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Original paper

THE EFFICACY OF FUNGICIDES AGAINST *CERCOSPORA BETICOLA* IN FIELD CONDITIONS

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This study is focused on the evaluation of the efficacy of conventional fungicides against Cercospora leaf spot (CLS) on sugar beet. The results showed that the best protection against CLS was achieved by treatment with kresoxim-methyl + epoxiconazole (T1) and tetraconazole (T2). The second highest fungicide efficacy was detected after treatment with (kresoxim-methyl + epoxiconazole -T1) + difenoconazole -T2, followed by (azoxystrobin + cyproconazole) + difenoconazole, (prochloraz + propiconazole) + tetraconazole, *Urtica dioica* plant extracts + *Salix* spp. plant extracts, (trifloxystrobin + cyproconazole) + tetraconazole, and picoxystrobin + tetraconazole. The positive effect of fungicide protection on yield and sugar content was higher in the year with a higher occurrence of CLS. Good CLS management could increase the root yield by up to 19.34%, and sugar yield by up to 23.83% in comparison to the untreated check. The highest sugar yield was achieved in the treatment by (prochloraz + propiconazole) + tetraconazole, followed by (kresoxim-methyl + epoxiconazole) + difenoconazole, (azoxystrobin + cyproconazole) + difenoconazole, (trifloxystrobin + cyproconazole) + tetraconazole, picoxystrobin + tetraconazole, and *Urtica dioica* plant extracts + *Salix* spp. plant extracts. The results showed a strong relationship of root yield and sugar yield on fungicide treatment during the vegetation. The occurrence of fungicide resistance in *Cercospora beticola* population has an important impact on efficacy of applied fungicides in field conditions. The highest economic effectiveness coefficient was achieved at treatment by (prochloraz + propiconazole) + tetraconazole.

Key words: *Cercospora beticola*, fungicides, field, efficacy, yield

Sugar beet is an economically important crop in Europe. Cercospora leaf spot (CLS), caused by a phytopathogenic fungus *Cercospora beticola* Sacc. is one of the most important diseases of sugar beet. The CLS is very aggressive and can completely damage the sugar beet leaves under favourable conditions. Plants with damaged leaves produce new ones (retro-vegetation), however, it leads to a reduction of root yield by 25 – 50% (Shane & Teng 1992). The yield loss could achieve up to 40% of sugar yield (Balandžić *et al.* 2020). In Slovakia, sugar beet is growing mainly as a technical crop for sugar production. CLS has been reported from all sugar beets growing localities of Slovakia. Generally, the occurrence of CLS is mostly affected by weather conditions during the growing season. The damage depends even on the resistance of the genotype and provided agronomical measures, including sowing of fungicide-treated seeds, proper crop rotation, deep tillage, fertilisation, and weed protection. CLS harmfulness could be satisfactorily managed by fungicide-based programs using appropriate decision-support tools (Tedford *et al.* 2019). The use of fungicides is certainly necessary if sensitive or

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tolerant sugar beet hybrids are sown.

