sciendo

RURAL SUSTAINABILITY RESEARCH
49(344), 2023
ISSN – 2256-0939



Received: 26 January 2023 Revised: 11 April 2023 Accepted: 06 June 2023

Impact of Fungicide Treatment Schemes on the Severity of Leaf Blotches in Winter Wheat

***Agrita Švarta, Gunita Bimšteine, Biruta Bankina, Jānis Kaņeps, Zinta Gaile**
Latvia University of Life Sciences and Technologies, 2 Liela street, Jelgava, Latvia

Abstract. The common control method of leaf blotches is the application of fungicides; however, the results of trials are inconsistent. The aim of the present study was to evaluate the impact of the fungicide treatment intensity on the severity of leaf blotches and to assess the correlation between the development of diseases and winter wheat (*Triticum aestivum*) yield in 2018–2021. The development of diseases was evaluated regularly. In this study, the severity of leaf blotches at the medium milk ripening (GS 75–77) was used. Tan spot dominated in 2018, 2019, and 2021, but Septoria tritici blotch dominated in 2020. Fungicides significantly decreased the severity of tan spot and Septoria tritici blotch, but the efficacy of used fungicide treatment schemes differed during trial years – it was more pronounced under higher pressures of leaf blotches. In the year with a high severity of Septoria tritici blotch, the best efficacy was obtained when fungicide was used two times (at GS 32–33 and GS 55–59), but for tan spot – when the dose of fungicide was done in two or three applications. Usage of fungicides increased wheat yield only under high pressure of diseases. A strong significant correlation between the severity of Septoria tritici blotch at GS 75–77 and grain yields was established only in 2020, when the severity of the disease was higher.
Key words: tan spot, *Pyrenophora tritici-repentis,* Septoria tritici blotch, *Zymoseptoria tritici*, disease control, yield.

Introduction

The most important wheat (*Triticum aestivum*) leaf diseases in Europe are Septoria tritici blotch (caused by *Zymoseptoria tritici*) and tan spot (caused by *Pyrenophora tritici-repentis*) (Bankina *et al.*, 2021; Fones & Gurr, 2015; Willocquet *et al.*, 2021). The reduction of grain yield due to foliar diseases is considerable and can range up to 10–74% (Bhatta *et al.*, 2018; Wiik, 2009).

The development of leaf blotches mainly depends on meteorological conditions (El Jarroudi *et al.*, 2022; Kuzdraliński *et al.*, 2015; Willocquet *et al.*, 2021). Optimal temperatures for the germination of the conidia of *Z. tritici* are between +15 °C and +25 °C (Boixel *et al.*, 2022; Gomes *et al.*, 2016), but for conidia of *P. tritici-repentis* – between +20 °C and +25 °C (Bouras, Kim, & Strelkov, 2009). The development of the leaf blotches is facilitated by a high level of humidity in the canopy (Boixel *et al.*, 2022; Bouras, Kim, & Strelkov, 2009; Gomes *et al.*, 2016). Increasing leaf moisture promotes spore germination and decreases the time for *Z. tritici* penetration into leaf tissues (Fones & Gurr, 2015).

The common control method of leaf blotches is the application of fungicides. Foliar fungicide treatment programmes are aimed to protect three upper leaves. In general, fungicide treatment programmes include one to three fungicide applications from stem extension to full flowering stage (Willocquet *et al.*, 2021), and in Ireland and other countries with humid and warm climate – even four applications with additional application of fungicides in the early pre-stem extension for the control of Septoria tritici blotch (Creissen *et al.*, 2018).

In order to choose optimal schemes for fungicide treatment, many research projects have been carried out all over the world, but the results obtained are contradictory even in a single region. There are many variations in disease severity, in the yield response to fungicides and in the interaction among them. The aim of the present study was to evaluate the impact of fungicide treatment intensity on the severity of leaf

* Corresponding Author's email: agrita.svarta@lbtu.lv

DOI: 10.2478/plua-2023-0004
© 2023 A.Švarta et al. This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/3.0/).

blotches and to assess the correlation between the development of diseases and winter wheat yield.

Materials and Methods

Field studies were conducted over 4 years (2018–2021) at the Research and Study Farm "Pēterlauki" (N 56º 30.658′, E 23º 41.580′) of the Latvia University of Life Sciences and Technologies. Field experiments with different fungicide treatment schemes and nitrogen doses were designed for winter wheat "Skagen". The variety is widely grown in Latvia, has a high baking quality, a good winter hardiness and is moderately resistant against leaf blotches.

