Progress of Asian soybean rust and airborne urediniospores of *Phakopsora pachyrhizi* in southern Brazil

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ABSTRACT

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Asian soybean rust, caused by the fungus *Phakopsora pachyrhizi*, was reported at epidemic levels in 2003/2004 and is the main soybean disease in Brazil. The aim of this study was to investigate the spread of Asian soybean rust and to quantify airborne urediniospores in the region of Campo Mourão, Paraná State, Brazil. Three experiments were conducted under field conditions during the 2007/08 and 2008/09 crop seasons. Using the disease gradient method, provided by the application of increasing levels of the fungicide tebuconazole, four Asian soybean rust epidemics at different intensities were obtained in each experiment. To quantify the urediniospores, weathercock-type spore collectors were installed during and between the two crop seasons. Disease progress curves were plotted for each epidemic, and maximum severity was estimated. The curves were fit to the logistic model, which provided higher coefficients of determination and more randomly distributed residuals plotted over time. Analyses of the area under the disease progress curve showed that the largest epidemics occurred in the 2007/2008 crop season and that the progress rates were higher for severity, even among plants protected with the fungicide. The number of urediniospores collected in the air was related to the presence of soybean plants in the cultivated crops. The quantity of urediniospores was also positively correlated to the disease severity and incidence, as well as to cumulative rainfall and favorable days for *P. Pachyrhizi* infection.

Additional keywords: soybean, soybean disease, epidemiology

RESUMO

Nascimento, J.F.; Vida, J.B.; Tessmann, D.J.; Zambolim, L.; Vieira, R.A. e Oliveira, R.R. Progresso de ferrugem asiática da soja e quantificação de urediósporos de ***Phakopsora pachyrhizi*** no ar, na região sul do Brasil. *Summa Phytopathologica,* v.38, n.4, p.280-287, 2012.

A ferrugem asiática, causada por *Phakopsora pachyrhizi*, relatada em nível epidêmico em 2003/04, é a principal doença na cultura as soja no Brasil. Este trabalho teve como objetivos estudar o progresso da ferrugem-asiática da soja e quantificar os urediniósporos no ar na região de Campo Mourão no Estado do Paraná, região Sul do Brasil. Três experimentos foram instalados em condições de campo, nas safras 2006/07 e 2007/08. Utilizando-se o método do gradiente de doenças, proporcionado pela aplicação de doses crescentes do fungicida tebuconazole, foram obtidas quatro epidemias em cada experimento com diferentes intensidades de ferrugem asiática. Para quantificar os urediniópóros, foram instalados coletores de esporos tipo catavento durante as duas safras e entressafras. As curvas de progresso da doença das epidemias foram plotadas e estimaram-se a severidade máxima. As curvas foram ajustadas ao modelo logístico por apresentarem maiores coeficientes de determinação e melhor aleatoriedade dos resíduos plotados no tempo. As análises da área abaixo da curva de progresso da doença mostraram que as maiores epidemias ocorreram na safra 2006/07 e as taxas de progresso foram maiores para a severidade, mesmo em plantas protegidas com o fungicida. A quantidade de urediniósporos coletados no ar foi relacionada com a presença de plantas de soja em lavouras cultivadas. A quantidade de urediniósporos também apresentou correlação positiva com a severidade, com a incidência da doença, com a precipitação acumulada e com os dias favoráveis a infecção por *P. pachyrhizi*.

Palavras-chave adicionais: *Pakopsora pachyrhizi*, epidemiologia, soja.

In South America, Asian soybean rust (ASR), caused by the fungus *Phakopsora pachyrhizi* Syd. & P. Syd., was identified in Paraguay during the 2000/01 crop season and in Argentina in 2002. During the 2001/02 season, it was detected in the state of Paraná in Brazil, which is the country's second largest soybean producer, and from there, it rapidly spread to other states. By 2004, ASR had already affected the main soybean producing regions in Brazil, causing an estimated 30% to 70% reduction in productivity during the 2003/04 crop season and making it the main disease affecting soybean crops in Brazil (10, 25, 26).

Climate is quite important among the factors that favor the epidemiology of ASR. Climate variations are influenced by macro-, meso- and microclimate. They can affect the different processes of the disease cycle and influence the rate of progress and severity of the epidemics. In soybean fields, rainfall seems to be the most important factor that influences the severity of the disease on a regional scale. In

Brazil, during the 2002/03 and 2004/05 seasons, rainfall-related variables, but not temperature-related variables, accounted for most of the variation in the severity of ASR epidemics (6). The high correlation between rainfall and disease severity can be explained because urediniospores of *P. Pachyrhizi* are released by raindrops, either through the effect of their splash or by the impact that they have on the leaves. Two experimental assays conducted during a single crop season in Brazil found a direct relationship between the duration of the wetting period and the onset of the first symptoms of the disease, as well as a direct relationship between the number of rainy days and the spread of the epidemic (21).

