

Spot blotch resistance in derivatives of European winter wheat

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Abstract: The effects of inoculum concentrations and the aggressiveness of spot blotch (*Bipolaris sorokiniana* (Sacc.) Shoemaker) isolates were evaluated on the resistance of 123 winter wheat advanced breeding lines developed from European winter wheat as well as on 3 control cultivars, BR8, BH1146, and Zentos. The test was conducted under laboratory conditions using a detached leaf technique. A total of 3 inoculum concentrations were used: 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL^{-1} . The results of the study revealed low resistance of the tested material when accessions were compared by the percentage of disease severity (DS), but considerably higher variability of resistance was determined when the area under the disease progress curve (AUDPC) was used for comparison. The correlations between DS and AUDPC across inoculum concentrations varied from medium to high ($r = 0.559^* - 0.909^{**}$; $*P < 0.05$, $**P < 0.01$) for isolates with higher aggressiveness, whereas it was high ($r = 0.785^{**} - 0.939^{**}$) for those with lower aggressiveness. The correlations between DS and AUDPC across isolates were high ($r = 0.769^{**} - 0.939^{**}$) for lower inoculum concentrations of 0.5×10^3 and 1×10^3 , whereas they varied from medium to high ($r = 0.559^* - 0.785^{**}$) for the highest spore concentration, 5×10^3 . All of the concentrations can be successfully used for the evaluation of resistance considering DS development and the subsequent differentiation of accessions. However, the lower inoculum concentrations provided a higher differentiation of the accessions tested. Cultivar BR8, described in the literature as being resistant, exhibited the highest resistance among the accessions tested for AUDPC and DS, with results of 77.5 and 30.5%, respectively. Cultivar BH1146, referred to in the literature as having medium resistance, was evaluated by DS at 44.2% and by AUDPC at 146.4. About 23% of the accessions tested possessed the same resistance level as BH1146, or higher. Cultivars Dream, Aspirant, and Biscay were the most common among the ancestry of the most resistant lines. This suggests that it may be possible to select modern European winter wheat cultivars with sufficient spot blotch resistance when large numbers of accessions are screened.

Key words: *Bipolaris sorokiniana*, inoculum concentration, resistance, winter wheat

Introduction

Spot blotch caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker is one of the most important foliar diseases limiting wheat production in warmer, nontraditional growing areas such as southeastern Asia (Vilareal et al. 1995). The fungus has a worldwide distribution, but as a pathogen it is most aggressive

under the conditions of high relative humidity and temperature associated with the low fertility of soils in South Asia, South America, Africa, and Australia (Sharma-Poudyal et al. 2005). However, the spread of the fungus as a pathogen to the northern hemisphere has been rather rapid over the past decade. Spot blotch is considered a harmful disease in some areas of the United States (Wegulo et al. 2009). An

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occurrence of *B. sorokiniana* as wheat pathogen in the northwestern part of the Russian Federation (Smurova 2008) suggests that this fungus has the potential to become a serious wheat pathogen in Europe. Conservation tillage practices are becoming more common in Europe. Such a situation a couple of decades ago was the main reason for the spread of tan spot (*Pyrenophora tritici-repentis* (Died.) Drechsler) (Wolf et al. 1998). The same factors can also be favorable for spot blotch (Duveiller and Sharma 2009). At present, *B. sorokiniana* under European conditions causes yield losses mostly due to root rot (Rossi et al. 1995) and seed black point, which negatively affects seed germination rates and causes root rots in seedlings (Hudec and Muchova 2008). Thus far, significant negative effects on the foliage of winter wheat have not been reported. Only limited data are available about the effects of this fungus on wheat leaves (Csösz et al. 2008).

Yield losses are variable, but they are important in fields with low inputs and under late-sown conditions. Diseased plots yielding up to 60% and 20% less than fungicide-protected plots of susceptible and resistant cultivars, respectively, have been found in Nepal (Duveiller and Sharma 2009). Diseased wheat plots in Mexico without fungicides yielded 43% less (Vilareal et al. 1995). In a recent study from the United States, Nebraska showed yield increases ranging from 27% to 42% when fungicides were applied. Rates of grain infection by this fungus in years that were favorable for the disease were detected to be as high as 70% in a study by Sharma-Poudyal et al. (2005). At higher latitudes, such as the Canadian and US prairies (Gonzalez and Trevathan 2000; Fernandez and Jefferson 2004) and in parts of Australia (Lehmensiek et al. 2004), *B. sorokiniana* is a dominant pathogen among fungi, causing common root rot and resulting in losses of up to 19%. In Turkey, *B. sorokiniana* has been observed to be widespread in the subcrown internodes and crowns of wheat (Eken and Demirci 1998).

The control strategy for diseases caused by *B. sorokiniana* is based on an integrated approach in which genetic resistance is a major element, since the economics of fungicide use have not always been applied in commercial grain production (Duveiller and Sharma 2009). It is also highly likely that the

pathogen will adapt to fungicides, as has happened with the majority of wheat pathogens (Jørgensen 2008). Recent studies show that, after several decades of intensive resistance breeding efforts, some progress has been achieved in Bangladesh (Siddique et al. 2006), the United States (Tobias et al. 2009), Australia (Lehmensiek et al. 2004), and Nepal (Sharma et al. 2004). Additionally, a broad range of resistance donors are available (Smurova 2008; Kumar et al. 2009; Duveiller and Sharma 2009).