Researched factors were (A) an untreated variant and four fungicide application schemes (Table 1), (B) four nitrogen fertiliser rates (N120(80+40), N150(80+70), N180(80+70+30), N210(80+80+50) kg ha^{-1}). Plots were arranged in randomised blocks in four replications, in total, twenty variants. More detailed information about the trial is given in previous publications (Švarta *et al.*, 2020; Švarta *et al.*, 2022). Nitrogen rates were not taken into account in this study because they did not affect the level of leaf blotches (data are not shown).

The doses of fungicides were calculated in relation to the main active ingredient in this trial, prothioconazole, as it does not pose a risk to consumer health when used according to good agricultural practices (EFSA, 2020), provides good wheat leaf disease control (Heick, Justesen & Jørgensen, 2017), and its registration has been extended by the EU. In the first spraying (GS 32–33), prothioconazole was used in combination with spiroxamine to achieve optimal mildew control. In the second spraying, prothioconazole was used in combination with bixafen and fluopyram to gain good leaf blotch control and reduce the risks of disease resistance.

The treatment frequency index (TFI) was used to characterise the intensity of fungicide treatment. TFI is calculated by dividing the total amount of active ingredients used in one season by the one registered dose. This indicator characterises the intensity of pesticide treatment (Jørgensen, 2008).

The development of diseases was determined regularly by visual assessment of leaves, but in this study, the severity at the stage of milk ripeness (GS 75–77) was used. At the present assessment, 50 upper leaves were evaluated from every plot – the same number of flag leaves and the first leaves.

The analysis of variance by R-studio was used for statistical analysis of the experimental data. The Bonferroni test was used for the comparison of means at $p<0.05$. Significantly different values were labelled

Table 1

The fungicide treatment schemes (Švarta *et al.*, 2020; Švarta *et al.*, 2022)

Variants	Treatment timing-growth stages (GS)*	Active ingredients of fungicides	Dose of commercial fungicides, L ha^{-1}	Treatment frequency index
F0 (untreated variant)	Without fungicides	-	-	-
F1 (half of full fungicide dose, one treatment)	55−59	Prothioconazole 130 g L^{-1}; Bixafen 65 g L^{-1}; Fluopyram 65 g L^{-1}	0.750	0.5
F2 (a full fungicide dose, one treatment)	55−59	Prothioconazole 130 g L^{-1}; Bixafen 65 g L^{-1}; Fluopyram 65 g L^{-1}	1.500	1.0
F3 (a full fungicide dose divide into two treatments)	32−33 55−59	Prothioconazole 160 g L^{-1}; Spiroxamin 300 g L^{-1}. Prothioconazole 130 g L^{-1}; Bixafen 65 g L^{-1}; Fluopyram 65 g L^{-1}	0.625 0.750	1.0
F4 (two full fungicide doses divide into three treatments)	32−33 55−59 63−65	Prothioconazole 160 g L^{-1}; Spiroxamin 300 g L^{-1}. Prothioconazole 130 g L^{-1}; Bixafen 65 g L^{-1}; Fluopyram 65 g L^{-1}. Metconazole 90 g L^{-1}	0.625 0.750 1.000	2.0

* – phenological growth stages of cereals according to the "Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie" scale (BBCH).

Table 2

Meteorological situation during the experiment

Year	Growth stages	Average temperature, ºC	Amount of precipitation, mm	Number of rainy days (>2 mm)
2018	31–39	16.2	4.0	1
	39–65	17.6	2.0	0
	65–73	17.9	0	0
	73–79	15.8	14.0	3
2019	31–39	13.3	14.0	1
	39–65	16.3	5.8	0
	65–73	20.5	1.6	0
	73–79	18.8	6.2	1
2020	31–39	7.9	34.2	6
	39–65	16.9	81.4	3
	65–73	21.0	59.8	1
	73–79	16.7	2.4	0
2021	31–39	11.7	14.2	2
	39–65	13.7	36.6	1
	65–73	20.0	14.0	2
	73–79	21.1	3.2	1

with different letters in superscript ($^{a, b, c}$). Correlation analyses (Pearson's correlation coefficient) were used to assess the relationship between the severity of leaf blotches and the grain yield.

