sup>a</sup> of “1”	d	2
RHthreshold	Threshold for relative humidity above which infection takes place	%	50
SSHthreshold	Threshold for daily sunshine hours below which favourable for spore release	h	5

<sup>a</sup>SAI is the spore availability index, see Eq. 1 and 2

seasons (2010–11 to 2014–15) and five sowing dates (31 October, 10, 20 and 30 November, 10 December) along with the respective weather data. The input of days to 50 % flowering was set as 60. Disease severity was summarised for the three locations, five seasons and five sowing dates.

#### Foliar fungicide application – timing and number

The model was run in Ishurdi, Bangladesh for the 2014–15 growing season to mimic a field experiment. The model inputs included sowing dates as of the experiment, days to 50 % flowering as 60, potential yield of 1500 kg ha<sup>-1</sup>, fungicide cost per spray of 3000 BDT ha<sup>-1</sup>, fungicide protection efficiency of 90 % and lentil farmgate price of 60 BDT kg<sup>-1</sup> (Supplementary Table 1). There were one, two and three weekly foliar fungicide applications in the weeks beginning 25 December and 1, 8, 15, 22 and 29 January. The results were expressed as disease severity and financial gain/loss against timing and number of foliar fungicide applications.

#### Statistical analysis

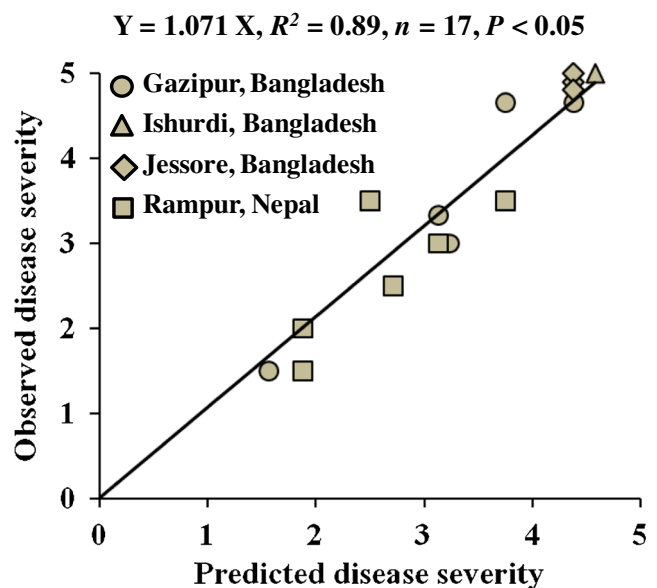
The relationships between time of sowing and decline in potential yield and that of disease severity and yield loss were established using regression analysis. Regression analysis was also used to analyse the performance of the model in the validation study. The values of the three parameters employed in the model calibration (MaxTthreshold-lower, MaxTthreshold-upper and SSHthreshold) were determined by analysing and comparing the mean squared deviations (MSD) of disease severity between the model's prediction and observations according to Kobayashi and Salam (2000). The regional, seasonal and time of sowing related disease patterns were compared at the 95 % confidence interval (CI) or standard error (SE) using the inbuilt formula in MS Excel 2010 (Nessa et al. 2015).