Comparing epidemics allows the exploration of similarities and differences between them, as well as the definition of models and general principles for several epidemiological phenomena, which allows hypothesis and theory testing (12). In the study of epidemics, the temporal dynamics of plant diseases have been emphasized because the spread of diseases is relatively easy to discern. In the temporal analysis of diseases, the progress curve provides the best representation of an epidemic. Interpreting the shape of these curves and determining their components, such as initial disease intensity, progress rate, final intensity, and area under progress curve, are essential for managing the epidemics (3).

Prior to the introduction of ASR in the United States, Pivonia & Yang (16) modeled the potential establishment of the disease and suggested that the disease could occur in areas where the fungus was capable of surviving throughout the year, including Africa and South America. If the disease were to become established in the United States, it would probably be restricted to certain areas in Florida and southern Texas. Pivonia & Yang (16) further concluded that the occurrence of rust epidemics in soybean-producing regions in the United States would depend on the south-north dispersion of urediniospores.

Sconyers et al. (18) used spore collectors to detect urediniospores of *P. pachyrhizi* at ten locations in the state of Georgia in the United States. Collectors were placed in the middle of "sentinel" plots with the objective of providing warning data to detect the presence of viable *P. pachyrhizi* urediniospores, which could serve as inoculum for the disease to develop in soybean crops. The results showed that ASR was reported in soybean fields at 5 to 55 days after airborne *P. pachyrhyzi* urediniospores had been detected in six locations. In two locations, airborne urediniospores were detected, but the disease did not occur in the sentinel plots, whereas in two other locations, no airborne urediniospores were detected and the disease did not occur. These data reinforce the idea that the presence of urediniospores does not necessarily lead to the onset of rust in soybean crops; inoculum concentrations, viability and environmental conditions are determining factors for the development of the disease. The aim of this study was to investigate the progress of ASR and to quantify airborne urediniospores in two municipalities in western Paraná State, southern Brazil.

MATERIAL AND METHODS

Progress of Asian rust: Two experimental assays were set up during the 2006/2007 crop season in western Paraná State, southern Brazil. One site was located at 24°11' S, 52°14' W at an elevation of 680 m, in the municipality of Campo Mourão (CM), and the other was located at 24°05' S, 52°21' W at an elevation of 623 m, in the municipality of Luiziana (LZ); the two locations were approximately 35 km apart. The same experimental trial was repeated in Campo Mourão in the 2007/08 crop season for a total of three experiments over two seasons. This area is an important soybean producing region, and ASR had occurred at epidemic proportions in commercial soybean crops in previous seasons because of the absence of control measures. According to Köppen & Geiger (11), the climate in the region of the assays is subtropical (Cfa), characterized by moderate temperatures with well-distributed rainfall and warm summers. Frost occurs during winter months, with average temperatures below 16°C. In the warmest month, high temperatures surpass 30°C. In the 2006/07 season, sowing at LZ occurred on November 5, 2006, using the semi-early cycle variety Embrapa 48. At CM, sowing occurred on November 25, using the medium-cycle variety BRS 154. In the 2007/08 season, sowing occurred on November 21, 2007, using the variety Embrapa 48.

To establish the different levels of the disease, incremental doses of the fungicide tebuconazole were applied at 15-day intervals. Fungicide applications started from the onset of the first symptoms until stage R6, at the following doses per hectare: D1 (0), D2 (0.250 L), D3 (0.500 L) and D4 (0.750 L). These dosages were used to obtain four disease levels. Four replicates were assigned to plots in a randomized block design. Each plot consisted of five 5-m rows, with a common border between plots. Plants were spaced 0.12 m apart, with 0.40 m between rows. The plots were maintained by using techniques recommended for soybean crops (7).

Starting at stage V2, leaflet samples from the experiments were weekly evaluated until the onset of the first ASR pustules, when tebuconazole spraying began. To evaluate severity, two previously labeled plants from the central row of each plot were weekly collected in each of the three experimental assays. Grades on the disease severity were attributed to all sampled leaflets by using a scale diagram ranging from 0.6% to 78.5%, as per GODOY et al. (8). This method served as reference to evaluate the effect of the disease levels at the time of each evaluation. After the data had been collected, severity data were arranged in time curves of disease progress. The area under the standardized progress curve of the disease (AUDPC*) was calculated by using the trapezoidal method of integration (5,22). The severity AUDPC* obtained for the diseased leaflets was then used to compare the effect of the different fungicide doses on the amount of foliar tissue affected by the disease.

Severity data were used to construct time curves for the progress of the disease. The studied variables were individually plotted graphically (y) as a function of time (x), allowing a comparison of the behavior of these variables among the treatments at the corresponding time periods.

From the variation in the time interval between disease evaluations, the integer variable AUDPC was divided by the respective observation period ($t_{i+1} - t_i$) and marked with an asterisk (*). Thus, the AUDPC* used to compare the different treatments corresponds to the area under the standardized progress curve and can be interpreted as the weighed average of the severity of the variable analyzed during the experiment (22).

The best fit model for the disease progress was selected by the coefficient of determination of the non-linear data (R^{*2}), which is obtained between the values of the real disease progress curve and the curve forecasted by the model, both without transformation, and by the randomness of the residuals plotted in time (5, 4).