C. beticola is a pathogen that can quickly develop resistance to fungicides. The reduced sensitivity or resistance to fungicides is reflected in the lower effectiveness of fungicides to control the disease. The reduced sensitivity was recorded in almost all areas where CLS occurred. The uprising fungicidal resistance is related to the broad application of systemic fungicides. In Central Europe, fungicides to control CLS in sugar beet could be applied based on thresholds of disease incidence (Kaiser *et al.* 2010). CLS management includes the application of many groups of fungicides, mainly the sterol demethylase inhibitor (DMI), e.g., fungicides such as tetraconazole, difenoconazole, and prothioconazole (Bolton *et al.* 2012). The Integrated Pest Management model for sugar beet crops is aimed at the actual epidemic situation and important thresholds, which support the need and timing of fungicide applications (Wolf *et al.* 2001). The fungicide application schedules could increase the yield of recoverable white sugar (Tedford *et al.* 2019), up to 20.64% of root yield and 30.67% of sugar yield (Kristek *et al.* 2015). At high disease occurrence, resistant cultivars provided a higher yield compared to susceptible cultivars. Consequently, the time of fungicide spraying can be delayed for resistant cultivars. It could help to decrease the fungicides use as in demand for integrated pest management (Kaiser *et al.* 2010). Fungal populations continuously treated with fungicides tend to have lower sensitivity to used fungicides in comparison with populations from untreated fields. Repeated applications of fungicides favoured the selection of less susceptible strains of the pathogen. Since alternation of different fungicides not only maintains a high level of disease control but is also a very good anti-resistance strategy measurement (Karaoglanidis *et al.* 2001). Combinations or exchanging of no cross-resistance fungicides could be applied for disease control in locations where the reduced fungicide efficacy was recorded (Karaoglanidis & Thanassoulopoulos 2003). Trifloxystrobin or pyraclostrobin applications could prevent the increase of benzimidazole or DMI resistance of *C. beticola* in the field (Karadimos *et al.* 2005; Karaoglanidis & Bardas 2006). Karaoglanidis *et al.* (2001) approved that the incidence of *Cercospora beticola* resistant isolates decreased at the end of the vegetation period.

This study aimed to estimate the efficacy of different fungicides against CLS in field conditions in the Slovak Republic.

MATERIAL AND METHODS

Estimation of the efficacy of tested fungicides was carried out in a sugar beet field (cv. Natura) in the Nové Sady location, the southwestern region of Slovakia, in 2017 and 2018. The experiments were carried out in four repetitions by completely randomized block design. In the trials, each plot had 20.25 m^2, at six rows 7.5 m long with a distance between rows of 0.45 m. Rows and plants surrounding the experimental plots were untreated. The fungicides used in the experimental plots are described in Table 1. The crop maintenance as a fertilisation, herbicide and insecticide treatments were used uniformly in the whole trial according to local agronomical practice (Table 2). Treatments were replicated four times and treated in two application timings – T1 (16 July 2017 and 20 July 2018, BBCH 39) and T2 (8 August 2017 and 17 August 2018, BBCH 39). The fungicides were applied by using a motor backpack sprayer Solo 433 with four Tee-Jet 8002VS flat fan nozzles at a volume of 300 litres/ha.

Disease severity was assessed prior the day of T2 treatment and then in 21-28-day intervals after T2 treatment. At each time, the percentage of diseased leaf area (attacked by CLS lesions) was counted on 30 leaves in four small areas per treatment. The fungicide efficacy (FE) was calculated according to Fan *et al.* (2016):

FE = [(disease incidence of control plot − disease incidence of treated plot)/(disease incidence of control plot)] × 100%.

For yield evaluation, plants were removed by hand from three completely middle rows within each plot. At harvest, from each beet, the tops and small lateral roots were removed before measuring weight. After measuring the root weight, the representative samples (5 kg) of yield were separated for laboratory qualitative analysis. The samples were then processed on the automatic link analyse machine Venema Sugar Installations (VENEMA,

