sciendo

DOI: 10.2478/bile-2023-0002

Biometrical Letters
Vol. 60 (2023), No. 1, 23 - 35

Progress in plant tolerance to the fungal disease Sclerotinia in breeding experiments on winter oilseed rape

Bogna Zawieja[1], Laura Slebioda[1], Tomasz Mikulski[2]

[1]Department of Mathematical and Statistical Methods, Poznan University of Life Sciences, Wojska Polskiego 28, 60-637 Poznań, Poland, e-mail: bogna.zawieja@up.poznan.pl
[2] Norddeutsche Pflanzenzucht Hans Georg Lembke KG, Hohenlieth, Germany

SUMMARY

Sclerotinia sclerotiorum is a pathogen which causes a disease of oilseed rape. Severe plant infection contributes to a decrease in the quality of the crop. It is therefore important to pay attention to whether hybrids are highly tolerant to this fungal disease at the early stages of breeding. In this study, the question of interest is whether there has been progress in increasing the tolerance of new hybrids to this pathogen. Three years of breeding experiments (2014, 2015, 2017) are included in the analysis. Each year, three to five experiments were carried out, with several dozen varieties and three standards. Each series of experiments was repeated in several locations. Because the degree of infection was assessed on a scale (from 1 – the highest infection – to 9 – the least infection), the analysis is carried out using an ordinal logistic model. It is noted that in earlier years the standard varieties' probability of infection with this disease had a smaller range (empirical probability 0.5–0.83) than in the last analyzed year (empirical probability 0.33–1.00). The results of the analysis show that in 2014 and 2015 several hybrids exhibited a significantly higher tolerance to Sclerotinia, but in 2017 none of the hybrids were significantly better than the standard. Perhaps breeding selection of hybrids has eliminated the less tolerant varieties. However, to be able to draw more general conclusions, it would be necessary to repeat the study in controlled conditions (a greenhouse), where the level of fungal spores and their effect on plants could be controlled. Obtaining tolerant hybrids will enable a reduction in production costs, since there will be no need to monitor whether disease infestation occurs and no need to use corresponding plant protection products.

Key words: degree of fungal infection, hybrids, ordinal logistic model, probabilities of infection, *Sclerotinia sclerotiorum*, standard variety

1. Introduction

Winter oilseed rape (*Brassica napus* L.) is a hybrid of *Brassica oleracea* and *Brassica rapa* (Chalhoub et al., 2014). Rapeseed is used to produce edible oil and

biodiesel, and also as an additive to fodder for animals. Since rapeseed oil initially contained, for instance, a high concentration of erucic acid, which is toxic (Charlton et al., 1975; Srivastava et al., 1975; Russo et al., 2021), its use was very limited. However, proper breeding led to significant reduction in the content of the acid and even its elimination (Krzymiański, 1968, 1970; Stefansson et al., 1961; Beszterda and Nogala-Kałucka, 2019), and thus the possibilities of using the oil have greatly increased. Another problem is fungal diseases of cultivated plants, which cause reduction of the quality and quantity of the yield (Derbyshire and Denton-Giles, 2016). These include *Sclerotinia sclerotiorum*, which causes the rapeseed stem disease called Sclerotinia stem rot. It is a very harmful pathogen that occurs in regions all over the world, causing huge economic losses every year (Ding et al., 2021). In some areas it can cause 10−20% loss of rapeseed production each year, with up to 80% losses in regions where the disease is severe. This disease is more likely to occur due to increased precipitation in particular (Koch et al., 2007). Sclerotinia appears when the right conditions exist: there must be pathogens (spores) in the soil and in the air, and very specific weather conditions must occur during wilting (April, May) (Palti J., 1963). Therefore, this disease does not occur in every studied location or every year. Since there are very few lines in conventional winter oilseed rape plant breeding that are resistant to this disease, and these lines come from China and are not adapted to the European climate (for example, the variety named Zhong You 821), field selection is important, which emphasizes horizontal, multigenic immunity (Li et al., 1999). Plant breeding needs methods that will help the breeder to assess new varieties of winter oilseed rape quickly and accurately for *Sclerotinia sclerotiorum* infection. Suitably collected and statistically presented data can help breeders make selection decisions. Methods of assessing plants infected by *Sclerotinia sclerotiorum* on a scale of 1–9 or by percentage are widely used by growers and registration offices throughout Europe. This is a quick method and, in the years of infestation, extremely effective. The aim of this study is to check whether there has been any progress in rapeseed breeding (new hybrids) in terms of tolerance to this disease. It should be noted that the use of

varieties tolerant to this disease will reduce production costs, saving the costs associated with monitoring whether the disease occurs and with the use of corresponding plant protection products.

