Agronomy Research **17**(3), 716–724, 2019
https://doi.org/10.15159/AR.19.137

Possibilities for the biological control of yellow rust (*Puccinia striiformis* f. sp. *tritici*) in winter wheat in Latvia in 2017–2018

L. Feodorova-Fedotova[1,2,*], B. Bankina[2] and V. Strazdina[3]

[1]Institute of Plant Protection Research, Latvia University of Life Sciences and Technology, Paula Lejina 2, LV–3001 Jelgava, Latvia
[2]Latvia University of Life Sciences and Technology, Faculty of Agriculture, Liela 2, LV–3001 Jelgava, Latvia
[3]Institute of Agricultural Resources and Economics, Stende Research Centre, "Dizzemes", LV–3258 Dizstende, Talsu distr., Latvia
[*]Correspondence: liga.feodorova-fedotova@llu.llv

Abstract. Yellow rust, caused by *Puccinia striiformis* f. sp. *tritici*, is a significant wheat disease worldwide. In Latvia, the distribution of yellow rust has increased recently and new aggressive races have been identified. The aim of this research was to investigate the possibilities for the biological control of yellow rust in winter wheat. A field trial was established in a biological field of winter wheat in Latvia in 2017 and 2018. Biological products that contained *Bacillus* spp., *Pseudomonas aurantiaca*, *Brevibacillus* spp., *Acinetobacter* spp., and chitosan were used for treatments, and one variant was left untreated. The efficacy of products was evaluated by the AUDPC (area under the disease progress curve) comparison. Differences in the severity of yellow rust between the trial years were observed. In 2018, the severity of yellow rust was lower than in 2017. In untreated plots, on flag leaf, the severity varied from 10.9% to 32.5% in 2017 and from 1.4% to 6.5% in 2018. In 2017, the severity of yellow rust reached its maximum on 05.07. at wheat growth stage (GS) 79, and in 2018 – on 20.06. GS 79. Both in 2017 and 2018, no significant differences ($p > 0.05$) were found in AUDPC values among the variants. After two years of investigations, the results were not convincing; therefore, further research is needed.

Key words: disease severity, biological control, *Bacillus* spp.

INTRODUCTION

Wheat is the main cereal grown in Latvia. In 2017, the total sown area of winter wheat was 375.7 thousand hectares with the average yield of 51.5 t ha^{-1} (Central Statistical Bureau of Latvia, 2018). One of the main risks in wheat cultivation is wheat leaf diseases such as Septoria tritici blotch, tan spot, and yellow rust.

Yellow rust, caused by *Puccinia striiformis* f. sp. *tritici*, has been considered one of the major threats for wheat growers for the last centuries (Singh et al., 2004; Wellings, 2011). Yellow rust is distributed all over the world, except Antarctica (Stubs, 1985; Chen, 2005).

P. striiformis f. sp. *tritici* is a biotrophic fungus that develops on live plant cells, negatively impacts plant photosynthesis, and uses host nutritions (Chen et al., 2014), thus provoking slower plant growth, yield reduction, and poor grain quality (Waqar et al., 2018). Yellow rust can reduce the amount of yield for 10–70% (Chen, 2005) if the wheat variety is susceptible and climate conditions are suitable for the development of yellow rust.

The situation about the distribution of yellow rust in Latvia is uncertain. In Latvia, detailed researches about the severity of yellow rust and its influence on winter wheat yield have not yet been performed; however, periodical observations have been made and the disease has been recently recorded in the northwest part of the country (Feodorova-Fedotova & Bankina, 2018).

It has been considered that *P. striiformis* f. sp. *tritici* is a temperate-climate zone pathogen (Chen et al., 2014); however, in the last decades, new epidemics of yellow rust were established in the regions where the disease had not been found before (Chen et al., 2000; Hovmøller et al., 2010). It was discovered that the causal agent of yellow rust is adapted to high temperatures (Milus et al., 2009). Air temperatures from 0 °C to 26 °C are suitable for successful development of yellow rust (Chen et al., 2014), and the minimum lasting dew period for successful development of yellow rust is from 4 to 6 hours at an optimal temperature (8 °C) (de Vallavieille-Pope et al., 1994). New, aggressive races with a shorter latent period and ability to produce more spores have appeared (Markell & Milus, 2008; Milus et al., 2009; Hovmøller et al., 2011).

