Influence of Agroclimatic Conditions, Life Form, and Host Species on the Species Complex of Wheat Septoria Pathogens

Yu. V. Zeleneva\textsuperscript{a,b, *}, O. S. Afanasenko\textsuperscript{c, **}, \textsuperscript{***}, and V. P. Sudnikova\textsuperscript{a}

\textsuperscript{a} Central Russian Branch, Michurin Federal Scientific Center, Novaya Zhizn', Tambov region, 392553 Russia
\textsuperscript{b} Derzhavin Tambov State University, Tambov, 392000 Russia
\textsuperscript{c} All-Russia Institute of Plant Protection, St. Petersburg, Pushkin, 196608 Russia

*e-mail: tmbsnfs@mail.ru
**e-mail: zelenewa@mail.ru
***e-mail: info@vizr.spb.ru

Received August 27, 2019; revised December 24, 2019; accepted February 16, 2020

Abstract—Currently, Septoria is the basis of the pathogenic complex on wheat crops in Russia, occupying the predominant position among harmful fungal diseases. In case of severe wheat damage, the crop loss caused by the fungus \textit{Zimoseptoria tritici} constitutes from 10–25 to 40–60\%. Crop loss caused by the parasitizing of the fungus \textit{Parastagonospora nodorum} ranges from 10–20 to 30–50\% during the years of epiphytoty. The question of the economic significance of \textit{Parastagonospora avenae} has not yet been examined completely. However, depending on the area of wheat cultivation and the year of observation, its part in the Septoria population can reach 76.9\%. It was of interest to study in detail the influence of the conditions of the specific year, life form, and species of wheat on the formation of the species composition of Septoria in the pathogenic complex of wheat. Among the complex set of factors included in the concept of the environment, a significant role belongs to its abiotic components, namely, climate and weather, but the variety as an environment-forming factor has a decisive role. Our studies were carried out in 2010–2017. During the research period, the weather conditions varied significantly over the years and were not always favorable for the development of plants and the formation of a good wheat crop. During the study, deviations from the long-term average annual values in the amount of precipitation during the vegetation period, and, in general, over the year, were noted. The years 2012, 2014, and 2015 were characterized by the highest moisture supply during the vegetation season. It has been shown that cooler days of April and May promote better development of \textit{P. avenae} and \textit{P. nodorum}. \textit{P. nodorum} obtains its predominant development during the years with more humid weather within the vegetation period of wheat, in contrast to \textit{Z. tritici}, which is more resistant to low humidity. These data demonstrate the adaptation of the pathogen to the conditions of an increased temperature regime and reduced amount of rainfall.

Keywords: agroclimatic conditions, wheat, cultivars, pathogen, resistance
DOI: 10.1134/S1062359021100277

INTRODUCTION

The development of plant diseases is subject to fluctuations. This is manifested in a change in the distribution area in different regions and in the intensity of crop damage (Goodwin et al., 2015; Kuzdraliński et al., 2015; Ben Jabeur et al., 2017). These indicators determine the size of the crop shortfall and the amount of economic damage (Goloshchapov, 2011; Schilly et al., 2011).

Among the complex set of factors included in the concept of the environment, a significant role belongs to its abiotic components, i.e., climate and weather, however, a decisive role remains with the variety as an environment-forming factor (Simón et al., 2007; Torriani et al., 2009; Sanin, 2013; Sklimenok and Buga, 2014; Evseev, 2015).

Since 2000, the authors of this article have been studying the species composition of the Septoria disease on the cultivars of winter and spring wheat in the territory of the Central Black Soil Region (Tambov, Lipetsk, Voronezh, Kursk, and Belgorod regions). It was of interest to study in detail the influence of the conditions of the year, life form, and species of wheat on the formation of the species composition of Septoria in the pathogenic complex of wheat (Plakhotnik et al., 2007; Zeleneva and Sudnikova, 2017, 2019; Zeleneva et al., 2018).