## Results

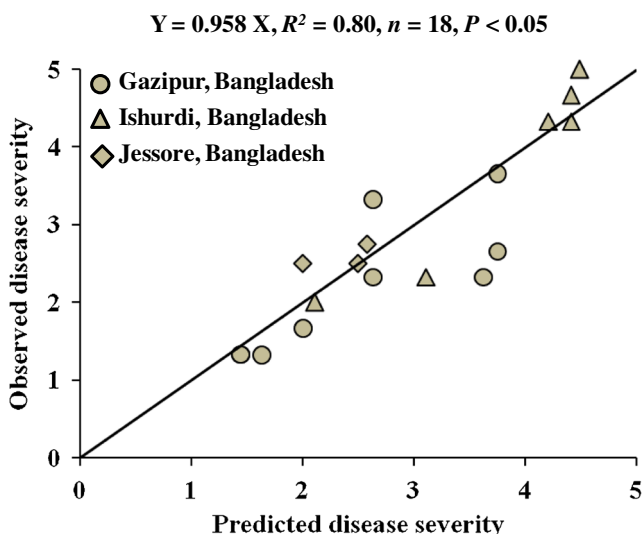
### Validation of Stempedia

Stempedia performed well when validated with data on disease development under natural environments in three locations in Bangladesh and one in Nepal (Fig. 3). Across the 17 datapoints, the average prediction of disease severity ( $3.31 \pm 0.97$ ,  $\pm$  is the SD) was close to observed values ( $3.49 \pm 1.20$ ). The relationship between the predicted and observed values of disease severity was strong and significant ( $R^2 = 0.89$ ,  $n = 17$ ,  $P < 0.05$ ).

The model was further validated with data on disease severity resulting from one to three foliar application of



**Fig. 3** Comparison of predictions from the Stempedia model and observations of the *Stemphylium* blight severity in lentil crops at three locations in Bangladesh and one location in Nepal. The disease in the observed plots developed naturally and fungicide was not applied for disease control. The symbols denote for observed experimental data and the straight line is the linear regression



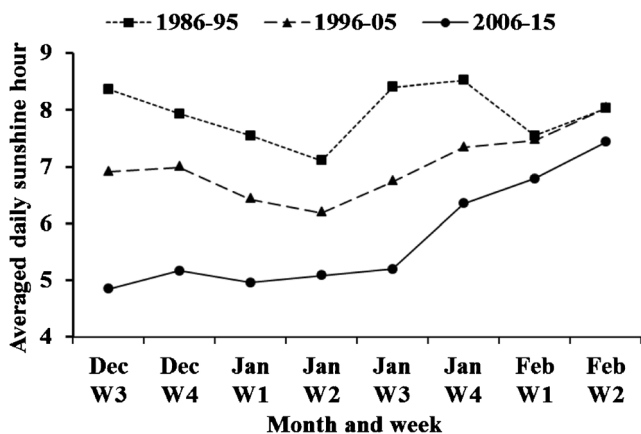
**Fig. 4** Comparison of predictions from the Stempedia model and observations of *Stempyllum* blight severity in lentil at three locations in Bangladesh. The disease in the observed plots developed naturally, with effective fungicides applied one to four times. The symbols denote for observed experimental data and the straight line is the linear regression

fungicide at three locations in Bangladesh. Overall, the model predictions agreed well with the observations (Fig. 4). Across the datasets, Stempedia predicted the average disease severity as  $2.93 \pm 1.07$  compared with the observed value of  $2.80 \pm 1.17$ . The association between predicted and observed disease severity was strong and significant ( $R^2 = 0.81, n = 18, P < 0.05$ ).

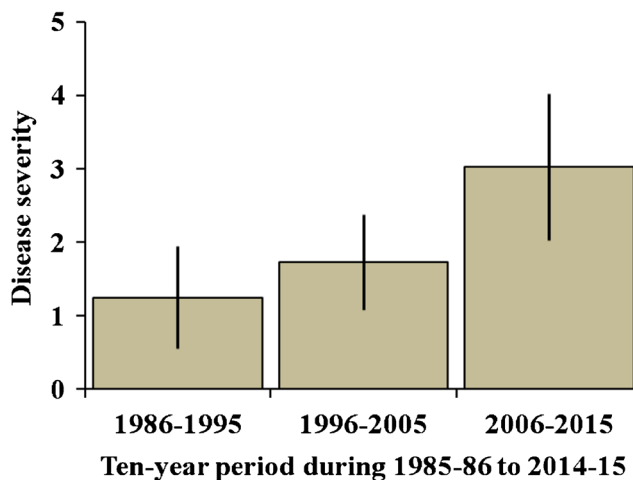
**Experimentation with the model**

*Long-term scenario in disease pattern*

The analysis of weather data from 1985 to 2015 showed that, among the weather variables, daily sunshine hour has gradually