An effective way to avoid yield losses caused by wheat diseases is the application of fungicides. Although chemical control is effective against yellow rust (Jørgensen et al., 2018), regular usage of fungicides can lead to the development of resistance (Oliver, 2014). Other, more environmentally friendly measures are necessary for the control of yellow rust.

Only a few kinds of researches about the applications of biological fungicides under field and greenhouse conditions regarding wheat diseases have been made. Products containing the bacteria are used for cereal disease control. *Bacillus* spp. cultures are used for the biocontrol of *Fusarium graminearum* in wheat. Several isolates can effectively reduce the growth of *Fusarium graminearum* in vitro (Stumbriene et al., 2018). *Bacillus subtilis* strain E1R-j can be used for the biocontrol of powdery mildew *Blumeria graminis* in wheat under greenhouse conditions (Gao et al., 2015). E1R-j inhibited the development of conidia, haustoria, and the extension of mycelia of powdery mildew. Li et al. (2013) concluded that *Bacillus subtilis* strain E1R-j inhibited the uredospore germination and reduced the severity of yellow rust under greenhouse conditions.

Serenade ASO, produced by the company 'Bayer CropScience', is a biofungicide containing *Bacillus subtilis* strain QST 713 and is mainly used in Europe for *Botrytis cinerea* control in strawberries, lettuce, and a broad spectrum of vegetables. Serenade ASO can reduce the severity of yellow rust in winter wheat, but, for a better result, it should be used together with other products (Reiss & Jørgensen, 2017).

The results obtained are contradictory. The severity of yellow rust and efficacy of biological plant protection products varied between the years of research. More researches regarding biocontrol of yellow rust under field conditions are required.

Authors of this research proposed a hypothesis that the usage of biological plant protection products in winter wheat control the severity of yellow rust, the efficacy of each biological plant protection product is different.

The aim of this research was to investigate the possibilities for the biological control of yellow rust in winter wheat.

MATERIALS AND METHODS

A field trial was established for winter wheat variety 'Edvins' in a biological field in the southwest part of Latvia (Institute of Agricultural Resources and Economics, Stende Research Centre, 57.189493 N, 22.561066 E) in 2017 and 2018. Winter wheat 'Edvins' is moderately middle susceptible to yellow rust (V. Strazdina, personal communication, 2 April 2018).

Sample plots were randomized, and the size of each plot was 2.5 m width and 10 m length. The space between rows was 0.125 m and space between plots – 0.5 m in both years of research. The seeding rate was 200 kg ha^{-1} in 2016 and 250 kg ha^{-1} in 2017. Sowing date was 14.09. and seedling growth started at 23.09. in 2016. Sowing date was 07.09. and seedling growth started at 16.09. in 2017. The soil was suitable for wheat cultivation, and crop management was used according to the practice under the conditions of wheat production in Stende Research Centre. Wheat seed was not treated before the sowing. The field trials consisted of seven variants in four replications.

Several biological products were used for applications (Table 1), and one variant was left untreated as a control. Plant protection products were used according to the producer reference.

Table 1. Biological products used in field trials in 2017–2018

No.	Biological products	Active substance	Dosage, L ha^{-1}, in 2017	Dosage, L ha^{-1}, in 2018
1.	Untreated	-	-	-
2.	Serenade ASO	*Bacillus subtilis* QST 713 13.96 g L^{-1}	4.0	6.0
3.	Bactoforce	*Bacillus spp.*	4.0	6.0
4.	BactoMix	*Bacillus subtilis* D V-845 and V-843 D, *Pseudomonas aurantiaca*, *Brevibacillus*, *Acinetobacter*, 1.3 × 109 KVV/ml	4.0	6.0
5.	Albit	Poli-beta-hydroksybutyrate 0.62%, organic matter 22%, NPK 7.5-6-4.5	0.04	0.08
6.	ChitoPlant	Chitosan 99.9%	0.2 kg ha^{-1}	0.4 kg ha^{-1}
7.	Serenade ASO + ChitoPlant	*Bacillus subtilis* QST 713 1.34% + Chitosan 99.9%	4.0 + 0.2 kg ha^{-1}	6.0 + 0.4 kg ha^{-1}

The field trial was treated with biological products four times in 2017. As results in 2017 showed that the severity of yellow rust on flag leaf at the end of vegetation was high – 32.5% (Fig. 1), for more efficient yellow rust control it was decided to enlarge treatment times to six in 2018. Treatment dates and plant growth stages (GS) according to BBCH scale (Hack et. al., 1992) are shown in Table 2.