MATERIALS AND METHODS

The studies were carried out in the period 2010 to 2017. To study the relationship between the frequency
of Septoria species and the agroecological conditions prevailing in different years, infectious material was collected on production crops and state variety plots, as well as from the collections of research institutes from collected on production crops and state variety plots, prevailing in different years, infectious material was of Septoria species and the agroecological conditions

![Species composition of Septoria on soft winter and spring wheat and durum wheat on the territory of the Central Black Soil Region during the years 2010–2017.](image)

The influence of agroecological conditions that have developed over the course of eight years of study on the frequency of the species $Z. tritici$, $P. nodorum$, and $P. avenae$ was determined using Fisher’s $F$-criterion (Table 1).

**RESULTS AND DISCUSSION**

The species composition of causative agents of the wheat Septoria disease over the period 2010 to 2017 was represented by the fungi $Z. tritici$, $P. nodorum$, and $P. avenae$ (=Stagonospora avenae f. sp. Triticea Johms), and $Parastagonospora nodorum$ (=Stagonospora nodorum (Berk) Castellani & E.G. Germano). The dominant species was $Z. tritici$. The results are shown in Fig. 1.

The abnormal weather conditions of 2010 with a high temperature regime and air and soil drought adversely affected the host plant and the pathogenic complex. Low development of Septoria blight on wheat was noted; however, the species $Z. tritici$ had the highest frequency in the pathogenic complex of Septoria blots: 96.71%. $P. avenae$ and $P. nodorum$ in 2010 had the lowest frequency for the entire study period (0.6 and 2.69%, respectively).

As shown earlier, $Z. tritici$ was the most abundant Septoria species throughout the years of study in Tambov region. According to the generalized results of the analysis of the frequency of Septoria species on wheat, it was shown that the frequency of the species $Z. tritici$ in 2011 amounted to 72.58; in 2015, 86.5; in 2016, 82.37; and in 2017, 81.08%. The years 2012, 2014, and 2013 should be highlighted separately. They were characterized by the most favorable agroecological conditions for the development of the species $Z. tritici$. Its frequency exceeded 90 cases out of 100 and amounted to 90.08, 90.16, and 92.42%, respectively.

In terms of the frequency, over eight years of study, $P. nodorum$ occupied a stable second position in the pathogenic complex of Septoria spots. In 2013, its indicator was 4.97; in 2014, 7.59; and in 2012, 7.68%. In 2015, 2017, 2016, and 2011, the frequency of $P. nodorum$ exceeded 10% and amounted to 10.04, 11.97, 14.08, and 15.2%, respectively.

$P. avenae$ is a rare species. It usually stands out at the late stages of wheat development, and therefore, does not harm the quality and quantitative indicators of agricultural products. Its frequency in 2012, 2013, and 2014 did not exceed 3%. In 2016, the indicator was 6.56%; in 2017, 9.67%; and in 2011 the frequency exceeded the threshold of 10% and amounted to 11.84%.

The influence of agroecological conditions that have developed over the course of eight years of study on the frequency of the species $Z. tritici$, $P. nodorum$, and $P. avenae$ was determined using Fisher’s $F$-criterion (Table 1).
According to Fisher’s criterion, the influence of agroclimatic conditions on the frequency of all three species of Septoria was revealed. The conditions of the year influenced particularly strongly the frequency of the species *Parastagonospora nodorum* (Fisher’s *F* test = 11.93).

A weak positive correlation was found between the frequency of *Z. tritici* and the average temperature in April (0.22) and May (0.13) (Table 2). An inverse weak correlation was found between the frequency of *P. nodorum* and *P. avenae* and the temperature in April (–0.167 and –0.233) and in May (–0.109 and –0.100, respectively). It follows that the warm temperature regime in May and April has a positive effect on the frequency of *Z. tritici*, while the cooler days of these months promote a better development of *P. avenae* and *P. nodorum*.

There is a weak negative correlation between the frequency of *Z. tritici* and the humidity in April and June and the average for four months (–0.097, –0.117, and –0.090, respectively). It should be noted that there is a weak direct relationship between the frequency of *P. nodorum* and humidity in April (0.089), June (0.116), and the average indicator for four months (0.092). The data given in Table 2 show that *P. nodorum* receives predominant development in the years with more humid weather during the growing season, in contrast to the species *Z. tritici*, which is more resistant to low humidity.