The meteorological conditions in all four trial years differed considerably (Table 2). The average air temperature in all vegetation periods was higher than the long-term indicators. The amount of precipitation during the trial years significantly varied: 2018, 2019 and 2021 – characterised as dry, but 2020 – with high rainfall.

Results

The dominant leaf diseases were tan spot and Septoria tritici blotch. The severity of both leaf blotches greatly varied (p<0.001) during the trial. Tan spot dominated in three years of trial: 2018, 2019, and 2021. In turn, Septoria tritici blotch dominated only in 2020. The first symptoms of both diseases were observed already at GS 31–32 (tan spot: 0.1% per all years; Septoria tritici blotch: without symptoms in 2018 and 2019, 0.1% in 2020, and 0.01% in 2021). However, their rapid development started only in the beginning of milk ripeness (GS 73 in all years). The most important differences of disease development have been observed at the GS 75–77. In the untreated variant (Fig. 1), the severity of tan spot differed significantly during the years: from 2.1% in 2018 to 18.7% in 2019. In 2018 and 2021, the values of the severity of Septoria tritici blotch were low (respectively 0.05% and 0.9%) and did not differ significantly. In turn in other trial years, the severity of Septoria tritici blotch increased significantly and the highest severity of the disease was obtained in 2020 (11.2%).

Fungicides significantly decreased the severity of tan spot (p<0.001) at GS 75–77, but the efficacy of used fungicide treatment schemes (p<0.001) differed during trial years. In 2018, when the severity of tan spot was low (2.1% at GS 75–77 in untreated variant), the efficacy of a half dose (FTI=0.5) of a single fungicide application at GS 55–59 was significantly lower than that in other variants. In 2020, when the severity of tan spot also was low (4.3% in untreated variant), all used treatment schemes significantly decreased the severity of tan spot at GS 75– 77 in comparison with the untreated variant (Fig. 2). There were no detected significant differences among other variants with fungicides.

The efficacy of fungicide treatment schemes was more pronounced in years when the severity of disease was higher (2019 and 2021). In 2019, when the differences in severity for tan spot at GS 57–59 among variants varied between 6.6% and 18.7%, the efficacy of a single fungicide application at GS 55–59 with half doses (TFI=0.5) was significantly lower

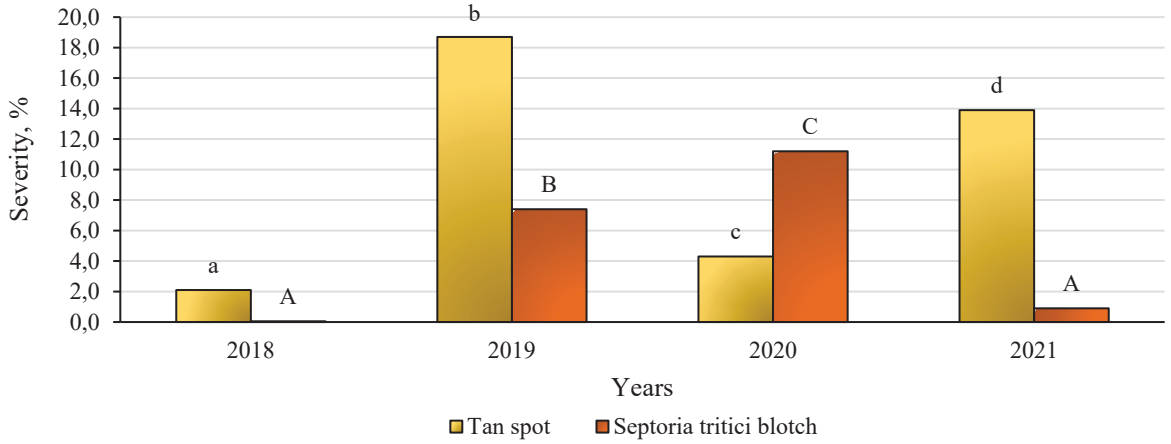


Figure 1. The severity (%) of leaf blotches at the last assessment (GS 75–77) in untreated plots in 1918–2021.