2. Research material

Single-replicate experiments with new oilseed rape cultivars were carried out in several locations in the years 2014, 2015, and 2017. In all years of the study the fungal stem disease Sclerotinia was observed. The analysis included only the locations where the disease was observed. The degree of infection is determined on a scale from 1 to 9, where 1 denotes complete infection and 9 no infection. In 2014 and 2015, three experiments were performed (1006, 1013, 1015). In 2017 there were five experiments (1131, 1132, 1133, 1134, 1135), which were repeated in several locations.

In 2014, the disease was observed in experiments 1006 and 1015 at the locations of Pawłowice, Falęcin, and Bezek, and in experiment 1013 at Pawłowice, Bezek, and Słupia (in these locations the sum of precipitation in April and May was approximately 140 mm, but in Bezek approximately 240 mm; it was an extremely warm year according to the meteorological institute IMGW, with mean temperature approximately 12 °C). In 2015 the disease was observed in experiments 1006 and 1015 at Kujawy, Tomaszów Bolesławiecki, and Słupia, and in experiment 1013 at Tomaszów Bolesławiecki and Słupia (in these locations the sum of precipitation in April and May was approximately 80 mm; it was an extremely warm year, with mean temperature approximately 12 °C). In 2017, Sclerotinia was observed in all five experiments in the locations of Tomaszów Bolesławiecki, Falęcin, and Krzyżewo (in these locations the sum of precipitation in April and May was approximately 120 mm, and the mean temperature approximately 11 °C). In 2016 the sum of precipitation in April and May was approximately 110 mm and the mean temperature was 12 °C; the mean temperature was as in the previous years, while the precipitation value was intermediate between those for 2014 and 2015 (and closest to the value for 2017).

However, Sclerotinia infection was not observed in that year (data on infection were not collected in the field), and it will thus be omitted from this study.

In each experiment different hybrids were tested and different reference (standard) varieties were used – in 2014 in experiment 1006: Mercedes (abbreviation SM), DKExquisite (SD), Visby (SV); in experiment 1013: PR44D06 (SP), NPZ1203Z (SN1); in experiment 1015: SLM1204 (SS1), Mercedes, SLM1305 (SS2); in 2015 in experiment 1006: Atora (SA), DKExquisite, Visby; in experiment 1013: NPZ14009W13 (SN2), NPZ14003W13 (SN3), Thure (ST); in experiment 1015: Visby, Atora, SLM14013W11 (SS3); in 2017: Atora, DK Exquisite, and Ragnar (SR).

3. Statistical analysis

An ordinal logistic model with the logit function was used (McCulloch and Searle, 2001; Agresti, 2002). The analysis was carried out separately for each experiment. Due to each experiment being a single replicate, only main effects of locations and lines, without interaction, could be applied in the model.

The model applied is expressed as follows:

$$\text{logit}(P(Y_{vk} \leq j)) = \log \frac{P(Y_{vk} \leq j)}{1 - P(Y_{vk} \leq j)} = \theta_j - \beta_k - \beta_v \qquad (1)$$

where Y_{vk} is the observation of the vth hybrid at the kth location, $P(Y_{vk} \leq j) = \pi_{vk1} + \pi_{vk2} + \cdots + \pi_{vkj}$ are the cumulative probabilities of a degree of infection corresponding to the vth hybrid at the kth location, $j = l, \ldots, J-1$ – is the category number, l is the lowest observed category in a given experiment, β_k is the random effect of the kth location ($k = 1,2 \ldots s$, s being the number of locations in the given trial), β_v is the fixed effect of the vth hybrid ($v = 1,2, \ldots o$, o being the number of hybrids in the given trial), and θ_j is the fixed cutpoint of the jth category. The random effect of location is assumed to have an asymptotically normal distribution $\beta_k \sim N(0, \sigma^2_{loc})$. Wald's statistic, which has approximately χ^2 distribution, is applied to test the hypothesis H_0: $\beta_v = 0$. In this paper the empirical p-value for the Wald test is given.