The obtained results of the analysis of variance of intergroup differences in the frequency of different species of Septoria are given in Tables 3, 4, and 5. Between the compared indicators of the frequency of the species *Z. tritici, P. nodorum, and P. avenae* on wheat cultivars in the different years of study, there are differences at the accepted level of significance between the indicators of 2010 and all other years of research. As noted above, this year was characterized by abnormally hot conditions, a low amount of precipitation (in some places none at all), and soil and air drought.

The conditions of 2011 also affected the frequency of the species *Z. tritici* and *P. avenae*. The conditions of 2011–2012, 2013, 2014, and 2015 were significantly different, influencing the frequency of the species (Tables 3, 4). With regard to the frequency of *P. nodorum* in 2011, there are differences from 2012, 2013, and 2014 (Table 5).

There were significant differences in the frequency of *P. avenae* in 2014 and 2017 (Table 3).

Such differences are associated with significant changes in the weather conditions during the study. Thus, the most moisture-secured were the years 2012, 2014, and 2015 (Table 3). The year 2011 was characterized by cool weather and a decrease in precipitation during the spring–summer months. In 2017 the precipitation dropped even less (312 mm) than in 2011 (396 mm); however, the differences in the frequency

### Table 1. Analysis of variance of the frequency indices of Septoria species on wheat cultivars of the Central Black Soil Region depending on the conditions of the year during plant vegetation (2010–2017)

| Septoria species (2010–2017) | Fisher’s *F*-criterion | *p* |
|-----------------------------|------------------------|-----|
| *Zimoseptoria tritici*      | 9.37                   | 0.00|
| *Parastagonospora nodorum*  | 11.93                  | 0.00|
| *Parastagonospora avenae*   | 6.73                   | 0.00|

The effects significant in the level of *p* < 0.05 are in italics.

### Table 2. Correlation coefficient indices of the species frequency of the genus Septoria

| Compared indicators       | *Zimoseptoria tritici* | *Parastagonospora nodorum* | *Parastagonospora avenae* |
|---------------------------|------------------------|-----------------------------|---------------------------|
| Average temperature in April | 0.221                  | –0.167                      | –0.233                    |
| Average temperature in May | 0.125                  | –0.109                      | –0.100                    |
| Average temperature in June | –0.046                 | 0.036                       | 0.035                     |
| Average temperature in July | –0.099                 | 0.087                       | 0.108                     |
| Average temperature for four months | 0.069                  | –0.059                      | –0.056                    |
| Humidity in April         | –0.097                 | 0.089                       | 0.077                     |
| Humidity in May           | –0.034                 | 0.056                       | –0.017                    |
| Humidity in June          | –0.117                 | 0.116                       | 0.075                     |
| Humidity in July          | 0.031                  | 0.002                       | –0.067                    |
| Average humidity for four months | –0.090                 | 0.092                       | 0.045                     |

Marked correlations are significant at the level of *p* ≤ 0.05.
### Table 3. Results of the analysis of variance of intergroup differences on the basis frequency of the species *Parastagonospora avenae* isolated from wheat, depending on the agroclimatic conditions of the year (values of the miscount $p$ in case of pairwise comparison with the Bonferroni correction)

| Year  | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------|------|------|------|------|------|------|------|
| 2011  | 0.000| –    | –    | –    | –    | –    | –    |
| 2012  | 0.000| 0.000| –    | –    | –    | –    | –    |
| 2013  | 0.000| 0.000| 1.000| –    | –    | –    | –    |
| 2014  | 0.000| 0.000| 1.000| 1.000| –    | –    | –    |
| 2015  | 0.000| 0.000| 1.000| 1.000| 1.000| –    | –    |
| 2016  | 0.039| 0.031| 0.249| 0.145| 0.080| 0.782| –    |
| 2017  | 0.016| 0.106| 0.096| 0.080| 0.028| 0.313| 1.000|

Sum total of the analysis of variance for comparison of three or more groups: $F = 11.259$, $p \leq 0.05$; the error when comparing all the groups simultaneously is 0.0001.