Table 2. Treatment dates and plant growth stages in 2017–2018

2017		2018	
date of treatments	GS	date of treatments	GS
28.04.2017	29–31	10.05.2018	31–33
08.05.2017	31–33	17.05.2018	37
18.05.2017	33–34	24.05.2018	41
29.05.2017	39	31.05.2018	55–57
		07.06.2018	65
		14.06.2018	73

The severity of yellow rust was assessed during the vegetation, starting from first symptoms until leaf yellowing and shrivelling at GS 79 (Table 3). The severity of yellow rust was assessed on 10 randomly selected leaves from each plot and expressed in percentages. Each leaf level was evaluated separately.

Meteorological conditions representing 2017 and 2018 are shown in Table 4. Average air temperature and amount of percipitation was determined.

Table 3. Assessment times and plant growth stages in 2017–2018

2017		2018	
Date of assessments	GS	Date of assessments	GS
14.06.2017	57–59	17.05.2018	37
20.06.2017	65	24.05.2018	41
27.06.2017	73–75	31.05.2018	55–57
05.07.2017	79	07.06.2018	65
		14.06.2018	73
		20.06.2018	75
		26.06.2018	77–79

Table 4. Meteorological conditions during the years of research (data from Stende Research Centre meteorological station)

	Average temperature, °C					Amount of precipitation, mm				
Month	I	II	III	average in a month	norm	I	II	III	in a month	norm
2017										
April	6.4	1.0	3.7	3.7	4.3	4.0	29.0	42.7	75.7	37.0
May	6.3	11.5	13.1	10.3	10.2	1.2	2.6	10.7	14.5	45.0
June	12.4	15.3	13.9	13.9	14.2	17.7	18.2	22.7	58.6	57.0
July	14.3	15.1	17.2	15.5	16.3	19.9	28.7	6.9	55.5	87.0
August	17.3	17.4	14.1	16.3	15.5	18.5	16.9	16.0	51.4	87.0
2018										
April	5.0	9.5	8.5	7.7	4.3	28.6	12.4	6.7	47.7	37.0
May	12.5	16.4	17.5	15.5	10.2	14.0	0.0	0.0	14.0	45.0
June	15.4	16.7	14.4	15.5	14.2	0.2	8.9	26.7	35.8	57.0
July	15.1	22.0	22.2	19.8	16.3	17.3	6.5	8.8	32.6	87.0
August	22.2	17.3	15.7	18.4	15.5	25.7	56.0	12.4	94.1	87.0

The impact of yellow rust was detected by calculating the AUDPC (area under the disease progress curve). It shows combined disease influence on plants during the vegetation (Simko & Piepho, 2012). The AUDPC was calculated using the formula (Simko & Piepho, 2012) (1):

$$A_k = \sum_{\mathrm{i}=1}^{\mathrm{N}_{i-1}} \frac{(y_i + y_{i+1})}{2} (\mathrm{t}_{i+1} - \mathrm{t}_i) \quad (1)$$

where N is assessment times, y is disease severity at the moment of assessment, and $t_{i+1} - t_i$ is the time period between assessment times.

The effectiveness of biological products was calculated according to the formula (2):

$$\mathrm{T} = \frac{(k - v) \cdot 100}{k} \quad (2)$$

where k is the severity (incidence, AUDPC) of the disease in the untreated variant, v is the severity (incidence, AUDPC) of the disease in the treated variant. Similar calculations has been made in Barro et al. (2017) research.

The yield and grain quality parameters (thousand kernel weight (TKW), g; protein content, %) were evaluated after the harvest.

For statistical analysis, 'MS Excel 2010' and 'R' programs were used. Correlation analysis, regression analysis, analysis of variance, analysis of covariance were used for the calculation of results.