Table 1

Characteristics of field trial treatments, Nové Sady, 2017 and 2018

Treatment	Fungicide [Manufacturer]	Active ingredient [FRAC[1] group, FRAC code]	Dose [L/ha]	Application time
1	Untreated control	–	–	–
2	Amistar Xtra (Syngenta)	azoxystrobin 200 g/l (QoI[5], 11) + cyproconazole 80 g/l (DMI[6], 3)	0.75	T1[2], BBCH 39
	Score (Syngenta)	difenoconazole 250 g/l (DMI, 3)	0.4	T2[3], BBCH[4] 39
3	Juwel (BASF)	kresoxim-methyl 125 g/l (QoI, 11) + epoxiconazole 125 g/l (DMI, 3)	1.0	T1, BBCH 39
	Score (Syngenta)	difenoconazole 250 g/l (DMI, 3)	0.4	T2, BBCH 39
4	Sfera 535 SC (Bayer)	trifloxystrobin 375 g/l (QoI, 11) + cyproconazole 160 g/l (DMI, 3)	0.4	T1, BBCH 39
	Eminent 125 ME (ISAGRO)	tetraconazole 125 g/l (DMI, 3)	0.8	T2, BBCH 39
5	Bumper Super (Adama)	prochloraz 400 g/l (DMI, 3) + propiconazole 90 g/l (DMI, 3)	0.75	T1, BBCH 39
	Eminent 125 ME (ISAGRO)	tetraconazole 125 g/l (DMI, 3)	0.8	T2, BBCH 39
6	Acanto (Du Pont)	picoxystrobin 250 g/l (QoI, 11)	1.0	T1, BBCH 39
	Eminent 125 ME (ISAGRO)	tetraconazole 125 g/l (DMI, 3)	0.8	T2, BBCH 39
7	Juwel (BASF)	kresoxim-methyl 125 g/l (QoI, 11) + epoxiconazole 125 g/l (DMI, 3)	1.0	T1, BBCH 39
	Eminent 125 ME (ISAGRO)	tetraconazole 125 g/l (DMI, 3)	0.8	T2, BBCH 39
8	Plan Tonic (Attend SA)	plant extracts (PC[7], *Salix* spp., *Urtica dioica*)	1.0	T1, BBCH 39
	Plan Tonic (Attend SA)	plant extracts (PC[7], *Salix* spp., *Urtica dioica*)	1.0	T2, BBCH 39

Note: [1]FRAC – Fungicide Resistance Action Committee (https://www.frac.info/); [2]T1 – application No. 1; [3]T2 – application No. 2; [4]BBCH – growth stages according to BBCH scale; [5]QoI – quinone outside inhibitors; [6]DMI – demethylation inhibitors; [7]PC – plant conditioner, activator of natural plant resistance.

Netherlands), for estimation of sugar content [%], and yield of polarised sugar [t/ha], which was calculated as follows:

$$Yps\ [t/ha] = (Y \times Dg) / 100$$

where: Yps – yield of polarized sugar [t/ha]; Y – yield of beet roots [t/ha]; Dg – digestion, estimated by laboratory analysis [°S].

All data were used for the analysis of variance (ANOVA) by using Fisher's *LSD* test ($p = 0.05$).

The economic effectiveness of fungicide application is defined as a relation between the achieved increase of yield caused by treatment by various doses of fungicides, and the increase of costs spent by fungicide application. The calculation of the economic effectiveness coefficient (C_{EE}) of fungicide application was as follows:

$$C_{EE} = P/N$$

where: P – the yield increase caused by fungicide treatment [Eur]; N – cost increases caused by fungicide treatment [Eur].

RESULTS AND DISCUSSION

The T1 application was carried out on 16 July 2017, and the first assessment of fungicide efficacy was conducted after three weeks (on 8 August 2017). The disease severity in the untreated control reached

T a b l e 2

Characteristics of growing measures and maintenance of sugar beet trial plots, Nové Sady locality