Research on *B. sorokiniana* resistance in European winter wheat is scant. Therefore, the present study aimed to determine *B. sorokiniana* resistance in the derivatives of European winter wheat cultivars and breeding lines and to reveal the possibility of spot blotch control with cultivar resistance. A survey of the derivatives' resistance under different inoculum concentrations and the complex evaluation of disease severity (DS) and area under the disease progress curve (AUDPC) should provide a clearer differentiation of the accessions' spot blotch resistance.

Materials and methods

Research was conducted from 2008 to 2010 at the Institute of Agriculture in Lithuania. The resistance of derivatives of European winter wheat cultivars and breeding lines to *B. sorokiniana* monoconidial isolates obtained from wheat straw and grain was evaluated under laboratory conditions using the detached leaves technique.

The fungus was isolated from winter wheat grain and straw samples randomly collected regardless of plant genotype from the Institute's winter wheat breeding nurseries during a single crop rotation in the seed ripening stage in 2005 and 2006. The breeding nurseries' fields were measured at 3.2 ha in both of these years. Monoconidial cultures were produced for each isolate. Received cultures were evaluated for colony growth rate and mycelium color according to the method of Jaiswal et al. (2007). Isolates were plated onto potato dextrose agar (2%) and grown at 20 °C for 7 days in continuous darkness. The 4 isolates were selected based on different colony growth rates and mycelium colors. Isolates 1 and 2 were isolated from grains while isolates 3 and 4 came from straw. Isolates 1 and 2 were characterized by a dark and smooth

mycelium growth type, isolate 3 had some white spots on the mycelium with abundant sporulation, and isolate 4 possessed a fluffy white-grey mycelium producing a low spore number.

The inoculum was prepared as follows: after 10 days of cultivation on V8 agar medium in an incubator at 20 °C under constant darkness, conidia were collected by flooding the petri plates with sterile distilled water and scraping the agar surface with a spatula to dislodge the conidia. The conidial suspension was filtered through a double layer of cheesecloth. The inoculum concentration was determined with the help of a hemocytometer and adjusted to 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL⁻¹. Next, 2 microliters of Tween 20 per 100 milliliters of prepared suspension was added as a surfactant.

In total, 3 controls with known resistance levels and 123 derivatives of European winter wheat were investigated. Accessions were seeded with surface sterilized seeds in seedling growing blocks in commercial soil substrates. Wheat seedlings were grown in growth chambers under a day/night photoperiod of 16/8 h and a day/night temperature regime of 16/20 °C for 10 days. Primary leaves were detached in 4-cm segments and placed into plastic boxes on filter paper moistened with water supplemented with benzimidazole at 100 mg L⁻¹. Four leaf segments were used per replication. The 2 cultivars widely used in research on *B. sorokiniana*, BR8 and BH1146, were used as resistant and medium resistant controls, respectively (Duveiller and Sharma 2009). The Lithuania-registered cultivar Zentos was used as a susceptible control. Control cultivars were placed twice per box. The test was replicated 3 times and repeated twice.

The prepared leaves were inoculated with the spore suspension by spraying it until run-off. The inoculated plant material was then incubated at 20 °C in the dark for 24 h. Afterwards, the plant material was stored in growth chambers under a day/night photoperiod of 16/8 h and a day/night temperature regime of 18/20 °C until scoring. The evaluation of resistance was done from day 4 to day 11 at the same time of day. The following scale was used to estimate disease development and the resistance of derivatives: 0%, 1.0%, 5.0%, 10.0%, 20.0%, 40.0%, 60.0%, 80.0%, and 100.0% of the leaf area diseased.

The AUDPC was calculated as the total area under the graph of DS against time, from the first disease evaluation to the last, with the following equation:

$$\text{AUDPC} = S_i = \sum_{i=1}^{n-1} [(t_{i+1} - t_i) (y_i + y_{i+1}) / 2],$$

where t is the time in days of each reading, y is the percentage of affected leaves at each reading, and n is the number of readings (Campbell and Madden 1990).

The resistance level of accessions compared by AUDPC varied from 77.5 to 466.2. Accessions evaluated by AUDPC at up to 100 were considered resistant (R), 100.1-150.0 as medium resistant (MR), 150.1-200.0 as medium resistant-medium susceptible (MR-MS), 200.1-250.0 as medium susceptible (MS), 250.1-300.0 as medium susceptible-susceptible (MS-S), 300.1-350.0 as susceptible (S), 350.1-400.0 as susceptible-highly susceptible (S-HS), and over 400.0 as highly susceptible (HS).

Duncan's multiple range test and correlation-regression analysis were performed at a significance level of $P < 0.05$ (*) and $P < 0.01$ (**).

Results

The spot blotch resistance of winter wheat accessions differed considerably in terms of their DS and AUDPC ratings (Figure 1). The screening technique used revealed low resistance in the majority of accessions when they were compared by DS, but a considerably higher variability of resistance was found in the case of AUDPC for all isolates and inoculum concentrations.

The correlations between the DS and AUDPC results of accessions across inoculum concentrations varied from medium to high ($r = 0.559^* - 0.909^{**}$) for isolates 1 and 2 with higher aggressiveness, whereas it was high ($r = 0.785^{**} - 0.939^{**}$) for isolates 3 and 4 with lower aggressiveness (Figure 1). The correlations between the DS and AUDPC of accessions across isolates were high ($r = 0.769^{**} - 0.939^{**}$) for lower inoculum concentrations of 0.5×10^3 and 1×10^3 spores mL⁻¹, whereas they varied from medium to high ($r = 0.559^* - 0.785^{**}$) for the highest inoculum concentration (5×10^3 spores mL⁻¹).