[a, b, c, d] – different letters mean significant differences (p=0.05) for tan spot
[A, B, C] – different letters mean significant differences (p=0.05) for Septoria tritici blotch

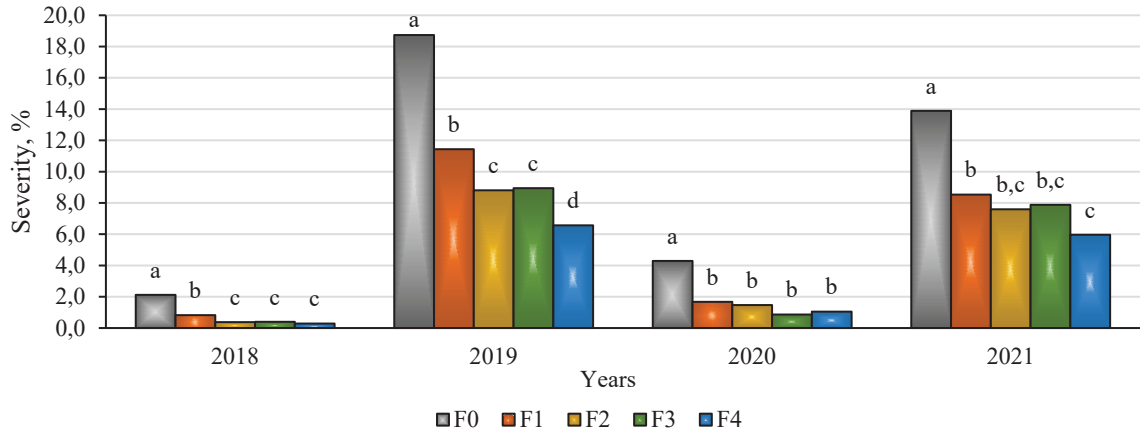


Figure 2. The severity (%) of tan spot at GS 75–77 depending on fungicide treatment scheme in 2018–2021: different letters mean significant differences (p=0.05) for each trial year.

than with full doses (TFI=1.0). A higher efficacy was obtained in the variants where the dose of fungicide was divided in two (TFI=1.0) or three applications (TFI=2.0). In 2021, when the severity of tan spot among variants varied from 6.0 to 13.9%, already a single fungicide application with half of full doses at GS 55–59 (TFI=0.5) ensured a similar efficacy to that of a full dose (TFI=1.0) or the treatment schemes with split fungicide application (TFI=1.00). The variant where treatment was divided into three applications (TFI=2.0) showed a similar effect to that of a single fungicide application at heading (GS 55–59) with full doses and the treatment done in two applications.

Fungicides significantly decreased (p<0.001) the severity of Septoria tritici blotch at GS 75–77 (Fig. 3). The efficacy of the used fungicide treatment schemes was significant only in 2020 and 2021 (p<0.001). In 2020, when the severity of Septoria tritici blotch at GS 75–77 reached 11.2%, the best efficacy was obtained in the variant where fungicide application was divided into two applications. Although TFI among other treatment schemes varied from 1.0 to 2.0 units, there were no significant differences detected among those variants. In 2021, the efficacy of a single fungicide application at GS 55–59 with half doses (TFI=0.5) was considerably lower than in other variants.

The wheat grain yield was notably affected by year conditions (p<0.001) and fungicide treatment (p<0.001). In two of the four years (2019, 2021), the fungicide treatment did not significantly influence wheat yields (Table 3). In 2018, the use of fungicide treatment significantly decreased grain yields. The relative yield varied from 99.9% to 91.9% compared