Maintenance	2017	2018
Cultivar	Natura	Natura
Previous crops	Winter wheat, corn, sugar beet	Winter wheat, alfalfa, alfalfa
Sowing date	22 March 2017	7 April 2018
Sowing depth	0.03 – 0.04 m	0.03 – 0.04 m
Number of seeds/ha	1.3 U/ha[1]	1.3 U/ha
Number of seeds/ 1m of row	6 ± 1	6±1
Emergence date	20 April 2017	26 April 2018
Row spacing	0.45 m	0.45 m
Spacing within row	0.17 – 0.20 m	0.17 – 0.20 m
Plant density	14 ± 1 pcs/m^2	14 ± 1 pcs/m
Basic fertilisation	16 March 2017 Amofos (100 kg/ha) + Urea (100 kg/ha)	29 March 2018 Urea (170 kg/ha)
Soil cultivation	22 March 2017	04 April 2018
Sowing	22 March 2017	05 April 2018
Herbicide treatment	08 April 2017 Betasana (2.5) + Ethosat (0.3) + Beetup Compact (0.8) + Betix (1.0 L/ha)	16 April 2018 Beetup Compact (0.5) + Betasana (2.5) + Oblix (0.2) + Pyramin Turbo (1.0) + Trend (0.2 L/ha)
Herbicide treatment	22 April 2017 Betasana SC (2.5) + Ethofol (0.3) + Beetup Compact (0.8) + Safari (1.0) + Trend (0.1 L/ha)	24 April 2018 Beetup Compact (1.0) + Betasana SC (2.5) + Safari (30 g/ha) + Oblix (1.25) + Trend (0.2 L/ha)
Herbicide treatment	03 May 2017 Betasana (2.0) + Ethosat (0.3) + Beetup Compact (1.0 L/ha) + Safari 50 WG (30 g/ha) + Trend (0.1 L/ha)	04 May 2018 Betanal MaxPro (1.5) + Beetup Compact (0.2) + Safari 50 WG (30 g/ha) + Asahi (0.2 L/ha)
Herbicide treatment	16 May 2017 Beetup Kompakt (1.5 L/ha) + Safari (30 g/ha) + Trend (0.1) + Asahi (0.2 L/ha)	–
Fertilisation	01 June 2017 Ammonium nitrate, 100 kg/ha	17 May 2018 Ensin (102 kg/ha)
Insecticide treatment	21 June 2017 Nurelle D (0.6 kg/ha)	18 June 2018 Nurelle D (0.6) + AT Mikro (2.0 L/ha)
Fertilisation	28 July 2017 Boron (3.0) + NPK[3] Mikro (5.0 L/ha)	–
Fertilisation	25 August 2017 NPK mikro (5.0) + K-500 (2.2 L/ha)	–
Harvest	28 September 2017, by hand	22 September 2018, by hand
Note: [1]U/ha – units per hectare; [2]pcs/m – pieces per meter; [3]NPK – nitrogen + phosphorus + potassium fertiliser.		

a level of 8.63% of the leaf area attacked. The results of the first assessment are shown in Table 3. The second fungicide treatment (T2) was performed on 8 August 2017 and the next assessment was conducted after four weeks (on 4 September 2017). The disease severity increased to 22.63% during August in the untreated control, due to higher precipitation and temperature than the long-term average (Table 6 and 7). Achieved FE varied between 41.31 – 68.73% after the T1 application and from 45.07 to 65.32% after the T2 application. In general, for CLS control, fungicide-based programs using an appropriate decision support tool can be used. In case of high disease severity, the classical application schedule

can reduce the disease occurrence by 84% (Tedford *et al.* 2019), which is similar to our results.

The comparison of tested fungicides after T1 application showed that the highest fungicide efficacy was achieved by Juwel in treatments No. 7 (68.73 %) and No. 3 (66.60%). The fungicide efficacy of other treatments varied between 41 and 48%. The assessments carried out after the T2 application reflected the efficacy of both the treatments – T1 and T2. The highest fungicide efficacy was recorded in treatment No. 2 (Amistar Xtra + Score) – 65.32% and in treatment No. 4 (Sfera 535 SC + Eminent 125 ME) – 64.65%. The good efficacy of trifloxystrobin + cyproconazole (Sfera 535 SC) was mentioned in the work of Karaoglanidis and Bardas (2006) who proved that satisfactory protection against CLS was provided by the treatment of trifloxystrobin at low concentrations. Results of laboratory experiments concerning a low sensitivity of *C. beticola* to certain fungicides usually do not correlate with field experiments, e.g. by fungicide Score (Karaoglanidis & Bardas 2006). The finding of these authors was also confirmed in our field experiments, where the fungicide Score achieved a good level of fungicide efficacy. Difenoconazole is characterised by high anti-sporulation activity by preventive application (Anesiadis *et al*. 2003). It is not fully in agreement with Karaoglanidis and Bardas (2006) who found–that difenoconazole (Score) provided only a moderate control efficacy against CLS.