Spot blotch resistance in derivatives of European winter wheat

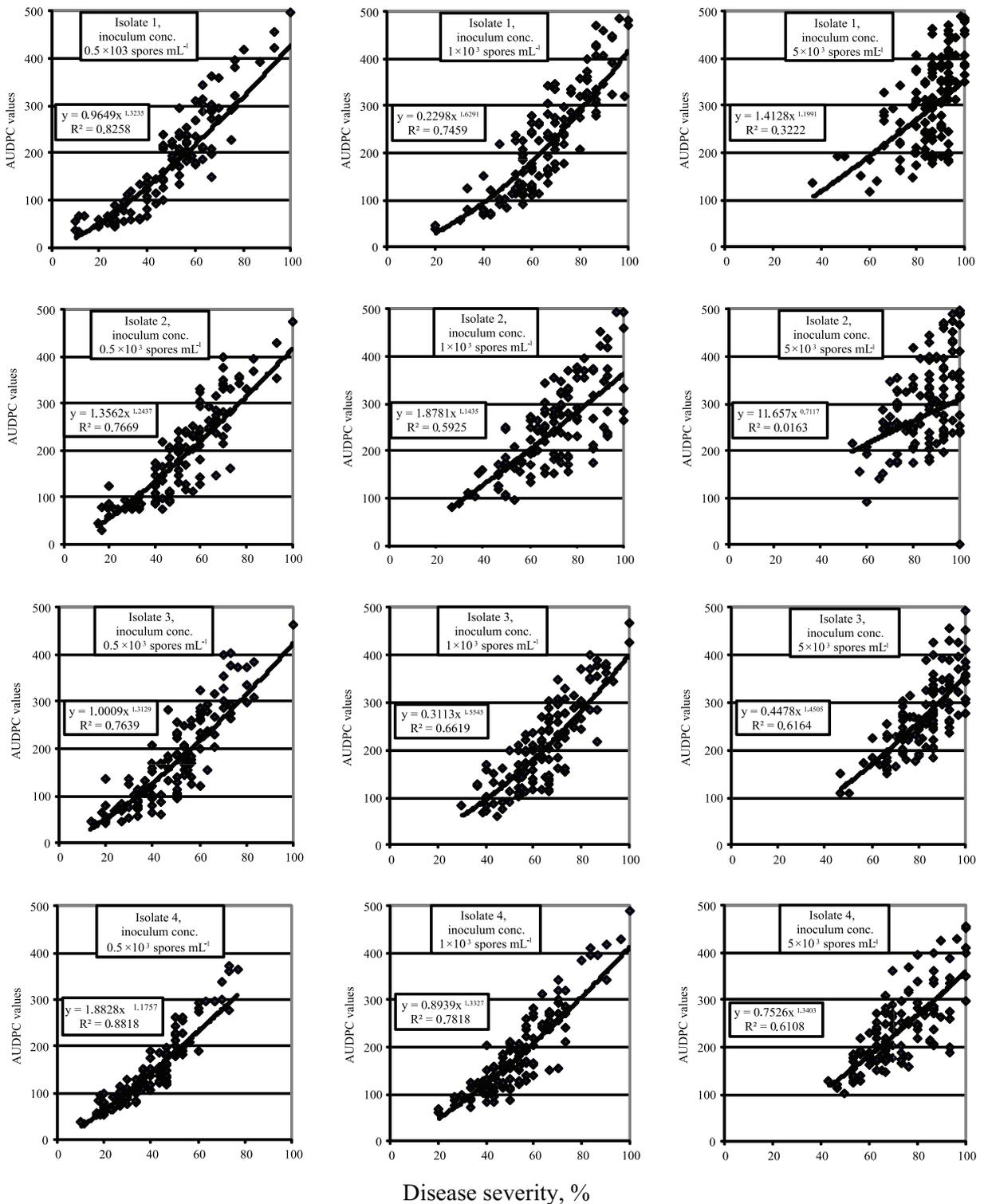


Figure 1. The distribution of winter wheat derivatives' spot blotch resistance reactions as influenced by isolates and inoculum concentrations.

Higher differences occurred for AUDPC values than for DS. Moreover, AUDPC showed higher differences in resistance at lower inoculum concentrations. DS differed by rates of 6.7 to 11.2, 3.3 to 5.0, and 1.7 to 2.7, whereas AUDPC values differed by 10.8 to 17.0, 6.1 to 12.7, and 4.2 to 5.5 at inoculum concentrations of 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL^{-1} , respectively. However, the effect of the isolates' aggressiveness on the variability of DS and AUDPC was not clear.

The mean DS and AUDPC index values per isolate across inoculum concentrations are presented in Figure 2. Isolates 1-3 showed statistically the same or similar aggressiveness per inoculum concentrations for DS but less similar aggressiveness for AUDPC. Isolate 4 exhibited statistically lower aggressiveness. The mean DS of isolates 1-3 for inoculum concentrations of 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL^{-1} was 49.8%, 67.3%, and 84.4%, whereas it was 39.0%, 53.8%, and 73.2% for isolate 4. The mean AUDPC for isolates 1-3 for inoculum concentrations of 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL^{-1} was 185, 234, and 297, whereas it was 146, 190, and 245 for isolate 4.