**Fig. 5** Weekly averaged sunshine hours from 1985-86 to 2014-15 in Gazipur, a district of central region of Bangladesh. Dec denotes for December, Jan for January, Feb for February, W for week. 1, 2, 3 and 4 indicate the first, second, third and fourth week of the month



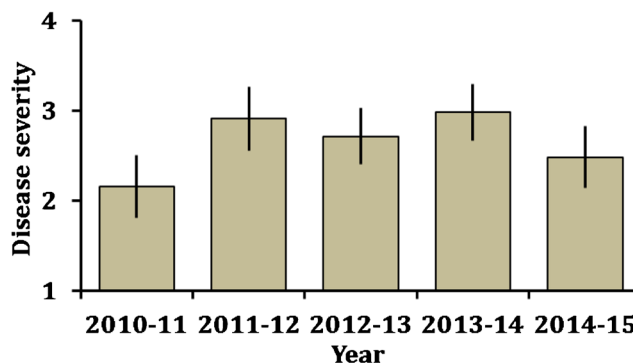
**Fig. 6** Predicted *Stempyllum* blight severity in Gazipur, a district of central region of Bangladesh, from 1985-86 to 2014-15 and summarised over a ten-year period. Y-bars represent 95 % confidence intervals

decreased in the Gazipur area of Bangladesh especially from the third week of December to the third week of January (Fig. 5). The change in daily maximum temperatures also occurred but not in the scale of sunshine hour (data not presented).

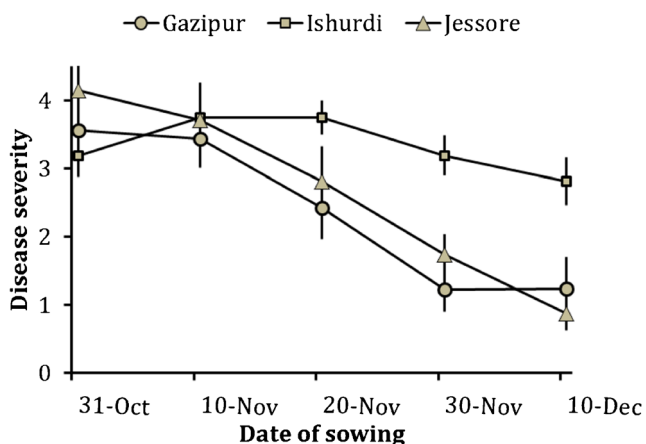
The model predicted that the severity of *Stempyllum* disease in the Gazipur area of Bangladesh has steadily increased since 1986. Figure 6 shows that the predicted disease severity during 1986-95 was low ( $1.25 \pm 0.55, \pm$  is CI at 95 % level) but increased in the next ten-year period ( $1.73 \pm 0.63$ ), and jumped high ( $3.03 \pm 0.62$ ) during 2006-15.

*Regional, seasonal and time of sowing related disease pattern*

In the last five years (2010-11 to 2014-15), the model predicts that Ishurdi (representing north-western districts) has been more prone to the disease ( $3.34 \pm 0.16, \pm$  is the SE) than Jessore (representing south-western districts,  $2.65 \pm 0.29$ ) and Gazipur (representing central districts,  $2.37 \pm 0.27$ ). The model also showed variability in disease severity across seasons (Fig. 7). For example, in the last five years across the



**Fig. 7** Predicted severity of *Stempyllum* blight disease on lentil showing seasonal variability from 2010 to 11 to 2014-15 at three locations in Bangladesh. Y-bars represent standard errors