The lowest efficacy after both treatments was recorded at treatments No. 6 (Acanto + Eminent 125 ME) and No. 8 (Plan Tonic + Plan Tonic). It corresponds with our previous findings (Hudec *et al.* 2020) where picoxystrobin (included in the preparation Acanto) reached a low inhibition effect on the mycelial growth of *C. beticola* in laboratory conditions. Bolton *et al.* (2012) compared the laboratory and field efficacy of tetraconazole. *In vitro* testing for fungicide sensitivity was performed with

T a b l e 3

The efficacy of tested fungicides against Cercospora leaf spot and yield parameters in 2017

Treatment	Fungicide	Dose [L/ha]	Application time	Yield [kg/treatment][1]	Sugar content [%][1]	Fungicide efficacy [%][1,2]	Sugar yield [t/ha][1]
1	Untreated control	–	–	86.00[a]	15.78[a]	–	10.28[a]
2	Amistar Xtra Score	0.75 0.40	T1 T2	84.90[a]	15.87[a]	46.72[a] 65.32[a]	10.21[a]
3	Juwel Score	1.00 0.40	T1 T2	85.50[a]	15.66[a]	66.6[a] 58.03[a]	10.14[a]
4	Sfera 535 SC Eminent 125 ME	0.40 0.80	T1 T2	88.80[b]	15.85[a]	47.88[a] 64.65[a]	10.66[a]
5	Bumper Super Eminent 125 ME	0.75 0.80	T1 T2	85.90[a]	15.83[a]	43.82[a] 54.86[a]	10.30[a]
6	Acanto Eminent 125 ME	1.00 0.80	T1 T2	88.40[b]	15.80[a]	41.31[a] 45.07[a]	10.58[a]
7	Juwel Eminent 125 ME	1.00 0.80	T1 T2	91.90[b]	15.77[a]	68.73[a] 61.05[a]	10.98[a]
8	PlanTonic PlanTonic	1.00 1.00	T1 T2	82.50[a]	15.76[a]	41.51[a] 43.67[a]	9.85[a]

Note: [1]Different letters in the same column indicated that the values were significantly different ($P \leq 0.05$) according to ANOVA (Analysis of variance), and Fisher's *LSD* (least significant difference) test.
[2]Evaluation of fungicide efficacy was carried out on 8 August 2017 (the day of T2 treatment) and 4 September 2017 (21-28-day intervals after T2 treatment).

T a b l e 4

The efficacy of tested fungicides against Cercospora leaf spot and yield parameters in 2018

Treatment	Fungicides	Dose [L/ha]	Application term	Yield [kg/treatment][1]	Sugar content [%][1]	Fungicide efficacy [%][1,2]	Sugar yield [t/ha][1]
1	Untreated control	–	–	98.40^{a}	15.72^{a2}	–	11.71^{a}
2	Amistar Xtra	0.75	T1	111.30^{b}	16.06^{a}	67.19^{d}	13.54^{b}
	Score	0.40	T2			15.92^{c}	
3	Juwel	1.00	T1	112.30^{b}	16.02^{a}	70.53^{d}	13.63^{b}
	Score	0.40	T2			29.29^{d}	
4	Sfera 535 SC	0.40	T1	105.90^{a}	16.27^{a}	56.14^{c}	13.05^{b}
	Eminent 125 ME	0.80	T2			−0.96^{a}	
5	Bumper Super	0.75	T1	117.40^{b}	16.31^{a}	70.53^{d}	14.50^{b}
	Eminent 125 ME	0.80	T2			18.63^{d}	
6	Acanto	1.00	T1	108.10^{b}	15.82^{a}	27.89^{b}	12.95^{b}
	Eminent 125 ME	0.80	T2			4.29^{b}	
7	Juwel	1.00	T1	98.00^{a}	16.23^{a}	79.30^{c}	12.05^{b}
	Eminent 125 ME	0.80	T2			35.98^{c}	
8	PlanTonic	1.00	T1	109.00^{b}	16.07^{a}	63.68^{d}	13.27^{b}
	PlanTonic	1.00	T2			24.52^{c}	

Note: [1]Different letters in the same column indicated that the values were significantly different ($P \leq 0.05$) according to ANOVA (Analysis of variance), Fisher's *LSD* (least significant difference) test.
[2]Evaluation of fungicide efficacy was carried out on 17 August 2018 (the day of T2 treatment) and 11 September 2018 (21-28 days intervals after T2 treatment).

the active ingredient of the commercial fungicide. They showed that the loss of disease control was at the same level for tetraconazole as for the original product Eminent. The authors present that the less sensitive isolate could cause higher disease occurrence in plants sprayed by tetraconazole (Eminent), but disease severity was not different between plants which were inoculated and non-inoculated with more sensitive isolate (Bolton *et al.* 2012).

