METEOROLOGICAL-BASED PREDICTIONS OF WHEAT HEAD BLIGHT EPIDEMIC IN THE SOUTHERN ARGENTINEAN PAMPAS REGION

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Summary

In Argentina, head blight is a highly risky disease (caused by *Fusarium graminearum*), although its occurrence is sporadic depending on prevalent environmental variables. These traits stimulated the development of predictive models of head blight occurrence which would help growers in the selection of control strategies. Empirical equations for predicting head blight incidence were developed at Pergamino (33° 56' S, 60° 30' W) associating temperature and moisture variables with mean disease data. Recently a new fundamental-empirical approach for estimating Fusarium index (incidence% x severity%/100) was developed using data of Pergamino and Marcos Juárez (32° 41' S, 62°07' W). In this study our objective was to validate both approaches at three more southern locations: La Dulce (38° 10' S, 58° 00' W), Miramar (38° 00' S, 57° 33' W) and Balcarce (37° 45' S, 58° 18W), for the 2001 crop season. Examining partial and mean deviation values between observed and predicted incidence data, an underestimation especially at La Dulce was assessed. A clear improvement of incidence goodness of fit estimations was obtained decreasing the heat accumulation defining the length of the wheat critical period for infection. Employing this last critical period length for the fundamental-empirical approach led to satisfactory Fusarium index predictions. This study showed that both approaches developed at northern locations of the Pampas region can be portable and useful for predicting disease intensity at more southern locations, making only a few changes.

Key words: Wheat, head blight, *Fusarium graminearum,* prediction systems

Introduction

Fusarium Head Blight (FHB), is a disease affecting the heads of wheat, barley, oats, rye, corn, triticale, canary seeds and some forage grasses. The crops most affected are wheat, barley and corn. The disease has a worldwide distribution, being common in humid and semihumid wheat growing areas (Wiese 1987; Cook and Veseth 1991; Bai and Shaner 1994). Wheat head blight or scab is caused by several species of *Fusarium*. In Argentina, 90% of the pathogens isolated from blighted heads were *Fusarium graminearum* Schwabe [teleomorph *Gibberella zeae* Schwein (Petch) (Galich and Galich 1994; Carranza *et al.* 2002; Reis and Carmona 2002; Barreto, pers. comm.).

In our country, the wheat cropping area is very extensive (nearly 6.000.000 ha), distributed in five provinces with different ecological conditions (Buenos Aires, Córdoba, Santa Fe, Entre Ríos and La Pampa). Therefore, no one epidemic has ever covered the whole area at the given time. Latitude, temperature and the importance of susceptible grass weeds and rotational crops (particularly *Zea mays* L.) influence the pathogen's distribution (Pomeranz *et al.* 1990), while the frequency and timing of spring rainfall appear to regulate disease outbreaks (Sutton 1982; Wiersma *et al.* 1996; Reis, 1987).

In the central northern region (southeastern of Córdoba, southern Santa Fe and northern Buenos Aires) the worst outbreaks occurred in 1945-46, 1967, 1977-78 and 1985. Yield losses, in 1978, ranged from 10 to 30 % in Marcos Juárez (Cordoba province) and Oliveros (Santa Fe province). Favorable meteorological conditions once again prevailed in 1993, enhancing *F. graminearum* infection and causing wheat losses ranging from 24 to 50% in the southern and southeastern Santa Fe and Córdoba provinces, respectively (Galich and Galich 1996). According to Pergamino (Buenos Aires province) assays, kernel number rather than kernel size was seriously affected as a consequence of pathogen action (Annone and Frutos 1988).

In the southeast wheat growing area, the main durum wheat (*Triticum durum* Desf.) region of southern Buenos Aires and La Pampa province, severe epidemics occurred in 1963, 1976, 1978 and 1985, with crop losses as high as 70%. The epidemic was so severe that 60% of samples from farms were below established standards.

Previous research at Pergamino led to development of empirical regression equations for predicting head blight incidence based on temperature and moisture (rainfall and relative humidity). These equations were developed with mean disease data calculated from those annually observed from 1978 to 1990 on many wheat cultivars (Moschini and Fortugno 1996). Two of these meteorological based empirical equations satisfactorily predicted head blight incidence at two more northern locations, changing the maximum temperature threshold of the model temperature variable (Moschini *et al.* 2001). Similarly, empirical logistic regression models were developed in U.S. to predict Fusarium head blight epidemics based on meteorological variables using rainfall, temperature and relative humidity data, processed in a 17 day period around wheat anthesis (De Wolf *et al.* 2003). Recently successful Fusarium index (incidence% x severity% /100) estimations were achieved using a meteorological-based system which combined elements derived from the fundamental (Andersen, 1948) and empirical approaches (Moschini *et al.* 2002).