RESULTS AND DISCUSSION

Peculiarities of the dynamics of the development of yellow rust was observed in untreated plots in both years of investigation. In 2017, the first symptoms of yellow rust were observed on 14.06. – on the second leaf of wheat GS 57. Six days later, on 20.06., yellow rust was found on the flag leaf of wheat GS 65. A rapid development of yellow rust during grain formation was observed (Fig. 1). Meteorological conditions in June 2017 (Table 4) were favourable for the development of yellow rust. Sufficient amount of precipitation (58.6 mm per month) and the average air temperature of 13.9 °C enabled yellow rust to grow and produce spores successfully. The identification of yellow rust was made according to well recognizable visual symptoms on wheat leaves. At the end of vegetation, at GS 79, the severity of yellow rust reached its maximum in untreated plots – 32.5% on the flag leaf and 24% on the second leaf (Fig. 1).

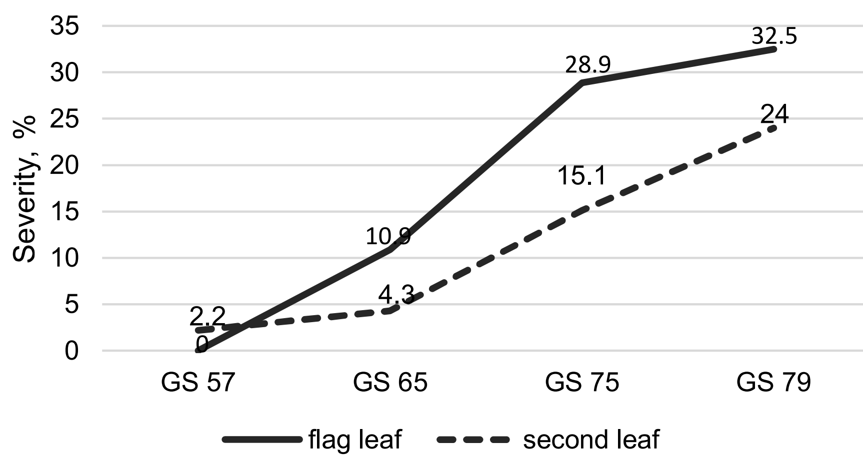

Figure 1. Severity of yellow rust on flag leaf and second leaf in untreated plots in 2017.

In 2018, the severity of yellow rust in untreated plots was lower compared to 2017. In 2018, the first symptoms of yellow rust were observed on the second leaf on 31.05. GS 55–57. Yellow rust for the first time was observed on the flag leaf on 07.06. GS 65. Meteorological conditions – lack of rain in the first and second ten-day period of May (Table 4) – were not favourable for the development of yellow rust. De Vallavieille-Pope et al. (1994) ascertained that dry period has a negative impact on spore germination.

After rainfall in the second and third ten-day period, the severity of yellow rust reached its maximum (6.5%) on the flag leaf in untreated plots (Fig. 2).

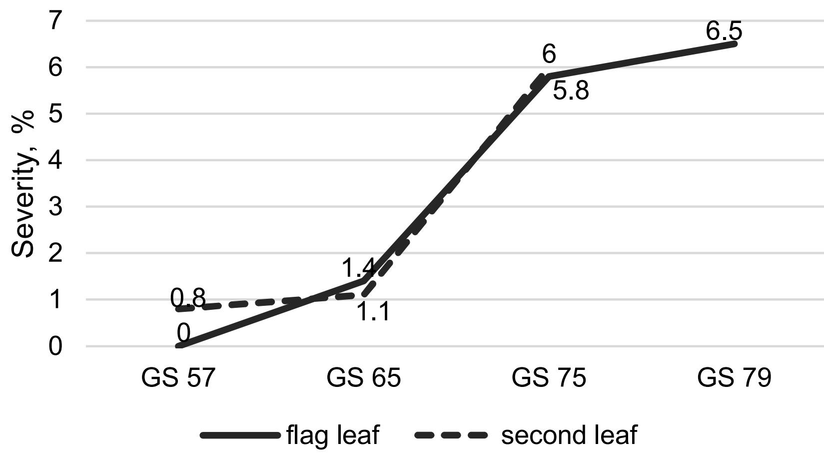

Figure 2. Severity of yellow rust on flag leaf and second leaf in untreated plots in 2018.