During the 2006/2007 season, the disease was evaluated at 67, 73, 79, 87, 94 and 101 days after sowing (DAS) in the LZ experiment and at 60, 65, 72, 79, 88 and 94 DAS in the CM experiment. In the 2007/08 season, evaluations were done at 62, 69, 75, 82, 89, 96, 103 and 110 DAS in the CM experiment.

Meteorology information for the study period was obtained from a weather station located near the experiments. Daily rainfall, relative air humidity and temperature were presented graphically.

Data on the severity of Asian rust was analyzed by fitting three mathematical models according to linear regression using SAS - *Statistical Analysis System* software (SAS Institute, Cary, NC, USA).

Quantification of airborne *P. pachyrhizi* urediniospores: This study was carried out in a soybean field located in Campo Mourão (24°11' S, 52°14' W at an elevation of 680 m) between December 1, 2006, and March 31, 2008.

Three weathercock-type spore collectors were placed on the field in November, which is the sowing season for most soybean crops in western Paraná (17). The collectors remained in the field during the 2006/07 and 2007/08 crop seasons, as well as in the off-season.

Each collector was placed at 1.50 m from the ground and approximately 40 m apart. The impact surface for spore collection was a microscope slide (7.5 x 2.5 cm) covered by a thin layer of silicone wax. The slides remained exposed to urediniospore impact for 24 hours and were daily replaced.

The mean number obtained from all three collectors was analyzed.

Meteorology information for the study period was obtained from a weather station located 50 meters apart from the experiments.

The number of *P. pachyrhizi* urediniospores captured in the collectors and the intensity of ASR observed in the previous experimental assays were analyzed by means of correlation with temperature and rainfall using SAS - *Statistical Analysis System* software (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

In general, the progress of ASR varied according to the crop season and the prevailing weather in each region of the experiment (Figure 1).

Figure 1A shows the severity progress curves for ASR in the 2006/07 season at LZ. The disease began at 87 days after sowing (DAS), when the plants were in stage R_5 (early pod filling) and reached the maximum level of 15.5% in the plot without tebuconazole treatment (Level 1). At CM, during the same season, the disease began at 73 DAS in R_4 (full pod formation) and reached level 1, with 50.3% of severity in the non-treated plot (Figure 1B). During the 2007/08 crop season at CM, the disease began at 96 DAS, when the plants were in stage R_5 and reached 29.3% severity in the non-treated plot, reaching level 1 (Figure 1C). The temperature, the number of foliar wetting hours and the interaction between both variables influenced the different rates of incidence and severities of ASR. Likewise, Alves et al. (1) showed that the temperature, the number of foliar wetting hours and their interaction could lead to differences in the intensity of ASR.

The severity of ASR was greater at CM, with the disease beginning earlier in the 2007/08 crop season (73 DAS), in stage R_4, even though the seeding of variety BRS 154 occurred later (November 25 2006). Under these conditions, severity reached its highest levels (Figure 1B). At LZ, where seeding of the semi-early variety Embrapa 48 occurred earlier (november 5 2006), the disease began in R_5 and had lower levels of severity. During a 30-day period after detecting the disease in soybean crops, Del Ponte et al. (6) observed a high correlation between Asian rust epidemics and high rainfall, but a low correlation with temperature. Thus, rain can prolong foliar wetting, promote spore release due to turbulence, cause spores to set on leaves, and reduce temperature within the canopy of plants. Comparing the environmental conditions of both crops in the present study, the average temperature was approximately 20°C for the first crop and 23°C for the second crop; cumulative rainfall was greater and more distributed in the first crop and lower in the second crop. Because increased rainfall extends the foliar wetting period, this favored the occurrence of a more severe Asian rust epidemic in the first crop (Figure 2).

The AUDPC of Asian rust severity in leaves treated with tebuconazole are presented in Figure 3. A difference can be observed in the pattern of the epidemics at CM between the 2006/07 and 2007/08 crop seasons, with greater severity in the first season.

Among the models fit to the temporal progress of the disease (monomolecular, logistic and Gompertz), the logistic model provided the best fit to the data for the progress of the severity of Asian rust in both crop seasons. Specifically, the logistic model had higher coefficients of determination (R^{*2}) and lower residuals (Table 1).

For the logistic model during the 2006/2007 season, R^{*2} values ranged from 0.74 to 0.91 for LZ and from 0.53 to 0.85 for CM. In the 2007/2008 crop season (CM), R^{*2} values ranged from 0.29 to 0.40 (Table 1).

The progress curves obtained for Asian rust at LZ and CM during the 2006/2007 season and at CM during the 2007/2008 season, estimated with the logistic model at the different severity values, indicated different patterns. A maximum severity rate of 0.6 was observed in non-treated plants (level 1) only at CM during the 2006/07 season. Conversely, in plants treated with tebuconazole, there was a reduction to 0.5% (level 2), 0.3% (level 3) and 0.3% (level 4) at CM during the 2006/07 crop season. These results suggest a higher severity of Asian rust, with a more significant epidemic in this region.

The t-test showed a significant difference in the progress rate of the disease (*r*) estimated by the logistic model among the different levels of severity. A tendency towards variation related to the disease level was also observed. Level 1 (not treated with tebuconazole) showed the highest disease rates. These results indicate that the disease progressed at the same rate in both municipalities (Table 2).