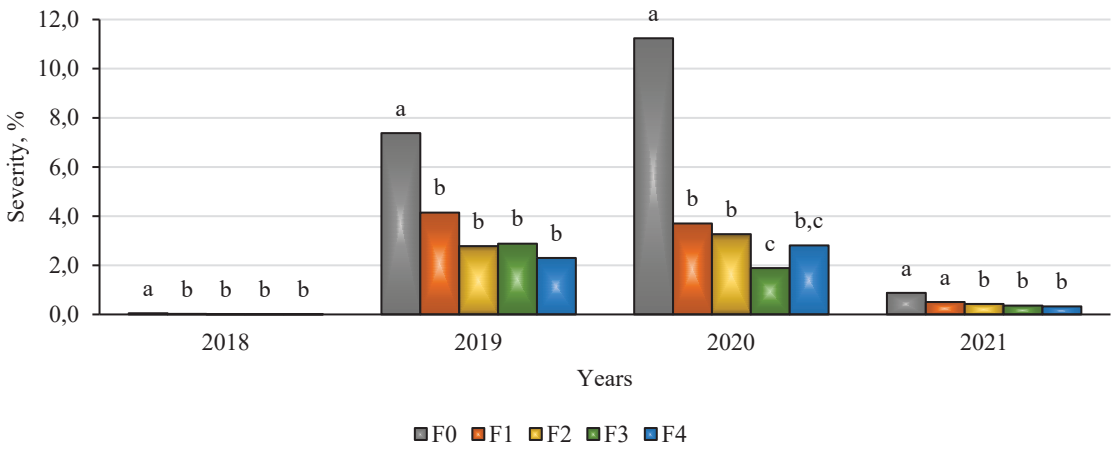


Figure 3. The severity (%) of Septoria tritici blotch at GS 75–77 depending on fungicide treatment scheme in 2018–2021: different letters mean significant differences (p=0.05) for each trial year.

Table 3

The relative yield (%) compared to control plots, depending on fungicide treatment scheme, 2018–2021

Fungicide treatment schemes (p<0.001)	2018	2019	2020	2021
F0	100.0	100.0	100.0	100.0
F1	99.9	103.3	110.1	100.2
F2	95.9	103.3	106.5	100.0
F3	91.9	104.9	110.4	100.6
F4	96.4	103.3	110.5	101.8

Table 4

The relationships between the severity of leaf blotches at GS 75–77 and grain yield (Pearson's correlation coefficients)

Year	Tan spot		Septoria tritici blotch	
	r	*p*–value	r	*p*–value
2018	0.39	<0.001	0.21	ns
2019	-0.13	ns*	-0.02	ns
2020	-0.61	<0.001	-0.75	<0.001
2021	-0.24	0.034	-0.02	ns

*ns – not significant

to control plots, depending on fungicide treatment scheme. Significant yield losses were already obtained in the variant with full doses (TFI=1) of a single fungicide application at heading (GS 55– 59). In 2020, fungicide treatment significantly increased grain yields (106.5–110.5%) compared to control plots.

A moderate, significant correlation between the severity of tan spot at GS 75–77 and grain yields was established in 2020, and a weak, significant correlation – in 2018 (Table 4). A strong, significant correlation between the severity of Septoria tritici blotch at GS 75–77 and grain yields was established only in 2020.

Discussion

This study demonstrated the effect of four fungicide treatment schemes (different intensities of fungicide treatment, and the comparison between full and split doses) on the severity of tan spot and Septoria tritici

blotch as well as the grain yield of winter wheat in 2018–2021.

The control of leaf diseases is an urgent issue in all grain production regions. Septoria tritici blotch is widespread in countries with humid climate, such as Ireland, the UK, Northern France, and Germany (Fones & Gurr, 2015). Tan spot occurs in cooler climates (Cotuna *et al.*, 2015) and is a widespread leaf disease in the Nordic-Baltic region (Bankina *et al*., 2021; Jalli *et al*., 2020; Ronis & Semaškienė, 2011). However, molecular analyses of wheat leaves confirm that mixed infection with *P. tritici-repentis* and *Z. tritici* is common, but the disease which will dominate depends on environmental conditions and farming practice (Justesen *et al*., 2021). Similar to other research in Latvia (Bankina *et al*., 2014; 2021), fast progress of both leaf blotches started only after heading.

The rapid development of leaf blotches is commonly associated with the amount of rainfall received in May and June and with the frequency of the rainfall (Byamukama *et al*., 2019), especially for Septoria tritici blotch. The high rainfall favours conidia transport from the lower leaves to the upper and the germination of spores (El Jarroudi *et al*., 2022). Similar to other research, in our trials, Septoria tritici blotch dominated in the year with the highest amount of precipitation (2020) (Creissen *et al*., 2018; Verikaite *et al.*, 2022). Although research reports that precipitation increases the severity of tan spot (Schierenbeck *et al*., 2019), there was a low severity of tan spot in 2020. This is an unexpected result, which might be affected by the concurrence between *P. tritici-repentis* and *Z. tritici.* The relationship between both pathogens has not been sufficiently studied yet. The development of tan spot was also influenced by air temperature. Although both years (2018 and 2019) could be characterised as dry and warm, and values of the severity of tan spot at GS 75–77 significantly differed. In 2018, the average daily temperature from flowering to full milk ripeness did not exceed +19.9 ºC, and some days even decreased to +12.4 ºC, which slowed the development of disease. The optimal temperature for the germination of conidia is above +20 ºC, but at +10 ºC, conidia germination ability considerably decreases (Hosford, Larez & Hammond, 1987). At such meteorological conditions, the severity of tan spot reached only 2.1% at GS 75–77. By contrast, in 2019, both the average daily temperature was higher and appropriate as the optimal temperature for spore germination and little precipitation promoted the development of tan spot (18.7% at GS 75–77).