The AUDPC values were compared to assess the efficacy of treatments both in 2017 and 2018. Treatment with biological products did not significantly ($p > 0.05$) decrease the level of yellow rust. In 2017, a slight tendency to reduce the impact of yellow rust both on flag leaf and second leaf was observed by using the biological product 'Albit' at the dosage of 0.04 L ha^{-1}. The variant treated with 4.0 L ha^{-1} of 'BactoMix 5' exhibited the highest AUDPC value in 2017 (Fig. 3); in contrast, in 2018, the dosage of 6.0 L ha^{-1} of 'BaxtoMix 5' showed a tendency to reduce the impact of yellow rust (Fig. 4). Yellow rust migrates with the help of wind (Chen et al., 2014) and this could be a reason of irregular incidence of yellow rust in research sample plots. Irregular incidence of yellow rust could influence the efficacy of biological products.

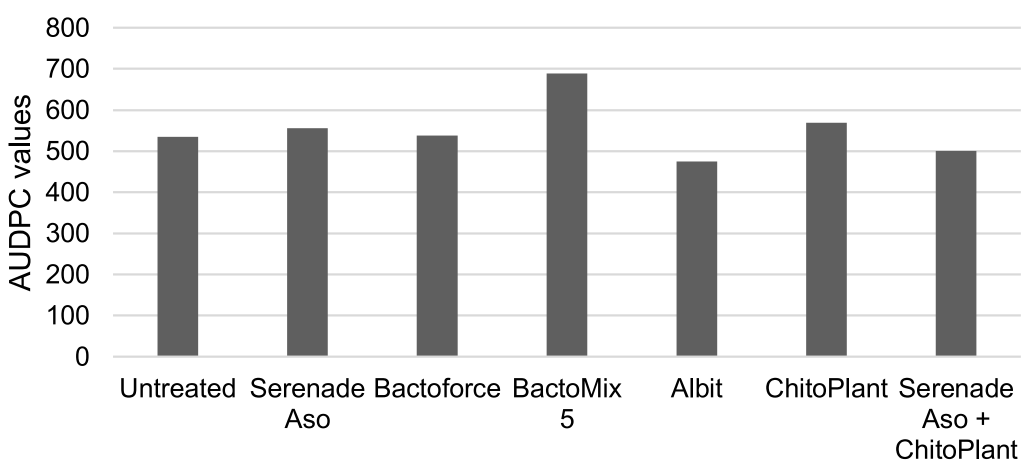

Figure 3. The development of yellow rust depending on biological control variants in 2017.

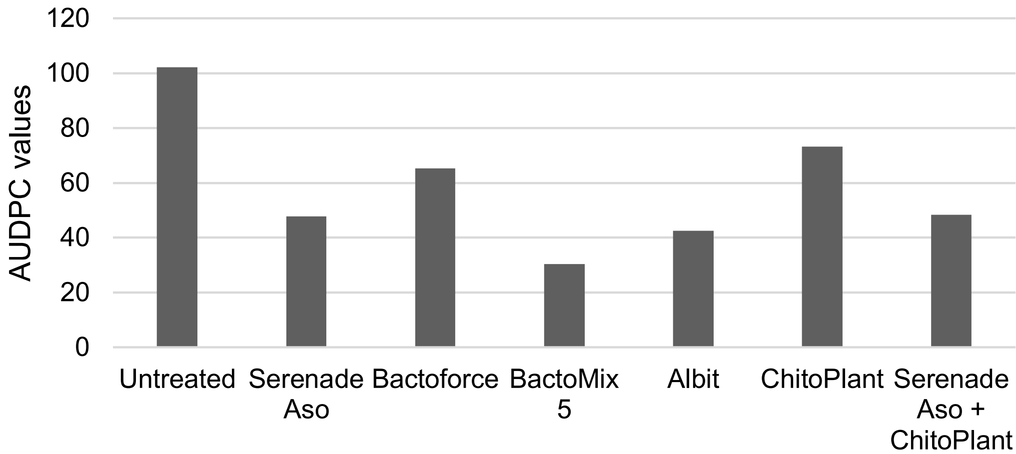

Figure 4. The development of yellow rust depending on biological control variants in 2018.