The logistic model was the best fit for the data on Asian rust, with R^{*2} values for severity between 0.53 and -0.91. However, a reduction was observed in the progress rates of the disease, which were higher in the first season and lower in the second one. This reduction was likely due to climate and/or pathogen factors, since the same soybean variety was used in both crops. Other studies have shown that the logistic model was the best fit for the data on Asian rust, with a coefficient of determination between 0.95 and 0.98 for two experiments (21). The duration of the Asian rust epidemic may differ depending on the sowing season, with maximum levels occurring at 40 to 60 days after seeding in fall and at 80 to 100 days after seeding in summer (24).

Comparing the progress of Asian rust in the three experimental assays, severity was higher in the first season than in the second one. On the other hand, during the first crop season at LZ, although the environmental conditions were favorable, disease severity was lower when compared to the second season at CM. This result was likely due to earlier sowing at LZ, when there was lower availability of pathogen inoculum in the region, as well as to the use of a semi-early variety. A similar behavior for Asian rust epidemics in Brazil was observed by Silva et al. (19). According to Gonçalves et al. (9), semi-early soybean varieties show lower severity of the disease, possibly because they reach the maturation stage earlier in the season. Xavier et al. (23) suggested that later soybean seeding favors the development

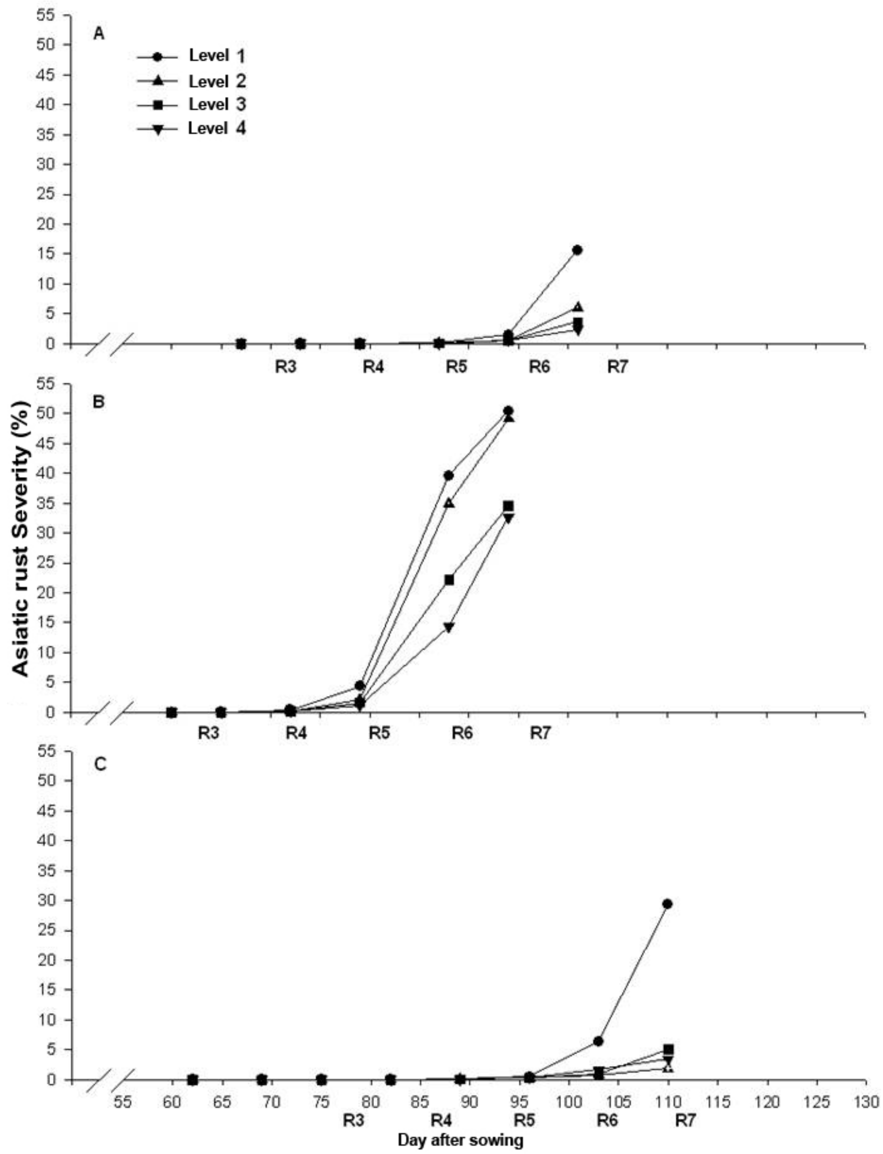

Figure 1. Progress curves for the severity (% of symptomatic leaf area) of Asian rust (*Phakopsora pachyrhizi*) for increasing disease levels during the 2006/07 crops at Luiziana and Campo Mourão, Brazil (A and B) and 2007/08 crop at Campo Mourão (C). Non-treated plants (Level 1) and plants treated with tebuconazole (Levels 2, 3 and 4, at the following dosages per hectare: 0.250, 0.500 and 0.750 L, respectively).