Our results support the findings of other researchers that fungicide treatment significantly reduced the severity of tan spot and Septoria tritici blotch (Bhatta *et al*., 2018; Jørgensen *et al*., 2014; Verikaite *et al*., 2022). Several research projects show that rapid development of tan spot started only after flowering, and a single fungicide application ensures good efficacy (Bankina *et al*., 2014; Wegulo, Breathnach, & Baenziger, 2009; Wyczling, Lenc, & Sadowski, 2010). In our trial, a single treatment provided the efficacy similar to two or three applications only in years when severity of tan spot was low. In turn, in the year when severity was high (18.7% in 2019), the increase in treatment intensity provided better plant protection against tan spot. The most effective proved to be the scheme applying the fungicides three times. S. Rodrigo and colleagues (Rodrigo *et al*., 2014) had obtained that even in wet years, one application used between flowering and maturation significantly decreases the severity of Septoria tritici blotch. Results of our study indicate that in the years when severity of Septoria tritici blotch was high, the best efficacy was obtained when fungicide application was done two times: at GS 32–33 and GS 55–59. This coincides with findings in Lithuania, where the most effective control of Septoria tritici blotch was obtained when fungicide was divided into two applications: the first application was done 8–10 days after rain, and the second application after two weeks coincided with full emergence of flag leaf (Verikaite *et al*., 2022).

Calculations of grain yield losses due to leaf blotches are mainly based on field trials. Yield losses are calculated as the difference between an untreated control plot and a plot with fungicide treatment (Jalli *et al*., 2020). Several research projects suggest that the strong relationship between the severity of leaf blotches and grain yield was established from flowering to milk ripening stage, and yield losses tended to increase when disease severity increased (Bancal, Robert, & Ney, 2007; Jalli *et al*., 2020; Wegulo, Breathnach, & Baenziger, 2009; Wiik, 2009). M. Bhatta and colleagues (Bhatta *et al*., 2018) obtained the strong relationship between the severity of diseases and yield at a later growing stage (GS 85). In our study, a strong significant correlation between the severity of Septoria tritici blotch at GS 75–77 and grain yields was established only in 2020, under the higher pressure of diseases. Similar results were obtained in Lithuania in 2020 (Verikaite *et al*., 2022).

Conclusions

The severity of tan spot and Septoria tritici blotch varied significantly over trial years and was affected by meteorological conditions. The more severe development of Septoria leaf blotches was recognised during the year with a higher amount of precipitation. All used fungicide treatment schemes significantly reduced the severity of leaf blotches at the stage of

medium milk ripening (GS 75–77). Application of fungicides increased wheat yield only under high pressure of diseases. A strong significant correlation between the severity of Septoria tritici blotch at GS 75–77 and grain yields was established only in 2020, when the severity of leaf blotches was higher.

References

Byamukama, E., Ali, S., Kleinjan, J., Yabwalo, D. N., Graham, C., Caffe-Treml, M., … Berzonsky, W. (2019). Winter wheat grain yield response to fungicide application is influenced by cultivar and rainfall. *Journal of Plant Pathology* 35(1), 63–70. DOI: 10.5423/PPJ.OA.04.2018.0056.

Bancal, O. M., Robert, C., & Ney, B. (2007). Modelling wheat growth and yield losses from late epidemics of foliar diseases using loss of green leaf area per layer and pre-anthesis reserves. *Annals of Botany* 100(4), 777–789. DOI: 10.1093/aob/mcm163.

Bankina, B., Gaile, Z., Balodis, O., Bimšteine, G., Katamadze, M., Kreita, Dz., … Priekule, I. (2014). Harmful winter wheat diseases and possibilities for their integrated control in Latvia. *Acta Agriculturae Scandinavica, Section B –Soil & Plant Science* 64(7), 615–622. DOI: 10.1080/09064710.2014.949296.