The proportion of all of the isolates' mean DS and AUDPC was very similar. It was 1.35 and 1.27 at inoculum concentrations of $1 \times 10^3:0.5 \times 10^3$ spores mL^{-1} , respectively; 1.73 and 1.62 at inoculum concentrations of $5 \times 10^3:0.5 \times 10^3$ spores mL^{-1} , respectively; and 1.27 for both parameters at inoculum concentrations of $5 \times 10^3:1 \times 10^3$ spores mL^{-1} . Similar proportions were detected for individual isolates. The proportion of individual isolates' DS at inoculum concentrations of $1 \times 10^3:0.5 \times 10^3$ spores mL^{-1} ranged from 1.29 to 1.40, at inoculum concentrations of $5 \times 10^3:0.5 \times 10^3$ spores mL^{-1} from 1.64 to 1.87, and at inoculum concentrations of $5 \times 10^3:1.0 \times 10^3$ spores mL^{-1} from 1.22 to 1.36. The proportion of individual isolates' AUDPC at inoculum concentrations of $1 \times 10^3:0.5 \times 10^3$ spores mL^{-1} ranged from 1.18 to 1.32, at inoculum concentrations of $5 \times 10^3:0.5 \times 10^3$ spores mL^{-1} from 1.50 to 1.73, and at inoculum concentrations of $5 \times 10^3:1 \times 10^3$ spores mL^{-1} from 1.22 to 1.31. Very similar proportions at inoculum concentrations of $1 \times 10^3:0.5 \times 10^3$ and $5 \times 10^3:1.0 \times 10^3$ spores mL^{-1} were detected for DS and AUDPC.

Figure 3 shows the disease development at inoculum concentrations of 0.5×10^3 , 1×10^3 , and 5

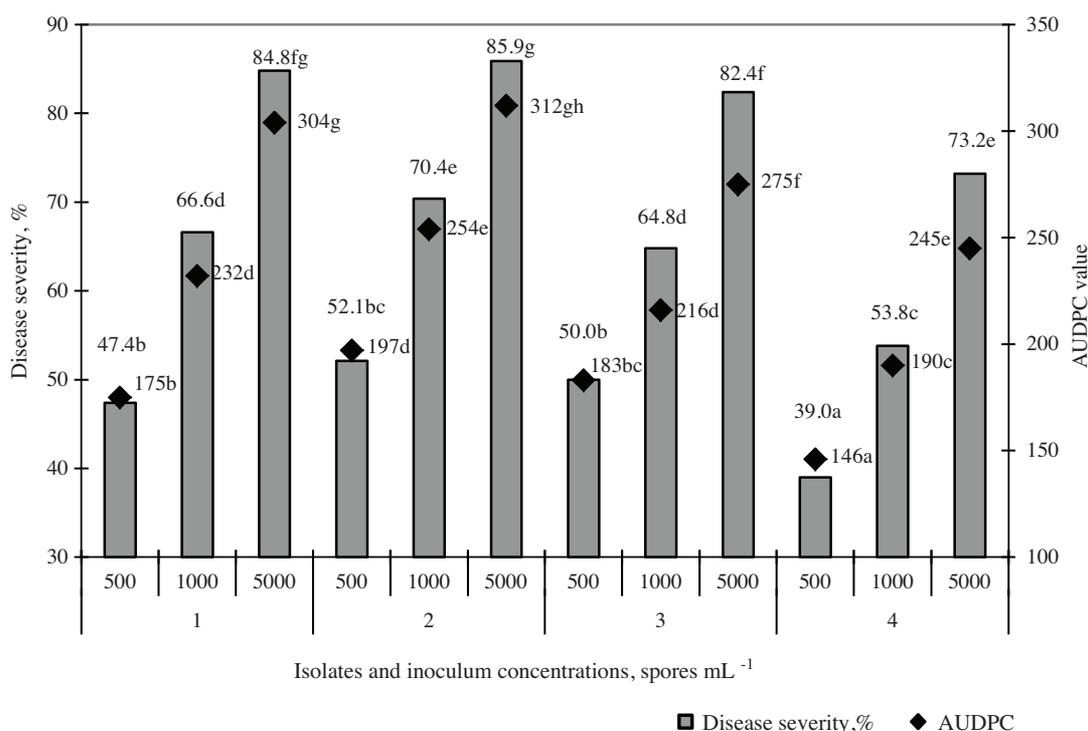


Figure 2. The mean DS and AUDPC curve as influenced by isolate and inoculum concentrations.