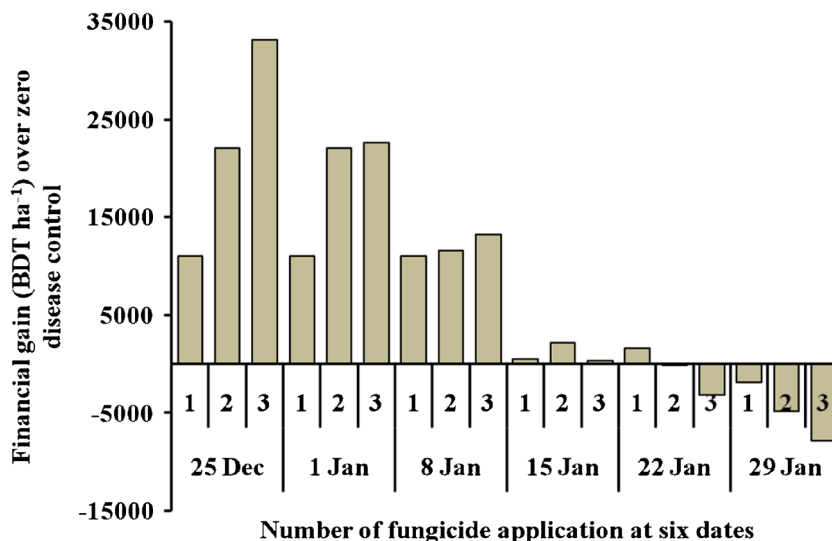
**Fig. 8** Predicted severity of Stemphylium blight disease on lentil showing variability due to the time of sowing at three locations in Bangladesh from 2010 to 11 to 2014–15. Y-bars represent standard errors

three regions, the 2010–11 growing season had the lowest severity ( $2.15 \pm 0.35$ ), whereas 2013–14 had the highest ( $2.98 \pm 0.32$ ). The results from the model run further indicate that time of sowing strongly affected disease severity (Fig. 8). In general, sowing the crop later reduced the disease severity. However, the pattern of variation in disease severity varied between locations. For example, Ishurdi had less disease variability ( $2.81 \pm 0.35$  to  $3.19 \pm 0.29$ ) than Jessore ( $0.88 \pm 0.25$  to  $4.15 \pm 0.38$ ) or Gazipur ( $1.22 \pm 0.33$  to  $3.56 \pm 0.40$ ).

*Foliar fungicide application – timing and number*

The model responded to timing and frequency of foliar fungicide application to control the disease. In general, increased financial gain predicted with the earlier application of foliar fungicide (Fig. 9). The response of frequency of fungicide application was evident only in the first two dates of application (25 December and 1 January). Fungicide

**Fig. 9** Financial gain or loss from one, two or three applications of an effective foliar fungicide in controlling Stemphylium blight of lentil. The fungicide was applied at weekly intervals beginning on 25 December



application from mid-January onwards produced negligible financial gain or loss.

**Discussion**

In this study, a weather-based model Stempedia was developed to understand the risk of Stemphylium blight, a major disease of lentil in South Asia. This model is the first of its kind for this pathosystem. Testing the model at multiple locations, predominantly in Bangladesh, across several years, Stempedia was confidently applied to address five key questions: (i) Is the severity of Stemphylium blight disease increasing day-by-day? If so, why? (ii) Is there a region-to-region variability in disease severity? (iii) Is there a season-to-season variability in disease severity? (iv) Does the disease severity alter with time of sowing? (v) How many applications of an effective foliar fungicide are required to economically control the disease? And, at what crop growth stage? Those questions were addressed by running the validated model at three locations of Bangladesh, Gazipur (representing central districts), Ishurdi (representing north-western districts) and Jessore (representing south-western districts).

Stempedia predicted an increasing trend in disease severity over the last 30 years in the central districts of Bangladesh. This is also evident from unpublished field data (AU Ahmed, Principal Scientist, Plant Pathology Division, Bangladesh Agricultural Research Institute (BARI), Bangladesh). This change, according to the model, was associated with variation in two weather variables, mainly sunshine hours and partly daily maximum temperature during the third week of December to the third week of January; this period is defined as the early part of the ‘disease susceptible window’ of the crop. During this time, the study area experienced increasing cloudy conditions, a predominant factor for the disease

infestation (Bakr and Ahmed 1992). Furthermore, mean daily maximum temperature in the study area have decreased to the disease-conducive range of 20 to 28 °C (Bakr and Ahmed 1992). Foliar application of fungicides for disease control is recommended in Bangladesh from mid- to the end-January (Tapan K. Day, Chief Scientist, Plant Pathology Division, Bangladesh Agricultural Research Institute (BARI), Bangladesh). The changing scenarios in the weather pattern warrant revision of this recommendation.