The breeding trials included three or two standard varieties, but in the ordinal logistic model (1) only one standard can be used. Thus the "best" standard variety (understood as the most tolerant to Sclerotinia) was chosen using the empirical probabilities calculated separately in each trial. The standard with the highest empirical probability for a high category (7, 8 or 9) was selected.

The calculations were performed using the clmm function from the ordinal package (Christensen, 2022) implemented on the R computing platform.

4. Results

Because in the analysis of the experiments three or two standard varieties were used, one of them had to be selected for comparison with the hybrids. For this purpose, as mentioned above, the empirical probabilities were used. These probabilities are shown in Table 1 (with the selected standards bolded). When two standards had the same probabilities one of them was chosen, or the standard with the larger sum of probabilities in two neighboring categories was determined to be the best (the correctness of the choice was verified after performing the analysis; that is, the unselected standard could be the same or worse than the chosen standard).

The results of the logistic analysis for each experiment are presented in Table 2. A coefficient greater than zero means that the given hybrid is better than the standard. In experiments 1006 and 1015 in 2014 and 2015, and in experiment 1131 in 2017, some hybrids exhibited significant differences from the standard. The hybrids 2, 8, 16, 19, 32 from trial 1006, hybrid 12 from the 1015 trial in the 2014 year, and hybrids 3 and 26 from trial 1006 in the 2015 year are more disease-tolerant than the standard variety, while the hybrids 5, 6, 13, 19, 20, from trial 1015 in the 2014 year, hybrids 17, 22, 25, 32 from trial 1006 in the 2015 year and 1, 2, 7, 9, 10, 13, 20, 31, 33 from trial 1015 in the 2015 year and 12 from trial 1131 in the 2017 year are significantly less tolerant to the fungal disease than the standard.

Table 1. Empirical probabilities of Sclerotinia occurrence for standard varieties, depending on category

Year		2014				
Trial	Category	5	6	7	8	9
1006	SV	0.00	0.33	0.00	0.67	0.00
	SD	0.00	0.33	0.00	0.67	0.00
	SM	0.00	0.00	**0.50**	**0.50**	0.00
1013	SP	0.00	0.00	0.50	**0.50**	
	SN1	0.00	0.00	0.83	0.17	
1015	SS1	0.00	0.00	0.17	**0.83**	0.00
	SM	0.00	0.33	0.17	0.50	0.00
	SS2	0.00	0.16	0.17	0.67	0.00
Year		2015				
	Category	4	6	7	8	9
1006	SA	0.00	0.00	0.66	0.17	0.17
	SD	0.00	0.00	0.50	**0.50**	0.00
	SV	0.00	0.33	0.33	0.33	0.00
	Category	5	6	7	8	
1013	SN2	0.00	0.00	**0.50**	**0.50**	
	SN3	0.00	0.50	0.25	0.25	
	ST	0.00	0.25	0.25	0.50	
	Category	3	5	6	7	8
1015	SV	0.00	0.00	0.00	0.33	0.67
	SA	0.00	0.00	0.00	0.50	0.50
	SS3	0.00	0.00	0.00	0.33	**0.67**
Year		2017				
	Category	5	6	7	8	9
1131	SA		0.00	0.00	**1.00**	0.00
	SD		0.33	0.00	0.33	0.33
	SR		0.00	0.00	1.00	0.00
1132	SA	0.00	0.00	0.00	**0.67**	**0.33**
	SD	0.00	0.00	0.33	0.33	0.33
	SR	0.00	0.00	0.00	0.67	0.33
1133	SA		0.00	0.33	**0.33**	**0.33**
	SD		0.00	0.33	0.33	0.33
	SR		0.00	0.33	0.33	0.33
1134	SA		0.00	0.00	**0.67**	**0.33**
	SD		0.00	0.33	0.33	0.33
	SR		0.00	0.33	0.33	0.33
1135	SA	0.00	0.33	0.00	0.33	0.33
	SD	0.00	0.00	**0.33**	**0.33**	**0.33**
	SR	0.33	0.00	0.33	0.00	0.33

Bold type – the least infected hybrids or locations

Table 2. Coefficients and *p*-values from mixed ordinal logistic analysis for the significant hybrids (values smaller than zero indicate hybrids less disease-tolerant than the standard variety, values greater than zero indicate hybrids more tolerant than the standard variety, and coefficients equal to zero indicate hybrids infected to the same extent as the standard)