### Table 4. Results of the analysis of variance of intergroup differences on the basis frequency of the species *Zimoseptoria tritici* isolated from wheat, depending on the agroclimatic conditions of the year (values of the miscount $p$ in the case of pairwise comparison with the Bonferroni correction)

| Year  | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------|------|------|------|------|------|------|------|
| 2011  | 0.000| –    | –    | –    | –    | –    | –    |
| 2012  | 0.000| 0.000| –    | –    | –    | –    | –    |
| 2013  | 0.001| 0.000| 1.000| –    | –    | –    | –    |
| 2014  | 0.000| 0.000| 1.000| 1.000| –    | –    | –    |
| 2015  | 0.003| 0.000| 1.000| 0.466| 1.000| –    | –    |
| 2016  | 0.001| 0.024| 0.165| 0.003| 0.112| 1.000| –    |
| 2017  | 0.000| 0.116| 0.043| 0.001| 0.027| 1.000| 1.000|

Sum total of the analysis of variance for comparison of three or more groups: $F = 11.789$, $p \leq 0.05$; the error when comparing all the groups simultaneously is 0.0001.

### Table 5. Results of the analysis of variance of intergroup differences on the basis of the frequency of the species *Parastagonospora nodorum* isolated from wheat, depending on the agroclimatic conditions of the year (values of the miscount $p$ in the case of pairwise comparison with the Bonferroni correction)

| Year  | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|-------|------|------|------|------|------|------|------|
| 2011  | 0.000| –    | –    | –    | –    | –    | –    |
| 2012  | 0.000| 0.040| –    | –    | –    | –    | –    |
| 2013  | 0.000| 0.000| 1.000| –    | –    | –    | –    |
| 2014  | 0.000| 0.026| 1.000| 1.000| –    | –    | –    |
| 2015  | 0.005| 0.536| 1.000| 0.237| 1.000| –    | –    |
| 2016  | 0.000| 1.000| 0.094| 0.000| 0.069| 1.000| –    |
| 2017  | 0.014| 1.000| 1.000| 0.078| 1.000| 1.000| 1.000|

Sum total of the analysis of variance for comparison of three or more groups: $F = 6.896$, $p \leq 0.05$; the error when comparing all the groups simultaneously is 0.0001.
of *Z. tritici* with the years 2015 (518 mm) and 2016 (262 mm) were not recorded. Apparently, the compensatory effect of the factors of the temperature values was of importance. The results of the analysis of variance for intergroup differences in the frequency of *Z. tritici* showed a significant difference for the indicators of 2013 and 2016, despite approximately the same conditions during the vegetation season of plants. However, it appears that, in this case, the overwintering of the pathogen and differences in climatic characteristics of the preceding winter months, March and April, were essential.

Differences were registered in the frequency of *Z. tritici*, isolated from the infectious material in 2012–2017, 2013–2016, 2013–2017, and 2014–2017 (Table 4).

Thus, despite the fact that the agroclimatic conditions of the year have an impact on the frequency of *Z. tritici*, *P. nodorum*, and *P. avenae*, the differences established using the Fisher’s *F*-criterion (Table 4), were, apparently, influenced by the indicators of 2010 and 2011. In other years, no significant differences were found for the species *P. nodorum* and *P. avenae* (Tables 6, 8). For *Z. tritici*, in addition, there were differences in the frequency isolated from the infectious material in 2012–2017, 2013–2016, 2013–2017, and 2014–2017 (Table 7).

Analyzing the results of the dependence of the frequency of Septoria species on the life form and wheat species (Fig. 2), it can be noted that no significant effect was found. All life forms of wheat are affected by the three species of Septoria with the same pattern. The frequency of the species *Z. tritici* during the research period varied from 79.77% in the durum spring wheat to 86.26 and 88.49% in soft spring and winter wheat, respectively.

The frequency of *P. nodorum* on the cultivars of soft winter wheat was 8.18% and on spring soft wheat cultivars, 8.99%, and on the cultivars of durum spring wheat, the indicator exceeded 10% and amounted to 14.53%.