The model indicated that the north-western districts of Bangladesh were more disease-prone than the south-western or central districts. The model also predicted high disease severity in early-sown crops (prior to the third week in November) which is largely supported by experimental evidence (RARS 1988) providing further confidence in the model to aid decision-making in disease management. For example, disease control by manipulating sowing time can be explored by running the model with historical weather data in the major lentil growing districts of Bangladesh. However, manipulation of sowing time is not an agronomically acceptable option in these intensive lentil-based cropping systems which require early planting and, therefore, necessitate foliar fungicides for disease management. The key question remains, how many foliar applications are needed and when should they be applied to ensure financial benefit?

We ran a retrospective analysis with the model on the timing and frequency of an effective fungicide to control the disease in a disease-prone location, Ishurdi (a north-western district) during the 2014–15 cropping season. In the field experiment, the crop had one, two or three application of foliar fungicide at weekly interval from 30 January 2015. Fungicide application did not reduce disease severity and our model predicted the similar results. The model further demonstrated that the spray schedule needed to be initiated a month earlier (25 December) to gain the most financial benefit from fungicide application. The frequency of fungicide application was dependent on disease severity and the timing of application schedule. Results from earlier field experiments in the region suggest the onset of the disease occurs during late December to early January (RARS 1989, 1990, 1991).

The development and validation of the model have been successful in Bangladesh. The model has also undergone validation in a limited scale with Nepalese data. The disease has significant economic importance in Nepal and India (Subedi et al. 2015). Therefore, there is a scope of regional extension of the model after testing in respective environments. Furthermore, attempt may be undertaken to test the accuracy of the model under global perspective such as in Canada where lentil *Stemphylium* is a disease of concern (Mwikutuya and Banniza 2010). It may be noted that inter-continental testing of crop disease models can result in fruitful outcome (Salam et al. 2007).

## Conclusions

The *Stempedia* model can be used to determine regional and seasonal risks of *Stemphylium* blight disease on lentil. The model has the potential to determine risk aversion by manipulating sowing time, where feasible. This study further revealed that when fungicide application was necessary, particularly at early sowing, it should be scheduled during the early part of the 'disease susceptible window' of the crop for financial gain. Attempt is being undertaken to develop a risk forecasting system of the disease for the growers of Bangladesh by establishing collaboration between Bangladesh Agricultural Research Institute (BARI) and Bangladesh Meteorology Department (BMD).

**Acknowledgments** Funding for this research was provided by the Australian Centre for International Agricultural Research (ACIAR) under project CIM/2009/038. The study was undertaken by the senior author when he was on unpaid leave from the Department of Agriculture and Food, Western Australia (DAFWA), Australia.