In the present study our objective was to validate two meteorological-based empirical equations and a fundamental-empirical system to predict wheat head blight incidence and Fusarium index respectively at three southern locations of the Argentinean Pampas region: La Dulce, Miramar and Balcarce, for the 2001 crop season.

Materials and methods

Observed incidence, severity and Fusarium Index. Head blight incidence and severity observations were recorded for several wheat cultivars in three locations of the southern pampas region: La Dulce, (38° 10' S, 58° 00' W), Miramar (38° 00' S, 57° 33' W) and Balcarce (37° 45' S; 58° 18' W) for the 2001 crop season. Head blight incidence was calculated for each plot as the percentage of diseased heads. Severity was calculated as the percentage of diseased spikelets in the diseased heads. The available paired disease observations for the cultivars whose heading dates are the most frequent were averaged by location, resulting in 3 (n) observed disease incidence and severity values, which were used for validation purposes. Observed Fusarium index values resulted of multiplying incidence by severity, divided by 100 (Table 1).

Table 1. Mean observed incidence, severity and Fusarium index of head blight in wheat at three southern locations of the pampas region, for 2001 crop season

Location	Incidence	Severity	Fusarium Index	Heading date	Samples
	Mean	Mean	Mean		
	%	%	%		No.
La Dulce	38.1	10.6	4.0	10/31	12
Miramar	36.0	10.2	3.7	11/4	9
Balcarce	42.5	10.4	4.4	11/5	7

Predicted incidence (empirical approach). In a previous paper (Moschini and Fortugno 1996), meteorological-based predictive wheat scab incidence equations were developed for Pergamino. Annual mean percent disease incidence computed from the values recorded for the wheat cultivars grouped by their similar heading dates were used to fit the models. Using daily records of maximum (MaxT) and minimum (MinT) temperature, precipitation and relative humidity (average of the 0800, 1400 and 2000 h observations) obtained from a standard weather station, independent meteorological variables were calculated. These variables were processed in a time period beginning eight days prior to heading date (emergence of first heads) and ending when 530 degree days (DD) were accumulated (base temperature: 0° C). This period was regarded as the critical period length (CPL).

From the study in Pergamino, the following two equations were used to predict head blight incidence (PI %) at meteorological conditions of La Dulce, Miramar and Balcarce:

$$PI1\ \% = 20.37 + 8.63 \times NP2 - 0.49 \times DD926 \quad [1]$$

$$PI2\ \% = 18.34 + 4.12 \times NP12 - 0.45 \times DD1026 \quad [2]$$

where *NP2*: number of two-day periods with precipitation (≥0.2mm) and relative humidity > 81% in the first day and relative humidity ≥ 78% in the second day; *NP12*: total number of periods like NP2 and days with simultaneous records of precipitation (≥ 0.2mm) and relative humidity > 83%; *DD9260* and *DD1026* result from adding DDMaxT and DDMinT, which are calculated by the next procedure: if MaxT>26°C then DDMaxT= $\sum^d$ (MaxT-26); if MinT<9°C or <10°C then DDMiniT= $\sum^d$ (9-MinT) or $\sum^d$(10-MinT), being d=days of the CPL. Daily meteorological data for calculating these model variables were obtained from standard weather stations located in the experiment fields of the three locations. Observed wheat heading dates (when 50% of the heads were fully emerged) were specified in each location in order to perform estimations with equations [1] and [2] (Table 1).

Predicted Fusarium index (fundamental-empirical approach). In a recent study (Moschini *et al.* 2002), a total of 84 values of Fusarium index registered in commercial wheat cultivars (susceptible and moderately susceptible) at Pergamino and M. Juárez (10 crop seasons) were satisfactorily contrasted with predicted values. Predicted Fusarium index values were obtained following the next steps:

a) Daily progress of wheat heads with exposed anthers (%): from field observations in a single wheat cultivar, a polynomial function between the logit of the proportion of head with anthers (Anther, values from 0 to 1) and the time in degree days (DD: daily accumulation of mean temperatures >= to 12 °C) was fit.