Th & H	Coefficients (SE)	*p*-value	Th & H	Coefficients (SE)	*p*-value	Th & H	Coefficients (SE)	*p*-value
Year 2014, Trial 1006			Year 2014, Trial 1013			Year 2014, Trial 1015		
5|6	-6.47 (1.67)	0.0001				5|6	-8.53 (2.15)	0.0001
6|7	-3.46 (1.50)	0.0208	5|6	-6.96 (2.53)	0.0059	6|7	-5.84 (2.07)	0.0047
7|8	-0.51 (1.47)	0.7302	6|7	-4.47 (2.46)	0.0693	7|8	-3.31 (2.00)	0.0978
8|9	5.58 (1.56)	0.0003	7|8	-0.45 (2.38)	0.8513	8|9	3.98 (1.98)	0.0444
2	3.56 (1.35)	***0.0085***	2	-1.27 (1.54)	0.4117	2	0.85 (1.32)	0.5213
5	2.29 (1.47)	0.1188	5	-1.08 (1.51)	0.4734	5	-3.63 (1.42)	**0.0105**
6	0.05 (1.34)	0.9721	6	-1.82 (1.51)	0.2267	6	-3.52 (1.47)	**0.0165**
8	3.55 (1.35)	***0.0087***	8	0.61 (1.67)	0.7154	8	2.31 (1.35)	0.0856
12	1.05 (1.47)	0.4784	12	-0.26 (1.55)	0.8651	12	3.19 (1.52)	***0.0357***
13	-0.75 (1.25)	0.5497	13	-1.74 (1.54)	0.2585	13	-4.30 (1.43)	**0.0026**
16	3.56 (1.35)	***0.0085***	16	-0.87 (1.57)	0.5783	16	-0.58 (1.46)	0.6916
19	2.69 (1.35)	***0.0470***	.			19	-3.52 (1.47)	**0.0165**
20	0.89 (1.35)	0.5086				20	-4.30 (1.43)	**0.0026**
32	2.69 (1.35)	***0.0470***	.			32	-0.80 (1.42)	0.5723
Year 2015, Trial 1006			Year 2015, Trial 1013			Year 2015, Trial 1015		
4|6	-7.07 (1.70)	0.0000				3|5	-9.03 (1.94)	0.0000
6|7	-4.15 (1.58)	0.0087	5|6	-4.02 (1.11)	0.0003	5|6	-7.28 (1.83)	0.0001
7|8	-0.17 (1.54)	0.9107	6|7	-1.86 (0.94)	0.0482	6|7	-5.02 (1.77)	0.0046
8|9	5.76 (1.68)	0.0006	7|8	-0.27 (0.91)	0.7653	7|8	-1.25 (1.70)	0.4632
1	1.03 (1.45)	0.4801	1	-0.96 (1.38)	0.4857	1	-4.39 (1.50)	**0.0035**
2	1.03 (1.45)	0.4801	2	0.91 (1.45)	0.5324	2	-3.56 (1.41)	**0.0116**
3	3.78 (1.39)	***0.0064***	3	-0.40 (1.32)	0.7624	3	-0.90 (1.57)	0.5657
7	-0.01 (1.36)	0.9946	7	-0.40 (1.32)	0.7624	7	-2.91 (1.48)	**0.0487**
9	0.00 (1.37)	1.0000	9	0.00 (1.28)	1.0000	9	-2.91 (1.48)	**0.0487**
10	-1.48 (1.27)	0.2428	10	0.00 (1.28)	1.0000	10	-2.96 (1.48)	**0.0465**
13	-1.40 (1.26)	0.2652	13	-0.61 (1.22)	0.6196	13	-4.39 (1.50)	**0.0035**
17	-3.89 (1.34)	**0.0039**				17	-0.90 (1.57)	0.5693
20	1.00 (1.48)	0.4988				20	-2.96 (1.48)	**0.0465**
22	-2.63 (1.27)	**0.0385**				22	-2.99 (1.54)	0.0523
25	-2.66 (1.28)	**0.0375**				25	-0.90 (1.57)	0.5657
26	2.989(1.39)	***0.0314***				26	-1.61 (1.53)	0.2934
31	-1.40 (1.26)	0.2652				31	-3.78 (1.52)	**0.0125**
32	-3.21 (1.37)	**0.0197**				32	0.21 (1.67)	0.9004
33	-0.80 (1.29)	0.5337				33	-9.03 (1.94)	**0.0000**
Year 2017, Trial 1131			Year 2017, Trial 1132			Year 2017, Trial 1133		
			5|6	-13.09 (5.95)	0.0278			
6|7	-6.02 (2.18)	0.0057	6|7	-11.35 (5.88)	0.0537	6|7	-7.66 (2.43)	0.0016
7|8	-2.59 (2.08)	0.2132	7|8	-8.31 (5.84)	0.1546	7|8	-2.31 (2.09)	0.2701
8|9	3.08 (2.16)	0.1553	8|9	0.94 (5.32)	0.8604	8|9	2.06 (2.11)	0.3295
12	-4.03 (1.83)	**0.0278**	12	-5.00 (4.81)	0.2986	12	0.00 (1.86)	1.0000
Year 2017, Trial 1134			Year 2017, Trial 1135					
			5|6	-8.87 (3.91)	0.0232			
6|7	-14.91 (6.07)	0.0141	6|7	-7.76 (3.87)	0.0451			
7|8	-8.96 (5.86)	0.1264	7|8	-3.98 (3.79)	0.2941			
8|9	0.92 (5.23)	0.8604	8|9	2.49 (4.24)	0.5568			