Bankina, B., Bimšteine, G., Arhipova, I., Kaņeps, J., & Darguža, M. (2021). Impact of crop rotation and soil tillage on the severity of winter wheat leaf blotches. *Rural Sustainability Research* 45(340), 21–27. DOI: 10.2478/plua–2021–0004.

Bhatta, M., Regassa, T., Wegulo, S., & Baenziger, P.S. (2018). Foliar fungicide effects on disease severity, yield and agronomic characteristics of modern winter wheat genotypes. *Agronomy Journal* 110(2), 602–610. DOI: 10.2134/agronj2017.07.0383.

Bouras, N., Kim, Y.M., & Strelkov, S.E. (2009). Influence of water activity and temperature on growth and mycotoxin production by isolates of *Pyrenophora tritici-repentis* from wheat. *International Journal of Food Microbiology,* 131, 251–255. DOI: 10.1016/j.ijfoodmicro.2009.02.001.

Boixel, A.L., Gélisse, S., Marcel, T.C., & Suffert, F. (2022). Differential tolerance of *Zymoseptoria tritici* to altered optimal moisture conditions during the early stages of wheat infection. *Journal of Plant Pathology* 104, 495–507. DOI: 10.1007/s42161–021–01025–7.

Cotuna, O., Paraschivu, M., Paraschivu, A.M., & Sarateanu, V. (2015). The influence of tillage, crop rotation and residue management on tan spot (*Dreschlera tritici repentis* Died. Shoemaker) in winter wheat. *Research Journal of Agricultural Sciences* 44(2), 13–21.

Creissen, H.E., Glynn, E., Spink, J.H., & Kildea, S. (2018). The effect of fungicides applied pre-stem extension on Septoria tritici blotch and yield of winter wheat in Ireland. *Crop Protection* 104, 7–10. DOI: 10.1016/j.cropro.2017.10.003.

El Jarroudi, M., Kouadio, M., Junk, J., Maraite, H., Tychon, B., & Delfosse, P. (2022). Assessing the interplay between weather and Septoria leaf blotch severity on lower leaves on the disease risk on upper leaves in Winter wheat. *Journal of Fungi* 8(11), 1119. DOI: 10.3390/jof8111119.

EFSA. (2020). The 2020 European Union report on pesticide residues in food. *EFSA Journal,* 20(3), article 7215. DOI: 10.2903/j.efsa.2022.7215.

Fones, H., & Gurr, S. (2015). The impact of Septoria tritici blotch disease on wheat: An EU perspective. *Fungal Genetic and Biology* 79, 3–7. DOI: 10.1016/j.fgb.2015.04.004.

Gomes, C., Costa, R., Almeida, A. S., Coutinho, J., Pinheiro, N., Coco, J., … Maçãs, B. (2016). Septoria leaf blotch and yellow rust control by: fungicide application opportunity and genetic response of bread wheat varieties. *Emirates Journal of Food and Agriculture* 28(7), 493–500. DOI: 10.9755/ejfa.2016–04–345.

Heick M., Justesen A. F., Jørgensen, L.N. (2017). Anti-resistance strategies for fungicides against wheat pathogen *Zymoseptoria tritici* with focus on DMI fungicides. *Crop Protection* 99, 108–117. DOI: 10.1016/j.croppro.2017.05.009.

Hosford, R. M., Larez, C. R., & Hammond, J. J. (1987). Interaction of wet period and temperature on *Pyrenophora tritici-repentis* infection and development in wheats of different resistance. *Phytopathology* 77, 1021–1027. DOI: 10.1094/Phyto–77–1021.

Jalli, M., Kaseva, J., Andersson, B., Ficke, A, Nistrup-Jørgensen, L., Ronis, A., … Djurle, A. (2020). Yield increase due to fungicide control of leaf blotch diseases in wheat and barley as a basis for IPM decision-making in the Nordic-Baltic region. *European Journal of Plant Pathology* 158(2), 315–333. DOI: 10.1007/s10658–020–02075–w.

Jørgensen, L. N. (2008). Resistance situation with fungicides in cereals. *Zemdirbyste-Agriculture* 95(3), 373–378.

Jørgensen, L. N., Hovmøller, M. S., Hansen, J. G., Lassen, P., Clark, B., Bayles, R., ... Berg, G. (2014). IPM strategies and their dilemmas including an introduction to www.eurowheat.org. *Journal of Integrative Agriculture* 13(2), 265–281. DOI: 10.1016/S2095–3119(13)60646–2.