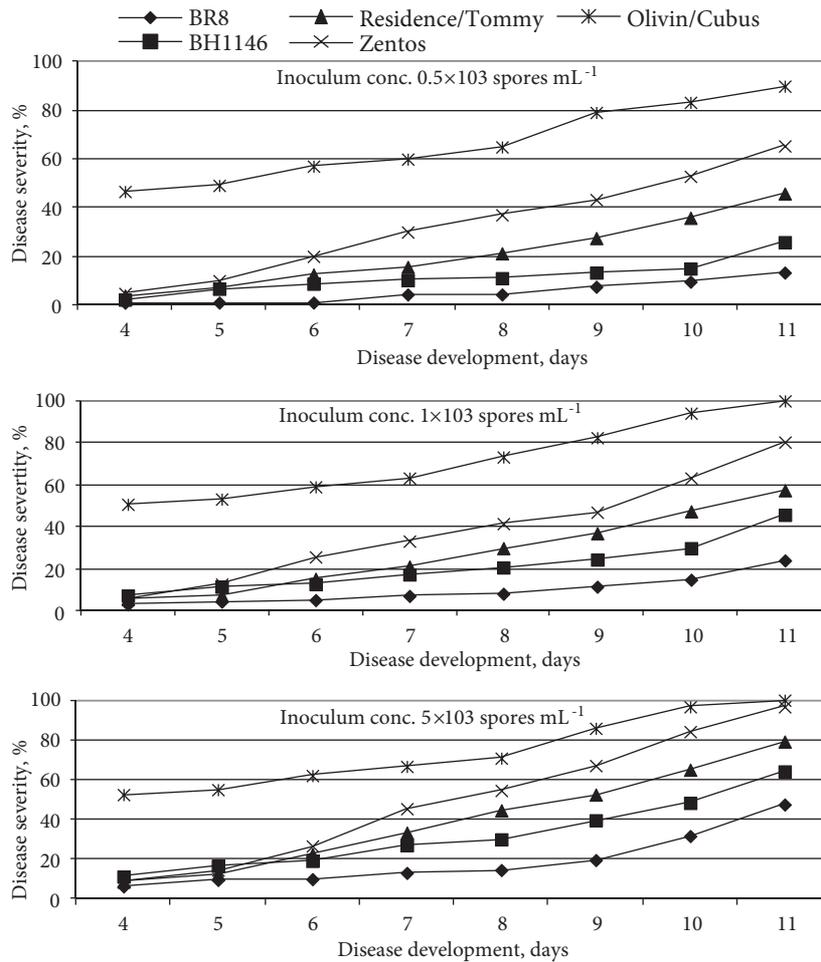


Figure 3. Spot blotch development on lines possessing different resistance levels at different inoculum concentrations.

$\times 10^3$ spores mL⁻¹ in 5 accessions possessing different degrees of resistance that were proportionally distributed in the final DS assessment. In general, DS development was rather even for all accessions. Although the first and second days of DS evaluation at inoculum concentrations of 1×10^3 and 5×10^3 spores mL⁻¹ showed that cultivar BH1146 was slightly more damaged than the more susceptible accessions Residence/Tommy and Zentos, the DS development rate in BH1146 declined. DS severity on the first day of evaluation was proportional to disease development. However, Olivin/Cubus showed very high DS upon initial development, but a slightly slower DS curve was observed during the entire evaluation cycle. The final DS was also proportional for all accessions, with the exception of the inoculum concentration of 5×10^3 spores mL⁻¹ for accessions Zentos and Olivin/

Cubus, whose DS reached the same point on the last day of evaluation.

The DS of more resistant accessions increased more rapidly than that of more susceptible accessions at higher inoculum concentrations. The DS of BR8 increased 1.8 times at an inoculum concentration of 1×10^3 compared to 0.5×10^3 spores mL⁻¹ and 3.57 times at an inoculum concentration of 5×10^3 compared to 0.5×10^3 spores mL⁻¹. A more susceptible accession, Residence/Tommy, showed 1.25 and 1.72 times lower proportions at the same inoculum concentrations. The most susceptible accession, Olivin/Cubus, showed a proportion of only 1.11 for the above inoculum concentrations.

All of the inoculum concentrations applied can be successfully used for resistance evaluation considering

DS development in the same accessions at different inoculum concentrations. The lower inoculum concentrations provided higher differentiation of the tested accessions. The most resistant accession, BR8, had DS values of 13.3%, 24.2%, and 47.5% on day 11 of disease development at inoculum concentrations of 0.5×10^3 , 1×10^3 , and 5×10^3 spores mL⁻¹, respectively. The most susceptible accessions had DS values of 90%, 100%, and 100% at the same inoculum concentrations.

The most resistant accessions (i.e., those which were found to be statistically more resistant than or not different from the medium resistant standard, BH1146) were sorted by AUDPC and presented in Table 1. Cultivar BR8, classified in the literature as resistant, was the most resistant among the total accessions tested by AUDPC and DS, with results of 77.5 and 30.5%, respectively. Cultivar BH1146,

known to be of medium resistance, was recorded as having a DS of 44.2% and an AUDPC of 146.4. The accessions tested were not purposively selected for spot blotch resistance during the breeding process. Nonetheless, 28 (22.6%) accessions possessed the same or higher resistance as BH1146. Cultivars Dream, Aspirant, and Biscay occurred in the largest number of tested lines, at 9, 7, and 6, respectively. As a result, the resistance of newly developed cultivars could be higher if they contained these ancestries in their pedigree. However, lines Dream/Aspirant and Biscay/Dream, possessing both of these cultivars as ancestors, were not found to be the most resistant.

In total, the accessions tested fell within 8 AUDPC groups (Table 2). Resistant cultivar BR8 was the only accession (0.8%) in the AUDPC group up to 100. Groups 2-5 were similar in the number of derivatives tested. The second AUDPC group, 100.1-

Table 1. The most spot blotch-resistant winter wheat accessions, with mean AUDPC values and DS averaged over all isolates and concentrations.