Bold – significantly different from standard; Italic – better than standard; Th – theresholds; H – hybrids

In 2014 and 2015, the highest empirical probabilities of infection of the standard varieties are observed for category 8 (Table 1). For category 9 these empirical probabilities are most often 0. In 2017 the highest empirical probabilities of infection of the standard varieties again occur for category 8 (Table 1), but for category 9 they are most often 0.33. This shows that the standard varieties were more tolerant to infection that year than in 2014 and 2015. It is difficult to obtain more tolerant hybrids, hence in 2017 none of the hybrids is significantly more tolerant than the standard. In 2014, the highest estimated probabilities for the hybrids are for category 8 (28 cases) and 7 (5 cases) in experiments 1006 and 1015, and for category 8 (only 5 cases) and 7 (12 cases) in experiment 1013. In 2015, the highest estimated probabilities for the hybrids are for category 8 (19 cases) and 7 (14 cases) in experiment 1006, 8 (30 cases) and 7 (3 cases) in experiment 1013, and 8 (16 cases) and 7 (17 cases) in experiment 1015. In 2017 the highest probabilities were for category 8 (30 cases) and 9 (3 cases) in experiments 1131 and 1133, only for category 8 (33 cases) in experiments 1132 and 1134, and for category 8 (31 cases) and 9 (2 cases) in experiment 1135. It is observed that the estimated probability is the highest in categories 7 and 8 in the years 2014 and 2015, and in categories 8 and 9 in 2017. Thus, the new hybrids probably have much better tolerance to fungal disease, hence it is more and more difficult to obtain a hybrid significantly better in terms of tolerance than the standard; importantly, however, the new hybrids were also not significantly more infected than the standard, although the rainfall was slightly lower than the average for 2014 and 2015 and the average temperature was only 1 °C lower than in the previous years.

The estimated probabilities for the standard varieties (Table 3) confirm the correct choice of the best standard. Example estimated probabilities are shown in Figure 1. Hybrids that are more tolerant than the standard variety, less tolerant than the standard variety, and not significantly different from the standard (with a coefficient close to zero; Table 2) are presented. In experiment 1006 in 2014, the significantly better hybrid 2 (having the largest coefficient value in this trial; see Table 2) attained the highest probability for category 8, and this was higher