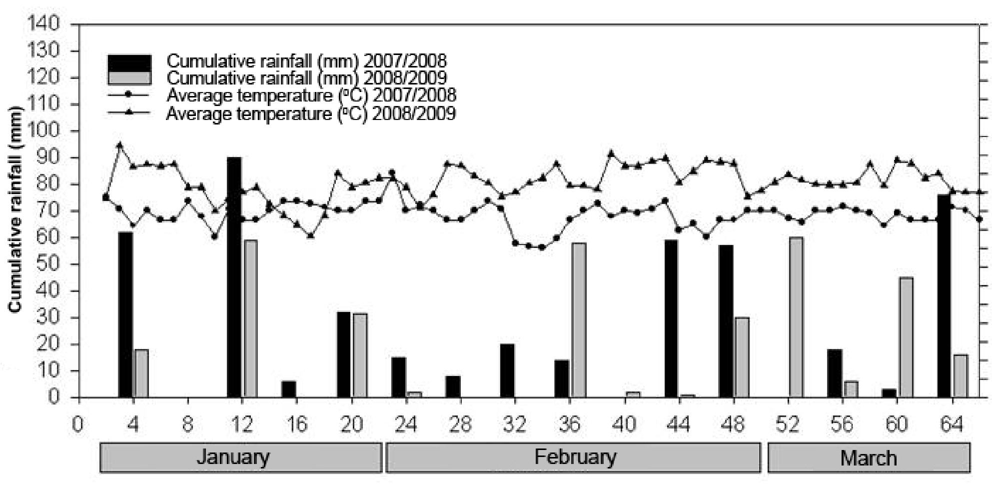

Figure 2. Daily cumulative rainfall data, average temperature observed during the period between January 10, 2006, and March 14, 2007 (2006/08 crop season), and January 10, 2007, and March 14, 2008 (2007/08 crop season), at the region of the experiments with Asian soybean rust (Campo Mourão and Luiziana, Brazil**)**

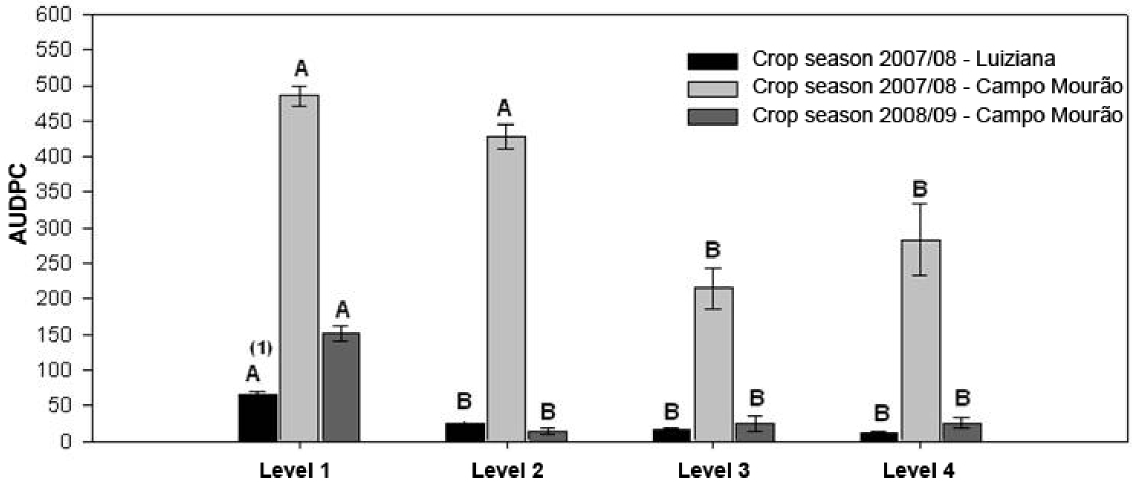

Figure 3- Area under the progress curve for the severity of Asian rust (*Phakopsora. pachyrhizi*) in soybean plants treated with tebuconazole as a function of time (AUDPC). Non-treated (Level 1) and treated plants (Levels 2, 3 and 4, at the following dosages per hectare: 0.250, 0.500 and 0.750 L, respectively), 2006/07 and 2007/08 crop seasons at Luiziana and Campo Mourão, Brazil.

Table 1. Parameters of the Logistic model fitted by linear regression to severity data for Asian rust (*Phakopsora pachyrizi*) in soybean plants treated with tebuconazole, during the following seasons: 2006/07 at Luiziana, 2006/07 at Campo Mourão, and 2007/08 at Campo Mourão/ Brazil, respectively.