The effectiveness of biological products fluctuated depending on application scheme: from –28.9% to 11.8% in 2017, and from 35.5% to 70.04% in 2018 (Table 5). Reiss & Jørgensen (2017) concluded that for optimal yellow rust control, timing is significant – treatments at the day of inoculation or one day later promoted the best control. This could be the reason why the effectiveness of biological products in 2017 was low. In 2017, the treatments might have been carried out too early; biofungicide application on inoculation day would have increased the efficacy of biological products. Also, Li et al. (2013) concluded that *B. subtilis* is preventive and has curative properties in the early stages of the development of yellow rust.

Table 5. Efficacy % of biological products in 2017 and 2018

Biological products	Efficacy, %	
	2017	2018
Untreated	–	–
Serenade ASO	–3.4	53.13
Bactoforce	–0.77	35.5
BactoMix 5	–28.91	70.04
Albit	11.17	57.25
ChitoPlant	–6.59	27.92
Serenade ASO + ChitoPlant	6.22	52.60

The vitality of *B. subtilis* is influenced by biotic factors such as humidity and air temperature. Rainfall can wash the bacterium from wheat leaves. Increased application timing and the dosage of biological products in 2018 (Table 1) might have shown a better effect for yellow rust control.

Disease pressure influences the efficacy of biofungicides. In 2017, disease pressure was moderate (Fig. 1), with the effectiveness of products from –28.9% to 11.8%; whereas in 2018, when disease pressure was low (Fig. 2), product effectiveness varied from 35.5% to 70.0%.

Reiss & Jørgensen (2017) concluded that 'Serenade ASO' reduced the severity of yellow rust to 30% under high disease pressure and up to 60% under moderate pressure, compared to control.

The evaluation of yield, thousand kernel weight, and protein content in 2017 and 2018 showed no significant differences ($p > 0.05$) between treated variants and untreated ones. Data are not shown in this article. Reiss & Jørgensen (2017) obtained similar results – they found that the yield in treated plots was not signifficantly different from untreated although the treatments with Serenade ASO increased the yield to 1–7%.

This was the first research regarding the biocontrol of yellow rust under field conditions in Latvia. More and extended investigations are required to obtain long-term information about the biocontrol of yellow rust.

CONCLUSIONS

1. The severity of yellow rust in the untreated plots differed between the years of investigation.
2. The application of biological plant protection products did not significantly reduce the severity of yellow rust in 2017 and 2018.

ACKNOWLEDGEMENTS. The research was supported by the project 'Distribution of yellow rust disease causal agent *Puccinia striiformis*, Wes. races in Latvia and measures to minimize damage in wheat fields".

REFERENCES

Barro, J.P., Forte, C.T., Trentin, D., Scariot, M. & Milanesi, P.M. 2017. Effectiveness of different fungicide formulations and number of applications in controlling wheat leaf rust. *Summa Phytopathologica* **43**(4), 276–280.

Central Statistical Bureau of Latvia. 2018. In 2017, second highest grain yield was reached. Press release, 16.2.2018., https://www.csb.gov.lv/en/statistics/statistics-by-theme/agriculture/agricultural-prices/search-in-theme/2377-sown-area-harvested-production-and. Accessed 21.1.2019.

Chen, X., Moore, M., Milus, E.A., Long, D.L., Line, R.F., Marshall, D. & Jackson, L. 2000. Wheat stripe rust epidemics and races of *Puccinia striiformis* f. sp. *tritici* in the United States in 2000. *Plant Disease* **86**(1), 39–46.

Chen, X.M. 2005. Review / Synthèse Epidemiology and control of stripe rust [*Puccinia striiformis* f. sp. *tritici*] on wheat. *Canadian Journal of Botany* **27**, 314–337.

Chen, W., Wellings, C., Chen, X., Kang, Z. & Liu, T. 2014. Wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. *Molecular Plant Pathology*, **15**(5), 433–446.

Feodorova-Fedotova, L. & Bankina, B. 2018. Characterization of yellow rust (*Puccinia striiformis* Westend.): review. *Research for Rural Development* **2**, 69–76.

Gao, X., Gong, Y., Huo, Y., Han, Q., Kang, Z. & Huang, L. 2015. Endophytic *Bacillus subtilis* strain E1R-J is a promising biocontrol agent for wheat powdery mildew. *BioMed Research International* **2015**, 1–8.