Table 3. Estimated probabilities of Sclerotinia occurrence depending on category

Year		2014				
Trial	Category	5	6	7	8	9
1006	SV	0.00	0.06	0.48	0.46	0.00
	SD	0.00	0.06	0.48	0.46	0.00
	SM	0.00	0.03	0.35	**0.62**	0.00
1013	SP	0.00	0.01	0.38	**0.61**	
	SN1	0.00	0.05	0.70	0.25	
1015	SS1	0.00	0.00	0.03	**0.95**	0.02
	SM	0.00	0.09	0.48	0.42	0.00
	SS2	0.00	0.02	0.16	0.82	0.00
Year		2015				
	Category	4	6	7	8	9
1006	SA	0.00	0.02	0.47	0.51	0.17
	SD	0.00	0.01	0.44	**0.54**	0.00
	SV	0.01	0.10	0.76	0.14	0.00
	Category	5	6	7	8	
1013	SN2	0.02	0.12	**0.30**	**0.57**	
	SN3	0.08	0.35	0.36	0.22	
	ST	0.03	0.16	0.34	0.47	
	Category	3	5	6	7	8
1015	SV	0.00	0.00	0.01	0.22	0.78
	SA	0.00	0.00	0.01	0.40	0.59
	SS3	0.00	0.00	0.00	0.18	**0.81**
Year		2017				
	Category	5	6	7	8	9
1131	SA		0.00	0.07	**0.89**	0.04
	SD		0.00	0.12	0.85	0.02
	SR		0.00	0.07	0.89	0.04
1132	SA	0.00	0.00	0.00	**0.72**	0.28
	SD	0.00	0.00	0.02	0.98	0.01
	SR	0.00	0.00	0.00	0.72	0.28
1133	SA		0.00	0.09	**0.89**	0.11
	SD		0.00	0.09	0.89	0.11
	SR		0.00	0.09	0.89	0.11
1134	SA		0.00	0.00	**0.71**	0.28
	SD		0.00	0.01	0.98	0.00
	SR		0.00	0.01	0.98	0.00
1135	SA	0.00	0.00	0.09	0.90	0.01
	SD	0.00	0.00	0.02	**0.91**	**0.07**
	SR	0.01	0.01	0.47	0.50	0.00

Bold type – the least infected hybrids or locations

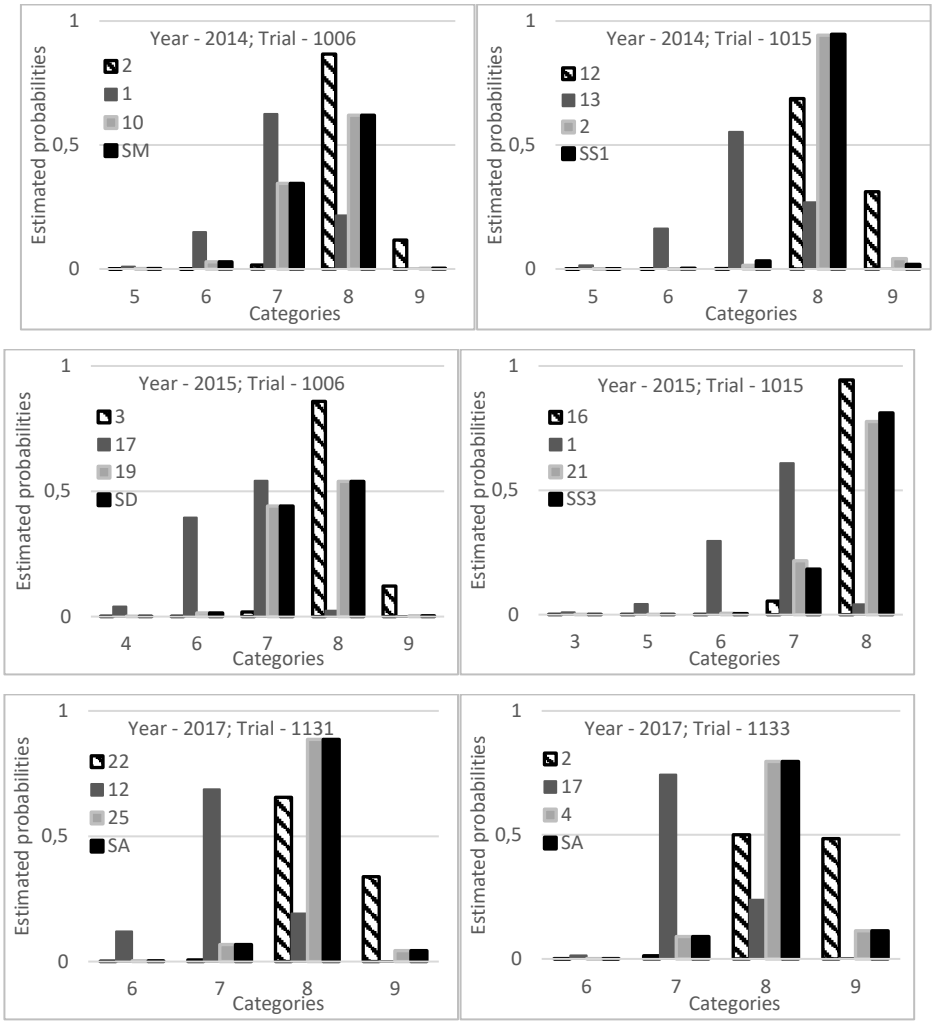


Figure 1. Estimated probabilities for some hybrids and standards in selected trials (the year and number of the trial are given in the legend)