$$LogitAnther= - 6{,}765052912 + 0{,}136395967 \times DD - 0{,}000694621 \times DD^2 + 0{,}000001384 \times DD^3 - 0{,}000000001 \times DD^4 \quad [3]$$

where LogitAnther is the natural logarithm of (Anther / 1- Anther), DD^2=DD x DD; DD^3=DD^2 x DD, DD^4= DD x DD^3. Solving (EXP(LogitAnther) / (1+EXP(LogitAnther)) x 100, the daily percentage of heads with anthers were obtained. The critical period for the infection (CPL) began 4 days prior the observed heading date and finished when 530 DD were accumulated.

b) Predicted severity: in controlled environment, Andersen (1948) established the percentage of infection (severity%) in wheat heads inoculated with *Fusarium graminearum* conidia, exposed to different wet period length (W: from 18 h to 72 h) and temperatures (T=15, 20, 25 and 30 °C). A polynomial function was fit between the logit of the severity (S, from:0 to 1) and W (h) and T (°C), like individual and interactive effects.

$$LogitS= 38{,}77166158 - 0{,}53815698 \times W - 6{,}02985565 \times T + 0{,}26849793 \times T^2 - 0{,}00396097 \times T^3 + 0{,}04990941 \times IT - 0{,}00092343 \times IT^2 \quad [4]$$

where LogitS is the natural logarithm of (S / 1-S); T^2= T x T; T^3= T^2 x T; IT= T x W; IT^2= T^2 x W. Values of predicted severity were obtained solving EXP(LogitS) / (1+EXP(LogitS)) x 100.

In order to use Eq. [4], equivalence rules defining W values and mean T during wet periods from daily precipitation (Prec), maximum and minimum temperature and relative humidity (RH%) registered at standard weather stations, were established. Using criteria derived from empirical approach (Moschini and Fortugno 1996), it was defined that:

1 day with Prec (>=0,2mm) and RH>= 81% is equal to W=24 h.

2 consecutive days with Prec and RH >= 81% is equal to W=48 h.

3 consecutive days with Prec and RH >=81% is equal to W=72 h. A maximum W period of 72 h was analyzed. If prior and/or after W period of 24 and 48 h, Prec and RH<=77 % are registered, 3 h of wet are added. If Prec and RH >77% and <81% (prior and/or after) are registered, 6 h of wet are added. Occurrence of RH>77 % and <81% after W periods, 3 h are added. The temperature during the wet period resulted of averaging the mean daily temperatures (T= MaxT+MinT / 2), weighted for the wet duration in each day involved. If T is <15°C, severity values are only calculated for wet periods >= 48 h.

c) The final predicted Fusarium index value resulted of adding the partial products between the percentages of heads with exposed anthers (a) and predicted severity (b) (divided by 100), calculated for all the wet periods found throughout the wheat critical period for the infection.

For the present study some small changes in the preceding methodology were carried out. CPL was defined as the time period beginning eight days prior to heading date and ending when 450 degree days (DD) were accumulated (daily accumulation of mean temperatures >= to 10 °C). If W period is lower than 48 h and T is between 15°C and 13.5 °C, 90 % of the calculated Fusarium index value for W=48 h was considered.

Validation. The correspondence between predicted incidence (Eq [1] and [2]) and Fusarium Index values and the observed ones in the three locations for the 2001 crop season, was analyzed comparing the signs and magnitudes of the partial deviations and mean deviations.

Results

Deviations between head blight incidence observations and predicted values by Eq. [1] and [2] were showed in Table 2. With wheat critical period length of 530 degree days, even though lower partial deviation values were obtained, excepting in La Dulce for incidence predicted by Eq. [1], a tendency to the underestimation could be pointed out due to the predominance of positive deviations.

Changing the CPL from 530 to 450 degree days, deviations between observed incidence values and those predicted from the models showed smaller absolute values and balance in their signs. Decreasing the CPL led also to a significant decrease in the mean deviation values for both equations (Table 2).

Table 2. Deviations (partial and mean) between observed head blight incidence (Obs.) and predicted by Eq. [1] or [2], for two critical period lengths (530 DD and 450 DD) in La Dulce, Miramar and Balcarce (2001 crop season). Mean observed and predicted values are also displayed

	CPL= 530 DD Deviation		CPL=450 DD Deviation	
Location	Obs. - Eq.[1]	Obs. - Eq.[2]	Obs. - Eq [1]	Obs. - Eq [2]
	%	%	%	%
La Dulce	16.1	2.3	11.7	1.5
Miramar	6.5	12.3	1.0	5.2
Balcarce	2.8	3.6	-0.3	-1.2
Mean deviation	8.4	6.0	4.1	1.8
Mean observed	38.8	38.8	38.8	38.8
Mean predicted	30.4	32.8	34.7	37.0

Nevertheless of presenting a little underestimation, the aptness of the fundamental-empirical system to predict Fusarium index was confirmed by the absence of significant differences between observed and predicted disease levels (lower positive partial deviations values) (Table 3). It is worth pointing out the satisfactory correspondence between the observed maximum and minimum Fusarium index values and those estimated for susceptible and moderately susceptible cultivars, according to the regression equations defined by Moschini *et al.* (2002).