Hack, H., Bleiholder, H., Buhr., L., Meier, U., Schnock-Fricke, U., Weber, E. & Witzenberger, A. 1992. Einheitliche Codierung der phanologischen Entwicklungsstadien mono- und dikotyler Pflanzen – Erweiterte BBCH-Skala, Allgemein. Nachrichtenbl. *Deut. Pflanzenschutzd*, **44**, 265–270.

Hovmøller, M.S., Sørensen, C.K., Walter, S. & Justesen, A.F. 2011. Diversity of *Puccinia striiformis* on cereals and grasses. *Annual Review of Phytopathology* **49**(1), 197–217.

Hovmøller, M.S., Walter, S. & Justesen, A.F. 2010. Escalating threat of wheat rusts. *Science* **329**, 369.

Jørgensen, L.N., Matzen, N., Hansen, J.G., Semaskiene, R., Korbas, M., Danielewicz, J., Glazek, M., Maumene, C., Rodemann, B., Weigand, S., Hess, M., Blake, J., Clark, B., Kildea, S., Batailles, C., Ban, R., Havis, N. & Treikale, O. 2018. Four azoles' profile in the control of Septoria, yellow rust and brown rust in wheat across Europe. *Crop Protection* **105**, 16–27.

Li, H., Zhao, J., Feng, H., Huang, L. & Kang, Z. 2013. Biological control of wheat stripe rust by an endophytic *Bacillus subtilis* strain E1R-j in greenhouse and field trials. *Crop Protection* **43**, 201–206.

Markell, S.G. & Milus, E.A. 2008. Emergence of a novel population of *Puccinia striiformis* f. sp. t*ritici* in Eastern United States. *Phytopathology* **98**(6), 632–639.

Milus, E.A., Kristensen, K. & Hovmøller, M.S. 2009. Evidence for increased aggressiveness in a recent widespread strain of *Puccinia striiformis* f. sp *tritici* causing stripe rust of wheat. *Phytopathology* **99**, 89–94.

Oliver, R.P. 2014. A reassessment of the risk of rust fungi developing resistance to fungicides. *Pest Manag. Sci.* **70**, 1641–1645.

Reiss, A. & Jørgensen, L.N. 2017. Biological control of yellow rust of wheat (*Puccinia striiformis*) with Serenade®ASO (*Bacillus subtilis* strain QST713). *Crop Protection* **3**, 1–8.

Simko, I. & Piepho, H.–P. 2012. The area under the disease progress stairs: Calculation, advantage, and application. *Phytopathology* **102**, 381–389.

Singh, R.P., William, H.M., Huerta-Espino, J. & Rosewarne, G. 2004. Wheat rust in Asia: Meeting the challenges with old and new technologies. In *Proceedings of* the 4th International Crop Science Congress (ed. R. P. Singh, H. M.William, J. Huerta-Espino and G. Rosewarne). Brisbane, Australia.

Stumbriene, K., Gudiukaite, R., Semaskiene, R., Svegzda, P., Jonaviciene, A. & Suproniene, S. 2018. Screening of new bacterial isolates with antifungal activity and application of selected *Bacillus* spp. cultures for biocontrol of *Fusarium graminearum* under field conditions. *Crop Protection* **113**, 22–28.

Stubbs, R.W. 1985. *The cereal rusts*. Orlando, Florida: Academic Press, 592 pp.

de Vallavieille-Pope, C., Huber, L., Leconte, M. & Goyeau, H. 1995. Comparative effects of temperature and interrupted wet periods on germination, penetration, and infection of *Puccinia recondita* f. sp. *tritici* and *P. striiformis* on wheat seedling. *Phytopathology* **85**, 409–415.

Waqar, A., Khattak, S.H., Begum, S., Rehman, T., Rabia, Shehzad, A., Ajmal, W., Zia, S.S., Siddiqi, I. & Ali, G.M. 2018. Stripe rust: A review of the disease, Yr genes and its molecular markers. *Sarhad Journal of Agriculture* **34**(1), 188–201.

Wellings, C.R. 2011. Global status of stripe rust: A review of historical and current threats. *Euphytica* **179**(1), 129–141.