than the probability for the same category in the case of the standard variety. For hybrid 1, having the lowest coefficient value (Table 2), the highest probability value occurred for category 7. The coefficient of hybrid 10 is equal to zero, indicating probabilities equal to those of the standard variety.

In experiment 1015 in 2014, it is seen that the probabilities for hybrid 2 (better than the standard, but not significantly) are almost identical to those of the standard, while the highest probabilities for hybrid 12 (significantly better) are

distributed between categories 8 and 9. The total probability for these categories is 0.998, compared with 0.965 for the standard, and thus hybrid 12 surpasses the standard.

In experiment 1006 in2015, the probability for the significantly better hybrid 3 was highest in category 8, while hybrid 19 had a coefficient equal to zero and probabilities similar to those of the standard variety (it did not differ significantly from the standard). Hybrid 17 had the greatest probability value for category 7, and it was shown to be significantly worse than the standard. Similar trends are seen in experiment 1015 in 2015, but category 9 did not occur in that trial. In 2017, the probabilities for hybrids with coefficients greater than the standard were greater than those of the standard in the last categories, while the probabilities of hybrids with coefficients lower than the standard were largest in category 7.

5. Conclusions and discussion

In this study, we have compared new hybrids in terms of Sclerotinia infection rated on a nine-point scale. Considering the successive selection of hybrids, this problem takes on great interest. In 2017 an increase in tolerance to the fungal disease Sclerotinia in new hybrids was observed, compared to 2014 and 2015. It should be noted that the intensity of Sclerotinia spores is not investigated in this study; therefore, although the results obtained may be interesting, they must be confirmed in further studies in more controlled conditions (for example, in a greenhouse). It is also shown that the applied statistical method, ordinal logistic analysis, can be used to analyze hybrids in terms of the presence of Sclerotinia. It is important to note that due to specific weather conditions Sclerotinia might not occur, for example, relating to humidity in May and June (Starzycka E. and Starzycki M., 2008) or temperature above 24 °C or below 7 °C (Bečka D. et al., 2016). Therefore, this disease did not occur in all of the studied locations every year. Kong et al. (2018) deal with the problem of detecting Sclerotinia stem rot on oilseed rape using chemometric methods. Different discriminant models are

applied to the data obtained by this method in order to select the best set of variables. They propose to use these variables in machine learning. The data set and algorithms obtained in this way can be used for quick detection of the disease. Similarly, Makowski et al. (2005) compare three rapid infection detection algorithms. Derbyshire and Denton-Giles (2016) write a review of current oilseed rape infection by Sclerotinia control practices and advances in these methods, and breeding methods for cultivars that tolerate this pathogen. Zhao et al. (2004) conclude that the proposed inoculation technique and sources of tolerance identified in their study can be used to determine inherited tolerance to Sclerotinia and to improve the tolerance of *B. napus* oilseed cultivars to this disease.

REFERENCES

Agresti A. (2002): Categorical Data Analysis. 3rd edition. John Wiley & Sons. ISBN 9780470463635.

Bečka D., Prokinová E., Šimka J., Cihlář P., Bečková L., Bokor P., & Vašák J. (2016): Use of petal test in early-flowering varieties of oilseed rape (Brassica napus L.) for predicting the infection pressure of Sclerotinia sclerotiorum (Lib.) de Bary. Crop Protection 80: 127–131.

Beszterda M., Nogala-Kałucka M. (2019): Current Research Developments on the Processing and Improvement of the Nutritional Quality of Rapeseed (*Brassica napus* L.). European Journal of Lipid Science and Technology 121(5): DOI: https://doi.org/10.1002/ejlt.201800045.