Pedigree	AUDPC	DS, %	Pedigree	AUDPC	DS, %
BR 8	77.5 ^{a*}	30.5 ^a	Biscay/Pobeda	135.3 ^{b-e}	46.2 ^{b-g}
Aspirant/3/Haven /Dean//Pentium	117.5 ^b	44.2 ^{b-e}	Aspirant/3/Haven /Dean//Pentium	136.6 ^{b-e}	56.3 ^{g-k}
Dream/Asketis	118.5 ^{bc}	51.7 ^{b-k}	Flair/Ansgar	136.9 ^{b-e}	58.1 ^{h-k}
Flair/ Lut.9329	119.9 ^{b-e}	54.7 ^{e-k}	Biscay/Pobeda	137.9 ^{b-e}	56.1 ^{f-k}
Aspirant/3/Haven /Dean//Pentium	121.2 ^{b-e}	42.8 ^{bc}	Bussard/ Purdue4930//Kris	137.9 ^{b-e}	59.7 ^{h-k}
Bill/Dream	122.3 ^{b-e}	54.7 ^{e-k}	Tarso/Lut.96-3	138.0 ^{b-e}	59.4 ^{h-k}
MV Emma/Convent	123.0 ^{b-e}	52.2 ^{b-k}	Aspirant/Belisar	140.9 ^{b-e}	52.9 ^{c-k}
Dream/Aspirant	124.5 ^{b-e}	44.6 ^{b-e}	Biscay/Pobeda	145.9 ^{b-e}	62.1 ^{jk}
Aspirant/3/Haven /Dean//Pentium	124.6 ^{b-e}	43.1 ^{b-d}	BH1146	146.4 ^{b-e}	44.2 ^{b-e}
Dream/Bill	125.4 ^{b-e}	53.8 ^{c-k}	Lut.9329/Solist	146.8 ^{b-e}	57.5 ^{g-k}
Bill/Asketis	126.5 ^{b-e}	48.8 ^{b-h}	Dream/Lut.9329	148.8 ^{b-e}	61.4 ^{i-k}
Biscay/Dream	131.1 ^{b-e}	54.9 ^{e-k}	Dream/Flair	150.0 ^{b-e}	62.2 ^{jk}
Biscay/Sj965491	131.6 ^{b-e}	54.4 ^{e-k}	Biscay/Pobeda	150.2 ^{b-e}	58.6 ^{h-k}
Olivin/Cubus	131.7 ^{b-e}	57.6 ^{g-k}	Dream/Aspirant	151.0 ^{b-e}	41.9 ^b
MV 0695/Dekan	134.9 ^{b-e}	54.2 ^{d-k}	Dream/91002G2.1	151.4 ^{b-e}	59.9 ^{h-k}

Means followed by the same letters do not differ according to Duncan's multiple range test at $P < 0.05$.

Table 2. The distribution of winter wheat accessions by AUDPC groups.

AUDPC groups	Resistance groups	Mean AUDPC	DS range, %	Mean DS, %	No. / % of accessions
≤100	R	77.5	30.5	30.5	1 / 0.8
100.1-150.0	MR	132.9	42.3-62.2	53.4	26 / 20.6
150.1-200.0	MR-MS	172.7	41.9-69.3	59.3	23 / 18.3
200.1-250.0	MS	228.2	51.9-71.5	62.2	27 / 21.4
250.1-300.0	MS-S	269.8	61.1-80.8	69.3	28 / 22.2
300.1-350.0	S	326.2	71.4-81.9	76.4	13 / 10.3
350.1-400.0	S-HS	380.6	74.7-90.8	83.2	5 / 4.0
≥400.1	HS	450	89.2-96.4	90	3 / 2.4

150.0, contained 26 (20.6%) accessions, including medium resistant cultivar BH1146. The third group (MR-MS) included 23 (15.9%) accessions, the fourth group was made up of 27 (21.4%), and the fifth group featured 28 (22.2%). Group 6 comprised 13 (10.3%) accessions, group 7 contained 5 (4%), and group 8 included 3 (2.4%).

Discussion

The mean AUDPC differentiated accessions' resistance better than the scores did due to the higher proportion of AUDPC between resistant and susceptible accessions. Although there was a high correlation of DS with AUDPC, the higher differences of AUDPC values than of DS values suggest that AUDPC results characterize accessions' resistance more comprehensively (Figure 1). The accessions differed in resistance level at the same growth stage and under the same conditions. Therefore, they may possess different resistance genes. Resistance of wheat to spot blotch depends mainly on quantitative genes, which differ in effectiveness. Some of them can be responsible for 50% of the effectiveness, whereas the least effective can be responsible for only a small percentage of the total resistance level (Smurova 2008; Duveiller and Sharma 2009; Kumar et al. 2010). Distribution of the tested accessions over AUDPC groups was close to normal (Figure 1, Table 2), suggesting that resistance depended mainly on polygenic traits. The variability of resistance

reactions among breeding lines could be explained by the variation of effectiveness among the existing resistance genes. The limited information available in the literature shows that resistance to spot blotch can be controlled by major genes (Neupane et al. 2007). The low frequency of accessions characterized by similar DS and AUDPC values to those of resistant control cultivars BR8 and BH1146 (Table 2) indicates the possibility of selecting modern European winter wheat cultivars with acceptable spot blotch resistance when large numbers of accessions are screened.

The isolates of *B. sorokiniana* did not differ considerably in virulence in wheat, a finding that has also been reported by Jaiswal et al. (2007). As a result, the selection of isolates depends on the level of aggressiveness. This, in turn, is selected according to the resistance level of the available breeding material. If wheat cultivars possess considerable resistance levels, the usage of more aggressive isolates highlights the most resistant ones. A precise survey can be achieved when an inoculum concentration of isolates with the desired aggressiveness is additionally selected according to the resistance level of the material (Figures 1 and 2). This technique could allow us to concentrate on resistance genes with lower efficiency to develop new breeding lines possessing some resistance (Sharma et al. 2004), or it could be useful in selecting more resistant cultivars from nonadapted material, as the introduction of efficient resistance and the release of new cultivars can take more than 2 decades.