*P. avenae* was recorded more often on the cultivars of soft winter wheat. Its frequency was 9.98%. Less commonly, this species affected the cultivars of soft and durum spring wheat: 4.82 and 5.90%, respectively.

The impact of life forms and species of wheat on the frequency of *Z. tritici*, *P. nodorum*, and *P. avenae* were determined using Fisher’s *F*-test. The critical level of significance when testing statistical hypotheses (*p*) was taken equal to 0.05 (Table 6).

According to Fisher’s *F*-criterion, the life form and species of the host plant significantly affect the frequency of the species *Z. tritici* and *P. nodorum* (*F*-criterion = 8.71 and 2.00, respectively). This method did not reveal the influence of life forms and wheat species on the frequency of *P. avenae*.

Using the Bonferroni test, a pairwise comparison was made of the average frequency of different Septoria species, depending on the life form and species of the host plant. The results are presented in Tables 7, 8, and 9.

The use of this statistical method made it possible to establish significant differences in the frequency of *P. avenae* on soft and durum wheat and no differences when comparing the frequency of the species isolated from soft winter and spring wheat.

A similar tendency was observed in relation to the frequency of *Z. tritici* on the cultivars of soft winter, soft spring, and durum spring wheat in pairwise comparison. Differences between soft and durum wheat cultivars were noted.

### Table 6. Analysis of variance of the indices of the frequency of the Septoria species in various life forms and wheat species of the Central Black Soil Region

| Septoria species      | Fisher’s *F*-criterion | *p*  |
|-----------------------|-------------------------|------|
| *Septoria tritici*    | 8.71                    | 0.00 |
| *Stagonospora nodorum*| 2.00                    | 0.00 |
| *Stagonospora avenae* | 1.48                    | 0.23 |

The effects significant at the level of *p* < 0.05 are in italics.

### Table 7. Results of the analysis of variance of intergroup differences on the basis of the frequency of the species *Parastagonospora avenae* isolated from wheat, depending on the life form and the host plant species (values of the discount *p* in the case of pairwise comparison with the Bonferroni correction)

| Life form and species | Life form and species          |
|-----------------------|--------------------------------|
| Soft spring wheat     | soft winter wheat soft spring wheat |
| Durum spring wheat    | 1.000000 0.010130 0.029337     |

Sum total of the analysis of variance for comparison of three or more groups: *F* = 4.546, *p* ≤ 0.05; the error when comparing all the groups simultaneously is 0.011.

### Table 8. Results of the analysis of variance of intergroup differences on the basis of the frequency of the species *Zimoseptoria tritici* isolated from wheat, depending on the life form and the host plant species (values of the discount *p* in the case of pairwise comparison with the Bonferroni correction)

| Life form and species | Life form and species          |
|-----------------------|--------------------------------|
| Soft spring wheat     | soft winter wheat soft spring wheat |
| Durum spring wheat    | 1.000000 0.003686 0.042913     |

Sum total of the analysis of variance for comparison of three or more groups: *F* = 5.292, *p* ≤ 0.05; the error when comparing all the groups simultaneously is 0.011.
and the indicator of average humidity, the conclusion can be made that P. nodorum predominantly develops in years with more humid weather during the vegetation season of wheat, in contrast to the species Z. tritici, which is more resistant to low moisture.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

REFERENCES

Ben Jabeur, M., Somai-Jemmali, L., and Hamada, W., Thyme essential oil as an alternative mechanism: biofungicide-causing sensitivity of Mycosphaerella graminicola, J. Appl. Microbiol., 2017, vol. 122, no. 4, pp. 932–939.

Evsiev, V.V., Septoria pselenis v Zaural’e (Wheat Septoria in the Trans-Ural’s Region), Saarbrucken: Paimarium Acad., 2015.

Goloshchepov, A.P., Nanotechnologies in protection of spring wheat from loose smut in the Kurgan region, in Metody issledovaniya v zashchite rasteni, genetike, selektsii i pervichnom semenovodstve (Research Methods in Plant Protection, Genetics, Selection, and Primary Seed Farming), Kurgan: Komnat, 2011, vol. 1, pp. 47–74.