Chalhoub B., Denoeud F., Liu S.Y. et al. (2014): Early allopolyploid evolution in the post-Neolithic Brassica napus oilseed genome. Science 345(6199), 950–953. DOI: 10.1126/science.1253435.

Charlton K.M., Corner A.H., Davey K., Kramer J.K., Mahadevan S., Sauer F.D. (1975): Cardiac lesions in rats fed rapeseed oils. Canadian Journal of Comparative Medicine 39, 261–9.

Christensen R.H.B. (2022): "ordinal—Regression Models for Ordinal Data." R package version 2022.11-16. https://CRAN.R-project.org/package=ordinal

Derbyshire M. C., Denton-Giles M. (2016): The control of Sclerotinia stem rot on oilseed rape (Brassica napus): current practices and future opportunities. Plant Pathology 65: 859-877. DOI: https://doi.org/10.1111/ppa.12517

Ding L.N., Li T., Guo X.-J., Li M., Liu X.-Y., Cao J., Tan X.-L. (2021): Sclerotinia Stem Rot Resistance in Rapeseed: Recent Progress and Future Prospects. Journal of Agricultural and Food Chemistry 69(10): 2965–2978. DOI:10.1021/acs.jafc.0c07351

Koch S., Dunker S., Kleinhenz B., Rohrig M., von Tiedemann A. (2007): Crop loss-related forecasting model for Sclerotinia stem rot in winter oilseed rape. Phytopathology 97: 1186–1194.

Kong W., Zhang C., Cao F., Liu F., Luo S., Tang Y., He Y. (2018): Detection of *Sclerotinia* Stem Rot on Oilseed Rape (*Brassica napus* L.) Leaves Using Hyperspectral Imaging. Sensors (Basel) 18(6):1764. DOI: 10.3390/s18061764.

Krzymański J. (1968): Variation in thioglycosides in rapeseed meal (*Brassica napus*). Meeting of the Associate Committees of National Research Council in Plant Breeding. Winnipeg, Manitoba, Canada 20.02.1968.

Krzymański J. (1970): Genetyczne możliwości ulepszania składu chemicznego nasion rzepaku ozimego. Hodowla Roślin Aklimatyzacja i Nasiennictwo 14: 95-133.

Li Y.C., Chen J., Bennet R., Wallsgrove R., Huang Y.J., He Y.H. (1999): Breeding inheritance and biochemical studies on Brassica napus cv. Zhongyou 821: tolerance to Sclerotinia sclerotiorum (stem rot). 10th International Rapeseed Congress, Canberra Australia.

Makowski D., Taverne M. Bolomier J., Ducarneb M. (2005): Comparison of risk indicators for sclerotinia control in oilseed rape. Crop Protection 24(6): 527-531. DOI: https://doi.org/10.1016/j.cropro.2004.10.003

McCulloch C.E., Searle S.R. (2001): Generalized linear and mixed models. Wiley, New York.

Palti J. (1963): Sclerotinia sclerotiorum in Israel. Phytopathologia Mediterranea 2(2): 60–64.

Russo M., Yan F., Stier A., Klasen L., Honermeier B. (2021): Erucic acid concentration of rapeseed (*Brassica napus* L.) oils on the German food retail market. Food Science & Nutrition 9(7): 3664–3672. DOI: 10.1002/fsn3.2327.

Srivastava V.K., Philbrick D.J., Hill D.C. (1975): Response of rats and chicks to rapeseed meal subjected to different enzymatic treatments. Canadian Journal of Animal Science 55: 331-335.

Starzycka E., Starzycki M. (2008): Najważniejsze wyniki badań nad zgnilizną twardzikową w rzepaku przedstawione na XII Międzynarodowym Kongresie Rzepakowym w Wuhan. ROŚLINY OLEISTE – OILSEED CROPS. 29.

Stefansson B.R., Hougen F.W., Downey R.K. (1961): Note on the isolation of rape plants with seed oil free from erucic acid. Canadian Journal of Plant Science. 41(1): 218-219. DOI: https://doi.org/10.4141/cjps61-028

Zhao J., Peltier A.J., Meng J., Osborn T.C., Grau C.R. (2004): Evaluation of Sclerotinia Stem Rot Resistance in Oilseed Brassica napus Using a Petiole Inoculation Technique Under Greenhouse Conditions. Plant Dis. 88(9): 1033-1039. DOI: 10.1094/PDIS.2004.88.9.1033.