Justesen, A. F., Corsi, B., Ficke, A., Hartl, L., Holdgate, S., Jørgensen, L. N., … Cockram, J. (2021). Hidden in plain sight: a molecular field survey of three wheat leaf blotch fungal diseases in north-Western Europe shows co-infection is widespread. *European Journal of Plant Pathology* 160(4), 949–962. DOI: 10.1007/s10658–021–02298–5.

Kuzdralínski, A., Szczerba, H., Tofil, K., Filipiak, A., Garbarczyk, E., Dziadko, P., … Solarska, E. (2015). Early PCR detection of the *Mycosphaerella graminicola* in the leaves of winter wheat in Poland. *Romanian Agricultural Research* 32, 273–277.

Rodrigo, S., Cuello-Hormogo, B., Gomes, C., Santamaria, O., Costa, R., & Poblaciones, M. (2014). Influence of fungicide treatments on disease severity caused by *Zymoseptoria tritici*, and on grain yield and quality parameters of bread-making wheat under Mediterranean conditions. *European Journal of Plant Pathology* 141, 99–109. DOI: 10.1007/s10658–014–0527–1.

Ronis, A., & Semaškienė, R. (2011). Relationship of AUDPC values of tan spot and Stagonospora glume blotch with grain infection in winter and spring wheat. *Zemdirbyste–Agriculture* 98(1), 11–18.

Schierenbeck, M., Fleitas, M. C., Gerard, G. S., Dietz, J. I., & Simón, M. R. (2019). Combinations of fungicide molecules and nitrogen fertilization revert nitrogen yield reductions generated by *Pyrenophora tritici-repentis* infections in bread wheat. *Crop Protection* 121, 173–181. DOI: 10.1016/j.cropro.2019.04.004.

Švarta, A., Bimšteine, G., Gaile, Z., Daugaviņa, L., & Plūduma-Pauniņa, I. (2020). Development of winter wheat blotches depending on fungicide treatment schemes and nitrogen rates. In 26th annual international scientific conference: Research for Rural Development 2020, 13–15 May 2020 (pp. 7–13). Jelgava, Latvia: Latvia University of Life Science and Technologies. DOI: 10.22616/rrd.26.2020.001.

Švarta, A., Bimšteine, G., Gaile, Z., Kaņeps, J., & Plūduma-Pauniņa, I. (2022). Winter wheat leaf blotches development depending on fungicide treatment and nitrogen level in two contrasting years. *Agronomy Research* 20(2), 414–423. DOI: 10.15159/ar.21.160.

Verikaite, K., Ramanauskiene, J., Armoniene, R., & Ronis, A. (2022). Evaluation of fungicide application programmes for Septoria tritici blotch in winter wheat. *Zemdirbyste–Agriculture* 109(2), 149–156. DOI: 10.13080/z–a.2022.109.019.

Wegulo, S. N., Breathnach, J., & Baenziger, P. S. (2009). Effect of growth stage on the relationship between tan spot and spot blotch severity and yield in winter wheat. *Crop Protection* 28, 696–702. DOI: 10.1016/j.cropro.2009.04.003.

Willocquet, L., Meza, W.R., Dumont, B., Klocke, B., Feike, T., Kersebaum, K.C., … Savary, S. (2021). An outlook on wheat health in Europe from network of field experiments. *Crop Protection* 139, article 105335. DOI:10.1016/j.cropro.2020.105335.

Wiik, L. (2009). Yield and disease control in winter wheat in southern Sweden during 1977–2005. *Crop Protection* 28, 82–89. DOI: 10.1016/j.cropro.2008.09.002.

Wyczling, D., Lenc, L., & Sadowski, C. (2010). Comparison of disease occurrence and green leaf area (GLA) of winter wheat depending on the forecrop and differentiated fungicidal protection used. *Journal of Plant Protection Research* 50(4), 489–495. DOI: 10.2478/v10045–010–0081–6.

Acknowledgement

The research was supported by the EIP-AGRI project "The development of the decision-making support system for restriction of the diseases, affecting leaves and ears of winter wheat" and by the European Social Fund within the project 522 (No. 8.2.2.0/20/I/001) "LLU Transition to a new funding model of doctoral studies".