Goodwin, S.B., Cavaletto, J.R., Hale, I.L., Thompson, I., Xu, S.S., Adhikary, T.B., and Dukovcovsky, J., A new map location of gene Stb3 for resistance to Septoria tritici blotch in wheat, Crop Sci., 2015, vol. 55, no. 1, pp. 35–43.

Kuzdralinski, A., Szczersa H., Tofil K., Filipiak A., Garbarczyk E., Dziedak P., Musynska, M., and Solarska, E., Early PCR detection of the Mycosphaerella graminicola in the leaves of winter wheat in Poland, Rom. Agricult. Res., 2015, no. 32, pp. 491–502.

Pakholkova, E.V., Akimova, E.A., Sanin, S.S., and Goodwin, S.B., Epidemiologic peculiarities of the Septoria species among winter wheat in the Central Region of the Russian Federation, in 50 let na strazhe prodolov’stvennoi bezopasnosti strany (50 Years on Guard of Food Safety of the Country), Bolshie Vyazmy: Vseross. Nauchno-Issled. Inst. Fitopatol., 2008, pp. 347–357.

Pakholkova, E.V., Salnikova, N.N., and Kurkova, N.A., Epidemiologic peculiarities of wheat septoria pathogens Z. tritici and P. nodorum, in Epidemiii boleznei rasteni: monitoring, prognoz, kontrol’, materialy mezhdunarodnoi konferentsii (Epidemics of Plant Diseases: Monitoring, Forecast, and Control: Proceedings of the International Conference), Bolshie Vyazmy: RS-dizain, 2017, pp. 74–81.

Plakhotchik, V.V., Sudnikova, V.P., and Artyomova, S.V., Some problems of methodology of wheat selection for resistance to Septoria tritici in the Central Black Soil region of Russia, in Aktual’nye voprosy immuniteta i zashchity sel’skokhoziaistvennykh kul’tur ot boleznei i vreditelei: materialy mezhdunarodnoi nauchno-prakticheskoi konferentsii (Topical Issues of Immunity and Protection of Agricultural Crops from Diseases and Pests: Materials of the International Scientific and Practical Conference), Odessa, SP-NTsNS, 2007, p. 20.
Sanin, S.S., Epiphytoties of cereal crops: spread in time and space, in Problemy mikologii i fitopatologii v XXI veke: materialy mezhdunarodnoi nauchnoi konferentsii (Problems of Mycology and Phytopathology in the 21st Century: Proceedings of the International Scientific Conference), St. Petersburg: Kopi-R Grupp, 2013, pp. 241–246.

Schilly, A., Risser, P., Ebmeyer, E., Hartl, L., Reif, J.C., Würschum, T., and Miedaner, T., Stability of adult-plant resistance to Septoria tritici blotch in 24 European winter wheat cultivars across nine field environments, J. Phytopathol., 2011, vol. 159, no. 6, pp. 411–416.

Simón, M.R., Ayala, F.M., Cordo, C.A., Röder, M.S., and Börner, A., The use of wheat/goatgrass introgression lines for the detection of gene(s) determining resistance to Septoria tritici blotch (Mycosphaerella graminicola), Euphytica, 2007, vol. 154, nos. 1–2, pp. 249–254.

Sklimenok, N.A. and Booga, S.F., Influence of weather factors onto development of Septoria leaf blotch of winter wheat, in Biologicheskaya zaschita rastenii—osnova stabilizatsii agroekosistem: materialy 8-i mezhdunarodnoi nauchno-prakticheskoi konferentsii (Biological Protection of Plants as the Stabilization Basis of Agroecosystems: Materials of the 8th International Scientific and Practical Conference), Krasnodar: Vseross. Nauchno-Issled. Inst. Biol. Zashchity Rast., 2014, no. 8, pp. 89–91.

Torriani, S.F., Brunner, P.C., McDonald, B.A., and Sierotzki, H., QoI resistance emerged independently at least 4 times in European populations of Mycosphaerella graminicola, Pest Manage. Sci., 2009, vol. 65, no. 2, pp. 155–162.