Intensity	R^2 [a]	R^{*2} [b]	b_1 [c]	dp_{b1} [d]	b_2 [c]	dp_{b2} [d]
Logistic (2006/07 season – Luiziana)						
Level 4	0.79	0.77	-7.3275	0.2237	0.1091	0.0131
Level 3	0.81	0.74	-7.4732	0.2394	0.1245	0.0140
Level 2	0.78	0.88	-7.5279	0.2975	0.1402	0.0174
Level 1	0.82	0.91	-7.5527	0.3301	0.1770	0.0193
Logistic (2006/07 season – Campo Mourão)						
Level 4	0.93	0.79	-7.2630	0.2559	0.2341	0.0142
Level 3	0.95	0.86	-7.3456	0.2014	0.2263	0.0112
Level 2	0.92	0.83	-7.2398	0.3020	0.2559	0.0168
Level 1	0.97	0.88	-6.7553	0.1748	0.2497	0.0097
Logistic (2007/08 season – Campo Mourão)						
Level 4	0.72	0.54	-7.6561	0.2079	0.0693	0.0071
Level 3	0.70	0.53	-7.6930	0.2157	0.0703	0.0073
Level 2	0.73	0.56	-7.5208	0.1679	0.0583	0.0057
Level 1	0.73	0.85	-8.1961	0.3337	0.1158	0.0113

[a] The coefficients of determination (R^2), as well as the values of b_1 and b_2, were estimated according to linear regression of severity values as a function of time in days; [b] Coefficient of determination obtained between the predicted and observed values; [c] b_1 and b_2 refer, respectively, to intercept, quantity of initial inoculum (y_0) and rate of progress of the disease (r), as estimated by the models; [d] Standard deviation obtained for each variable according to the model fit; ** Level 1 (non-treated plants); Levels 2, 3 and 4 (doses per hectare: 0.250, 0.500 and 0.750 L, respectively).

of rust and thus higher rates of rust severity and lower productivity.

In Brazil, the use of early soybean cultivar sown early in the recommended season is one of the recommended management practices to reduce the damage caused by Asian rust. In addition to these early cultivars escaping rust epidemics due to their reduced time on the field, because rust is a biotrophic pathogen, it multiplies during the first seedings, serving as the initial outbreak of the fungus and resulting in less inoculum pressure on these seedings (15).

In the first season of this study, with more favorable climate conditions, the progress of the disease was greater, even among plants protected with fungicide (Figure 3B). Because rainfall was more intense in the first season compared with the second one, it can be inferred that rainfall was the likely cause of greater rust severity. According to Del Ponte et al. (6), the intensity of rainfall may be positively correlated to the severity of Asian rust. However, other factors may have contributed to the high levels of disease reported in the second season, such as the amount of inoculum in the region, the plant density and the microclimate conditions.

In the present study, the weathercock-type spore collector made it possible to efficiently quantify the urediniospores of ASR. Figure 4 shows the number of *P. pachyrizi* urediniospores collected in the period between December 1, 2006, and March 31, 2008, as well as ASR intensity, average temperature, rainfall intensity (mm) and relative humidity (%). The first urediniospores were collected on December 8, 2006, during the first crop season and on December 11, 2007, during the second season (Figure 4A). The time period when most urediniospores were captured coincided with the period of greatest increase in ASR. The occurrence of the disease on soybean plants was observed in R_3 (early pod formation) in the first season, and in R_4 (full pod formation) in the second season (Figure 4B). After those initially infected stages, an explosive increase was observed in the number of collected urediniospores, which decreased after the end of the soybean cycle. In both seasons, disease severity peaked when the number of urediniospores was largest, coinciding with the heavier daily rainfall and more regular rainfall distribution during the reproductive period of soybean. Relative humidity ranged from 65% to 100% during the study (Figure 4C).

The urediniospore collectors were kept in the field during the soybean off-season. The number of collected urediniospores was