Comparison of wheat resistance data from the laboratory and field can show some inconsistencies. When laboratory and field data are compared, one should bear in mind that accessions that are evaluated as resistant in the laboratory at a seedling stage are characterized only by resistance reaction, not according to disease progress as in field conditions. Many studies have shown that under high disease pressure in field conditions, susceptible accessions are evaluated by disease severity of 70%-90% and AUDPC values over 2000, whereas resistant ones are characterized by 10%-30% disease severity and AUDPC values of up to 1000 (Kumar et al. 2009). Disease development in 5 selected accessions under different levels of infection pressure (Figure 3) showed similar final DS values but much lower AUDPC values due to the very short experimental period. Duveiller and Sharma (2009) indicated that regular disease assessments and a calculated AUDPC provide the most reliable characterization of wheat resistance to spot blotch. Our short-term study under laboratory conditions proved the advantage of AUDPC over DS for differentiating the most resistant accessions (Figures 1 and 3, Tables 1 and 2). Naturally, it is not expedient to evaluate daily all of the accessions intended for survey. A simple prescreening of the material by DS should reveal promising accessions, and a more detailed survey could be pursued later.

Smurova (2008) showed that the resistance reaction of wheat to spot blotch had a medium to strong correlation between laboratory and field conditions. Such correlation levels indicate the convenient possibility of searching for resistance sources among thousands of accessions. According to these relationships, our method could be useful for selecting the most resistant wheat accessions when numerous accessions are tested for resistance reactions in short-term tests. The same correlation level was obtained when the resistance to root rot at seedling and adult plant stages was compared (Smurova 2008). The correlation is lower when the resistance of wheat to spot blotch and root rot is compared (Conner 1990; Smurova 2008). However, it was determined that the resistance of different parts of barley plants to the same pathogen could be weak, medium, or strong depending on the set of tested cultivars and isolates (Arabi et al. 2006). Screening techniques also differ. Spot blotch resistance at the

seedling stage is usually tested over several days, whereas screening for root rot resistance can take up to several weeks. In this case, the higher influence of partial resistance on roots and spot blotch progress during vegetation is possible. However, wheat resistance to other leaf spot diseases, such as Septoria leaf blotch and tan spot, usually shows medium to high correlations at different phenological stages (De Wolf et al. 1998; Arraiano et al. 2001).

Under European conditions, *B. sorokiniana* is harmful to wheat, causing seedling (Hudec and Muchova 2008) and adult plant root rots (Rossi et al. 1995). Other fungi causing root rots are more harmful, however, which therefore usually masks the damage done to wheat by *B. sorokiniana*. The harmfulness of root rots has been proven to cause considerable damage. Evidence of winter wheat cultivars' resistance to the complex of these pathogens in Europe is limited, however, when compared to that concerning resistance to foliar pathogens. The main reasons for this disparity are the considerably higher costs and longer investigation periods. Another huge constraint is the fact that the selection of lines in early generations for the evaluation of root damage level results in plant losses. This could be done at harvesting, but there is usually a shortage of time for the detailed screening of thousands of lines. The evaluation of root health once at ripening is also relevant when the disease pressure is medium. The differences among the accessions will be insufficient under high disease pressure conditions, since roots will be rotted more severely. Wheat accessions do not differ markedly when the disease pressure is low. Detailed investigations of root rot resistance can be done with advanced breeding lines. However, the majority of breeding lines in early generations, even those possessing resistance to root rots, are discarded if they do not exhibit adequate yielding capacity. Valuable material for resistance breeding is also discarded.

Spot blotch is a more theoretically likely problem for European wheat at present. However, spot blotch may follow the pattern of tan spot; the latter disease spread all over the world (De Wolf et al. 1998) and, over the course of a few decades, the pathogen has become one of the most devastating diseases of wheat, much like spot blotch has in the Asian

region. A similar situation has occurred with barley Ramularia leaf spot (caused by *Ramularia collo-cygni*) in northern Europe and New Zealand (Walters et al. 2008). In both cases, it has been suggested that the introduction of varieties with increased susceptibility to abiotic stresses, coupled with decreased competition from other foliar pathogens as a result of improved resistance and technological control, are possible reasons for the appearance and increase of tan spot and Ramularia leaf spot. Changes in pathogens' adaptation to temperature regimes are also likely. Milus et al. (2009) proved that yellow rust, which is predominant in cool climate areas, has been on the increase in warmer areas in recent decades.

At present, the resistance of European winter wheat to tan spot and especially Septoria leaf blotch is rapidly improving (BSA 2010). This leads to a disease-free leaf surface and less competition, as well as to lower fungicide use. Therefore, pathogens occurring at low levels can readily cause epidemics under favorable conditions. As a result, it is likely that spot blotch could emerge in Europe as a devastating disease. The survey of the current winter wheat accessions, still under development, reveals some alternatives to control spot blotch through genetic resistance of the most agronomically advanced material.