## References

- Agarwal VK, Sinclair JB (1996) Principles of Seed Pathology, 2nd (Ed). CRC Press, Boca Raton, Florida
- Ahmed HU (1986) Recommendation in the methods of disease management of crop in Bangladesh. Plant Pathology Division, Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, Bangladesh, pp. 11–12
- Bakr MA (1991) Plant protection of lentil in Bangladesh. In: Erskine W, Saxena MC (eds) Lentil in South Asia: proceedings of the Seminar on Lentil in South Asia, 11–15 March. ICARDA, Aleppo, pp. 177–186
- Bakr MA, Ahmed F (1992) Development of stemphylium blight of lentil and its control. Bangladesh J Plant Pathol 8:39–40
- Bakr MA, Zahid MJ (1986) *Stemphylium* blight: a new disease of lentil in Bangladesh. Bangladesh J Plant Pathol 2:69–70
- Bayaa B, Erskine W (1998) Diseases of lentil. In: Allen DJ, Lenné JM (eds) The pathology of food and pasture legumes. CAB International, Wallingford, pp. 442–443
- Haque AHMM, Khalequzzaman KM, Anowar B (2013) Management of *Stemphylium* blight of lentil using fungicides. In: Zaman SM, Hossain MA, Khaleque AM, Ali OM, Hossain AM, Haque MAHM, Khalaquzzaman KM, Islam MM, Hossain MA (eds) Annual Research Report, Pulses Research Centre., BARI, Ishurdi, Pabna, Bangladesh, pp. 140–141
- Huq MI, Khan AZMNA (2008) Epidemiology of *Stemphylium* blight of lentil. Bangladesh J Sci Ind Res 43:513–520
- Kobayashi K, Salam MU (2000) Comparing simulated and measured values using mean squared deviation and its components. Agron J 92(2):345–352
- Mwikutuya E (2006) Epidemiology of *Stemphylium* Blight on Lentil (*Lens culinaris*) in Saskatchewan. MS thesis, Department of Plant Sciences, University of Saskatchewan, Saskatoon, Canada
- Mwikutuya E, Banniza S (2010) Influence of temperature and wetness periods on the development of *Stemphylium* blight on lentil. Plant Dis 94:1219–1224
- Nessa B, Salam MU, Haque AHMM, Biswas JK, Kabir MS, MacLeod WJ, D'Antuono M, Barman HN, Latif MA, Galloway J (2015) Spatial pattern of natural spread of rice false smut (*Ustilagoideae virens*) disease in fields. Am J Agric Biol Sci 10(2):63–73



- RARS (1988) Annual Report 1987–88. Plant Pathology Division, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh, pp. 6–9
- RARS (1989) Annual Report 1988–89. Plant Pathology Division, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh, pp. 13–18
- RARS (1990) Annual Report 1989–90. Plant Pathology Division, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh, pp. 17–24
- RARS (1991) Annual Report 1990–91. Plant Pathology Division, Regional Agricultural Research Station, Ishurdi, Pabna, Bangladesh, pp. 25–30
- Salam MU, Khangura RK, Diggle AJ, Barbetti MJ (2003) Blackleg Sporacle: a model for predicting onset of pseudothecia maturity and seasonal ascospore showers in relation to blackleg of canola. *Phytopathology* 93(9):1073–1081
- Salam MU, Fitt BDL, Aubertot JN, Diggle AJ, Huang YJ, Barbetti MJ, Gladders P, Jedryczka M, Khangura RK, Wratten N, Fernando WGD, Penaud A, Pinochet X, Sivasithamparam K (2007) Two weather-based models for predicting onset of seasonal release of ascospores of *Leptosphaeria maculans* or *L. biglobosa*, causes of phoma stem canker of oilseed rape. *Plant Pathol* 56(3):412–423
- Salam MU, Galloway J, MacLeod WJ, Davidson JA, Seymour M, Pritchard I, Salam KP, Diggle AJ, Maling T (2011) G1 Blackspot Manager model predicts the maturity and release of ascospores in relation to ascochyta blight on field pea. *Australas Plant Pathol* 40(6):621–631
- Shahiduzzaman M, Hossain MA, Kundu ND (2015) Efficacy of fungicides to control *Stemphylium* blight (*Stemphylium botryosum*) of lentil. *Bangladesh J Agric Res* 40(2):229–233
- Sinha JN, Singh AP (1993) Effect on environment on the development and spread of *Stemphylium* blight of lentil. *Indian Phytopath* 46: 252–253
- Subedi S, Shrestha SM, Bahadur KCG, Thapa RB, Ghimire SK, Neupane S, Nessa B (2015) Botanical, chemical and biological management of *Stemphylium botryosum* blight disease of lentil in Nepal. *Indian Phytopath* 68(4):415–423