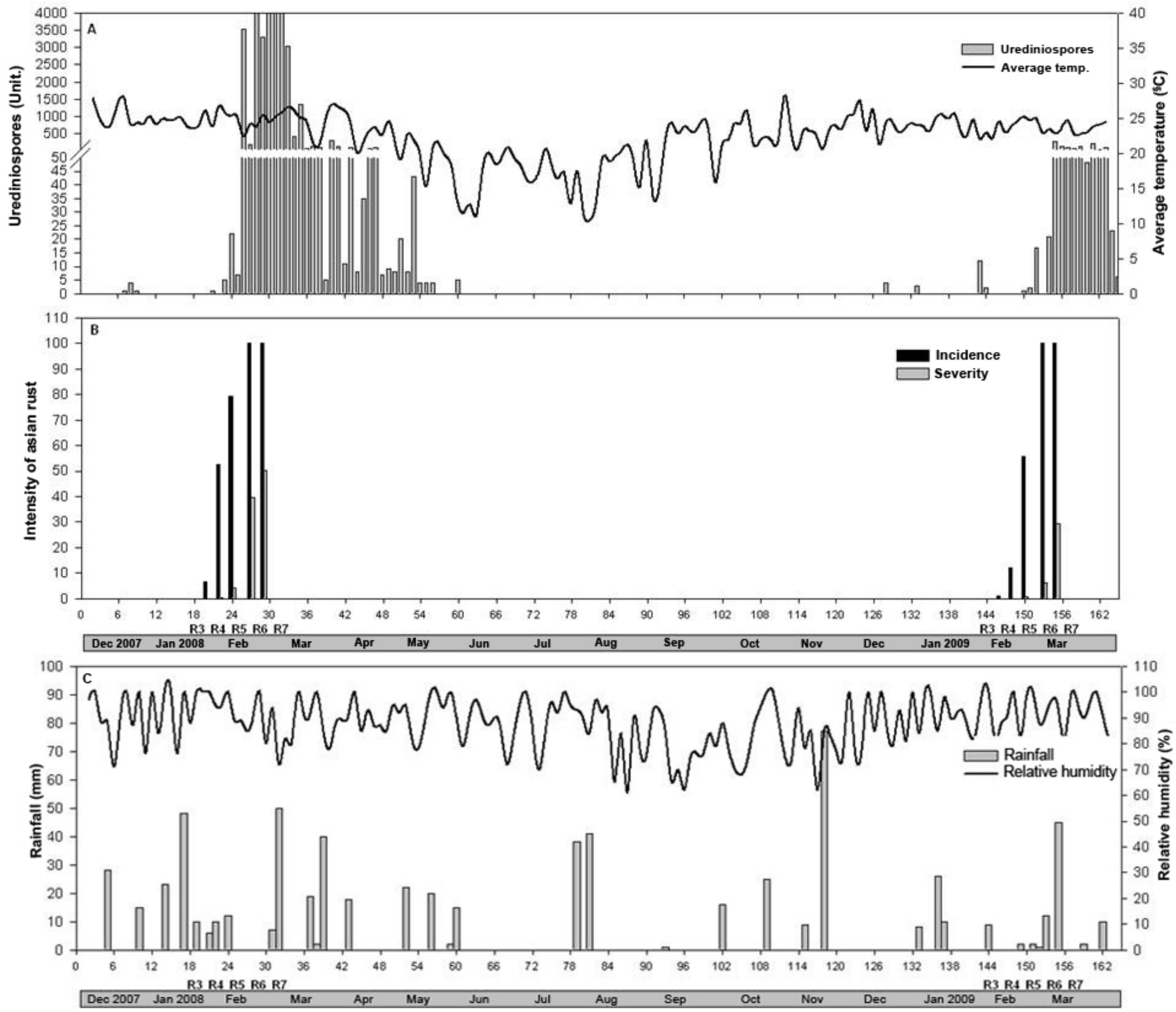

Figure 4- *Phakospsora pachyrhizi* urediniospores collected between December 1, 2006, and March 31, 2008, and average temperature (°C). The arrow indicates the start of urediniospore sampling. Region of Campo Mourão/Brazil (A). Incidence (% of symptomatic leaflets) and severity (% of symptomatic leaf area) of Asian rust in the 2006/07 and 2007/08 crop seasons (B). Rainfall (mm) and relative humidity (%) in the period between December 1, 2006, and March 31, 2008 (C).

reduced starting in March, which coincides with the start of the soybean harvest in the region, when there are practically no soybean plants with green tissue left. From June to early December 2007, no urediniospores were recorded in the spore collectors (Figure 4A).

Tables 3 and 4 show the results of the correlation analysis among collected urediniospores, rust intensity and climate variables for CM and LZ in 2006/07 and CM in 2007/08. In general, the number of collected urediniospores was positively correlated to the intensity of Asian rust and rainfall intensity in both seasons. In the first season, the urediniospore numbers were positively correlated to rust severity (Sev), cumulative rainfall (PA) and number of days with rainfall between 0 and 1 mm (Nd0) (r = 0.94, 0.95 and 0.94, respectively) ($P < 0.001$) (Table 3). Likewise, in the second season, in addition to the disease severity, the urediniospore numbers were positively correlated to the cumulative number of favorable days (DF) (defined as the combination of days with relative humidity between 90% and 100% and temperature between 18°C and 26°C) and the number of days with rainfall above 5 mm (Nd5), (r = 0.93, 0.93 and 0.93, respectively) ($P < 0.001$) (Table 4).

Results similar to those found in this study were obtained by Alves et al. (2) under more controlled conditions. Other severe epidemics of Asian rust have been observed in areas where daily average temperatures are lower than 28°C, with rainfall or period of foliar wetting between 10 and 12 hours throughout the season (20). The infective capacity of *P. pachyrhizi* varies according to the combination between the binomial temperature and the foliar wetting period, with optimal levels at 20 to 25°C and 12 h of wetting (13).

In general, the number of collected urediniospores was related to the presence of soybeans in the field. There was a high correlation among the number of urediniospores and rust severity, cumulative rainfall and favorable days. Rainfall during the time period preceding the largest number of collected urediniospores was 50 mm and was well distributed (Figure 4C). According to Del Ponte et al. (6), rainfall plays a primary role in the development of soybean rust, showing high correlation with the disease severity.

At CM, the first report of urediniospores occurred on December 8, 2006, during the first season, and on December 11, 2007, during the second season. This finding shows that urediniospores were present

Table 3. Correlation between collected urediniospores, Asian rust intensity and climate variables during the 2006/07 crop season in the region of Campo Mourão/Brazil.