References

- Arabi MIE, Al-Daoud A, Jawhar M (2006) Interrelationship between spot blotch and common root rot in barley. *Australas Plant Pathol* 35: 1-3.
- Arraiano LS, Brading PA, Brown JKM (2001) A detached seedling leaf technique to study resistance to *Mycosphaerella graminicola* (anamorph *Septoria tritici*) in wheat. *Plant Pathol* 50: 339-346.
- BSA (2010) Beschreibende Sortenliste. Bundessortenamt. Available at <http://www.bundessortenamt.de>, accessed 18 October 2010.
- Campbell CL, Madden LV (1990) *Introduction to Plant Disease Epidemiology*. John Wiley and Sons, New York.
- Conner RL (1990) Interrelationship of cultivars reaction to common root rot, black point, and spot blotch in spring wheats. *Plant Dis* 74: 224-227.
- Csösz M, Toth B, Cseuz L, Mesterhazy A, Varga J (2008) Occurrence of fungal pathogens causing leaf spot diseases of wheats in Hungary in 2000-2008. In: *Proceedings of the 18th General Congress of the EUCARPIA* (Eds. J Prohens, ML Badenes), Valencia, pp. 347-348.
- De Wolf ED, Effertz RJ, Ali S, Francl LJ (1998) Vistas of tan spot research. *Can J Plant Pathol* 20: 349-368.
- Duveiller E, Sharma RC (2009) Genetic improvement and crop management strategies to minimize yield losses in warm non-traditional wheat growing areas due to spot blotch pathogen *Cochliobolus sativus*. *J Phytopathol* 157: 521-534.
- Eken C, Demirci E (1998) The distribution, cultural characteristics, and pathogenesis of *Drechslera sorokiniana* in wheats and barley in Erzurum region. *Turk J Agric For* 22: 175-180.
- Fernandez MR, Jefferson PG (2004) Fungal populations in roots and crowns of common and durum wheat in Saskatchewan. *Can J Plant Pathol* 26: 325-334.
- Gonzalez MS, Trevathan LE (2000) Identity and pathogenicity of fungi associated with root and crown rot of soft red winter wheat grown on the upper coastal plain land resource area of Mississippi. *J Phytopathol* 148: 77-85.
- Hudec K, Muchova D (2008) Correlation between black point symptoms and fungal infestation and seedling viability of wheat kernels. *Plant Prot Sci* 44: 138-146.
- Jaiswal SK, Sweta S, Prasad LC, Sharma S, Kumar S, Prasad R, Pandey SP, Chand R, Joshi AK (2007) Identification of molecular marker and aggressiveness for different groups of *Bipolaris sorokiniana* isolates causing spot blotch disease in wheat (*Triticum aestivum* L.). *Curr Microbiol* 55: 135-141.
- Jørgensen LN (2008) Resistance situation with fungicides in cereals. *Zemdirbyste-Agriculture* 95: 373-378.
- Kumar U, Joshi AK, Kumar S, Chand R, Röder MS (2009) Mapping of resistance to spot blotch disease caused by *Bipolaris sorokiniana* in spring wheats. *Theor Appl Genet* 118: 783-792.
- Kumar U, Joshi AK, Kumar S, Chand R, Röder MS (2010) Quantitative trait loci for resistance to spot blotch caused by *Bipolaris sorokiniana* in wheat (*T. aestivum* L.) lines 'Ning 8201' and 'Chirya 3'. *Mol Breeding* 26: 477-491.
- Lehmensiek A, Campbell AW, Williamson PM, Michalowitz M, Sutherland MW, Daggard GE (2004) QTLs for black-point resistance in wheat and the identification of potential markers for use in breeding programmes. *Plant Breeding* 123: 410-416.
- Milus EA, Kristensen K, Hovmøller MS (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.
- Neupane RB, Sharma RC, Duveiller E, Ortiz-Ferrera G, Ojha BR, Rosyara UR, Bhandari D, Bhata MR (2007) Major gene controls field resistance to spot blotch in wheat genotypes 'Milan/Shanghai #7' and 'Chirya.3'. *Plant Dis* 91: 692-697.

- Rossi V, Cervi C, Chiusa G, Languasco L (1995) Fungi associated with foot rots on winter wheat in northwest Italy. *J Phytopathol* 143: 115-119.
- Sharma RC, Sah SN, Duveiller E (2004) Combining ability analysis of resistance to *Helminthosporium* leaf blight in spring wheat. *Euphytica* 136: 341-348.
- Sharma-Poudyal D, Duveiller E, Sharma RC (2005) Effects of seed treatment and foliar fungicides on *Helminthosporium* leaf blight and on performance of wheat in warmer growing conditions. *J Phytopathol* 153: 401-408.
- Siddique AB, Hossain MH, Duveiller E, Sharma RC (2006) Progress in wheat resistance to spot blotch in Bangladesh. *J Phytopathol* 154: 16-22.
- Smurova SG (2008) New Sources and Donors of Wheat Resistance to *Cochliobolus sativus* Drechs. ex Dastur. PhD thesis. All-Russia Institute of Plant Protection, St. Petersburg, p. 236.
- Tobias DJ, Stack RW, Puri KD, Riveland N, Zhong S (2009). Reaction of hard red spring wheats to common root rot under field conditions of Northern United States of America. *Euphytica* 167: 165-172.
- Vilareal RL, Mujeeb-Kazi A, Gilchrist LI, Del Toro E, (1995) Yield losses to spot blotch in spring bread wheat in warm nontraditional wheat production areas. *Plant Dis* 79: 893-897.
- Walters DR, Havis ND, Oxley SJP (2008) *Ramularia collo-cygni*: the biology of an emerging pathogen of barley. *FEMS Microbiol Lett* 279: 1-7.
- Wegulo SN, Breathnach JA, Baenziger PS (2009) Effect of growth stage on the relationship between tan spot and spot blotch severity in winter wheat. *Crop Prot* 28: 696-702.