Table 3. Deviations (partial and mean) between observed Fusarium index and predicted by the fundamental-empirical approach, with the corresponding extreme values, in La Dulce, Miramar and Balcarce (2001 crop season). Mean observed and predicted values are also displayed

Location	Deviation	Extreme Fusarium Index			
	Observed – Predicted	Observed		Predicted*	
	%	%			
La Dulce	1.3	2.8	6.0	3.9	6.4
Miramar	0.9	2.0	6.1	4.0	6.5
Balcarce	0.8	2.7	7.1	4.7	7.2
Mean deviation	1.0				
Mean observed	4.0				
Mean predicted	3.0				

* Extreme predicted Fusarium index (PFindex) values were calculated by the following regression equations: a) PFindexMS=1.5859+0.8588*PFindex b) PFindexS = 4.0914 + 0.8588*PFindex for moderately susceptible (MS) and susceptible (S) cultivars (Moschini *et al.*, 2002)

Discussion

Both models developed for Pergamino (Eq. [1] and [2]) and only changed in the length of the critical period for infection in which variables are processed, satisfactorily predicted head blight incidence in the three locations analyzed during 2001 crop season. Equation [2] had a clear lower mean deviation between observed and predicted values than equation [1].

Locations colder than Pergamino (where eq. [1] and [2] were developed), such as La Dulce, Miramar and Balcarce responded sharply to the decrease in the length (expressed as degree days) of the critical period for the infection, showing more accurate incidence predictions from the models. For the fundamental-empirical approach, the old length (530 DD of daily mean temperatures >=12 °C) resulted excessively long for these colder locations (38 to 41 days), unlike the new critical period (450 DD of daily mean temperatures >= 10°C) which lasted 28 to 30 days.

Multiple inoculation episodes in areas with moderate and severe outbreaks suggest that multiple infections contribute to cumulative head blight severity. This fact affects prophylactic disease management options (Francl *et al.* 1999). Keeping the latter in mind, conclusions derived from the validated fundamental-empirical system can be used to assist producers in disease control measures to be employed. From the start of the wheat critical period for infection (onset of wheat heading), environment monitoring can detect infection events and the corresponding predicted Fusarium index values, in order to decide a possible crop chemical protection. Through the fundamental-empirical system, the evolution of the multiple infection process can be determined event by event. In this case the disease is not only evaluated by the incidence (empirical approach) but also by the severity. Having the possibility of knowing the impact of each infective event on the Fusarium index, two consequences for the decision-making process are derived. For the lapse prior to each event, infective impact of weather conditions predicted by meteorological forecasts could be determined more accurately. For the lapse post infection but before symptom appearance (incubation period), a chemical disease control could be implemented in function of the accumulated Fusarium index value and the intensity of the last infective event analyzed. In order to implement this last target, the efficiency of disease control using fungicides applied throughout the incubation period should be deeply analyzed. At temperatures of 20 °C, at which many severe head blight infection events are observed in the Pampas region, Andersen (1948) found lengths of incubation periods ranging from 7 to 3 days, for plants inoculated in the flowering stage and exposed to continued wetness of 18 to 72 h respectively.

Regarding the meteorological-based empirical equations, it should be underlined the fact that their meteorological variables are calculated after finishing the entire wheat critical period for infection. At this point, the impact of having the estimated disease incidence from the equations could be not useful for the decision-making process respecting a chemical control. Nevertheless, the identification of the meteorological variables highly associated with the disease might be helpful to analyze weather forecasts. Accordingly, the probability of occurrence of 2 to 3 d periods of rainfall and high humidity and above normal temperatures derived from weather forecasts should be evaluated throughout the wheat critical period.

Conclusions

The worth of meteorological-based systems for predicting wheat head blight intensity, developed by empirical and fundamental-empirical approaches for northern locations of the Pampas region, should be carefully analyzed when they are used for other geographic areas. This study showed that both systems could be portable and useful for estimating head blight intensity at more southern locations changing the critical period length for the infection.

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