	Pearson's correlation coefficients for the variables[a]										
	Collected urediniospores[b]	Incidence[c]	Severity[d]	DF[e]	Taverage[f]	Tminimum[f]	Tmaximum[f]	PA[g]	Nd_0[h]	Nd_1[h]	Nd_5[h]
Collected urediniospores	-	-	-	-	-	-	-	-	-	-	-
Incidence	0.76	-	-	-	-	-	-	-	-	-	-
Severity	0.94*	0.85	-	-	-	-	-	-	-	-	-
DF	0.90	0.82	0.84	-	-	-	-	-	-	-	-
Taverage	NS	NS	NS	NS	-	-	-	-	-	-	-
Tminimum	NS	NS	NS	NS	NS	-	-	-	-	-	-
Tmaximum	NS	NS	NS	NS	NS	NS	-	-	-	-	-
PA	0.95*	0.81	0.90	0.98*	NS	NS	NS	-	-	-	-
Nd_0	0.94*	0.83	0.90	0.97*	NS	NS	NS	0.99*	-	-	-
Nd_1	0.77	0.70	0.69	0.92*	NS	NS	NS	0.91	0.90	-	-
Nd_5	0.89	0.91	0.87	0.97*	NS	NS	NS	0.96*	0.96*	0.89	-

[a]Significant correlation coefficients (P = 0.05), except for values marked with * (P<0.001); [b]Cumulative number of *Phakopsora pachyrhizi* urediniospores collected during seven days prior to each evaluation of the disease; [c]Incidence of Asian rust; [d]Severity of Asian rust; [e] Cumulative number of favorable days during a seven-day period prior to each evaluation of the disease. DF was defined as temperature between 18°C and 26°C combined with relative humidity between 90% and 100%; [f]Tave, Tmin, Tmax, means of average, minimum and maximum temperatures, respectively; [g]PA Cumulative rainfall during the evaluations of the disease; [h]Nd_0, Nd_1, Nd_5 Number of days with rainfall between 0-1 mm, 1-5 mm and above 5 mm, respectively.

Table 4. Correlation between collected urediniospores, Asian rust intensity and climate variables during the 2007/08 crop season in the region of Campo Mourão/Brazil.

	Pearson's correlation coefficients for the variables[a]										
	Collected urediniospores[b]	Incidence[c]	Severity[d]	DF[e]	Taverage[f]	Tminimum[f]	Tmaximum[f]	PA[g]	Nd_0[h]	Nd_1[h]	Nd_5[h]
Collected urediniospores	-	-	-	-	-	-	-	-	-	-	-
Incidence	0.83	-	-	-	-	-	-	-	-	-	-
Severity	0.93*	0.84	-	-	-	-	-	-	-	-	-
DF	0.93*	0.92*	0.89	-	-	-	-	-	-	-	-
Taverage	NS	NS	NS	NS	-	-	-	-	-	-	-
Tminimum	NS	NS	NS	NS	NS	-	-	-	-	-	-
Tmaximum	NS	NS	NS	NS	NS	NS	-	-	-	-	-
PA	0.90	0.94*	0.90	0.98*	NS	NS	NS	-	-	-	-
Nd_0	0.89	0.91*	0.86	0.98*	NS	NS	NS	0.98*	-	-	-
Nd_1	0.79	0.45	0.58	0.68	NS	NS	NS	0.58	0.64	-	-
Nd_5	0.93*	0.93*	0.89	0.99*	NS	NS	NS	0.99*	0.98*	0.64	-

[a]Significant correlation coefficients (P = 0.05), except for values marked with * (P<0.001); [b]Cumulative number of *Phakopsora pachyrhizi* urediniospores collected during seven days prior to each evaluation of the disease; [c]Incidence of Asian rust; [d]Severity of Asian rust; [e] Cumulative number of favorable days during a seven-day period prior to each evaluation of the disease. DF was defined as temperature between 18°C and 26°C combined with relative humidity between 90% and 100%; [f]Tave, Tmin, Tmax, means of average, minimum and maximum temperatures, respectively; [g]PA Cumulative rainfall during the evaluations of the disease; [h]Nd_0, Nd_1, Nd_5 Number of days with rainfall between 0-1 mm, 1-5 mm and above 5 mm, respectively.

in the region prior to the first records of the disease, which occurred on December 28, 2006, during the first season, and on December 19, 2007, during the second season. According to Sconyers et al. (18), Asian rust was observed on soybeans between 5 and 55 days after airborne urediniospores of *P. pachyrhyzi* had been detected in sentinel plots, including two locations in which airborne urediniospores were found, but the disease did not occur on the soybean crop.

At CM, most urediniospores were collected during the first crop season (2006/2007). That season had the largest Asian rust epidemic in soybean crops in the region.

The increase in the number of urediniospores began in R_3 (early pod formation) in the first crop season and in R_4 (full pod formation) in the second crop season. This increase in the number of collected urediniospores coincided with the higher intensity of the disease in the field.

The number of collected airborne urediniospores was related to the presence of soybeans in the field, and there were positive correlations among the number of collected urediniospores, cumulative rainfall, disease intensity and favorable days for Asian rust. The combination of rainfall, presence of urediniospores and favorability (defined as temperature between 18°C and 26°C and 90% to 100% relative humidity) determined the epidemic of Asian rust in soybean crops.

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