Fungicide treatment in 2017 led to an increase in root yield (up to 3%) and yield of sugar (up to 6.8%). The highest yield of sugar in 2017 was recorded for treatment No. 7 (Juwel + Eminent 125 ME) 10.98 t/ha, followed by treatment No. 4 (Sfera 535 SC + Eminent 125 ME) 10.66 t/ha. Despite the low fungicide efficacy of Acanto against CLS, the yield of sugar was in the third position from the top. The lowest yield of sugar was recorded by treatment No. 8 (Plan Tonic + Plan Tonic) at 9.85 t/ha; which corresponds with its low fungicide efficacy. In 2017, the difference in sugar yield and sugar content among the untreated control and other treatments was not statistically significant.

The most effective treatments in terms of average fungicide efficacy (of T1 and T2 treatment) against CLS in 2017 can be arranged in descending order (Figure 1): No. 7 (Juwel + Eminent 125 ME), No. 3 (Juwel + Score), No. 4 (Sfera 535 SC + Eminent 125 ME), No. 2 (Amistar Xtra + Score), No. 5 (Bumper Super + Eminent 125 ME), No. 6 (Acanto + Eminent 125 ME), and No. 8 (Plan Tonic + Plan Tonic).

In 2018, at the time of the first treatment, the severity of the disease reached 9.50% of the leaf area. The infestation increased to the end of August to a level of 52.33% of the leaf area in the untreated control, due to higher precipitation and temperature than the long-term average (Tables 6 and 7). The FE reported in 2018 (Table 4) varied between 27.89 and 79.3% after the T1 application and from 0.96 to 35.98% after the T2 application. Lower FE after the T2 application was caused by higher infection

pressure of CLS after T2 application. After the T1 application, significantly higher FE was recorded in treatment No. 7, followed by treatments No. 3, 5, 2, and No. 8. Significantly lower FE was measured in treatment No. 6 (Acanto).

After the T2 application, a significantly higher FE was recorded for treatment No. 7 again, but the lowest FE was recorded for treatments No. 6 (Acanto + Eminent 125 ME) and No. 4. (Sfera 535 SC + Eminent 125 ME). The low FE of tetraconazole (Eminent) could be influenced by the different sensitivity of *C. beticola* strains to this fungicide (Bolton *et al.* 2012).

T a b l e 5

The economic effectiveness of fungicide treatments in field experiments, 2017 and 2018

Fungicide [T1][1]	Price[3]	Fungicide [T2][2]	Price[3]	C_{EE}[4] 2017	C_{EE}[4] 2018	Ø C_{EE}[5]
Amistar Xtra	65.30	Score	143.14	–0.32	6.92	3.30
Juwel	62.69	Score	143.14	–0.57	6.43	2.93
Sfera 525 SC	136.66	Eminent 125 ME	48.52	2.00	5.76	3.88
Bumper Super	38.00	Eminent 125 ME	48.52	0.15	16.64	8.39
Acanto	51.93	Eminent 125 ME	48.52	1.62	5.49	3.55
Juwel	62.69	Eminent 125 ME	48.52	3.39	1.34	2.37
PlanTonic	12.48	Plan Tonic	12.48	–8.46	21.55	6.55

Note: [1]Fungicide applied in T1 term of application.; [2]Fungicide applied in T2 term of application; [3]Actual price of fungicide Eur/liter-kg-package (Meravá, 2018); [4]C_{EE} – economic effectiveness coefficient (calculated from average price of sugar in years 2017 and 2018 (Meravá, 2018); [5] Ø C_{EE} – average value of economic effectiveness coefficient from years 2017 and 2018.

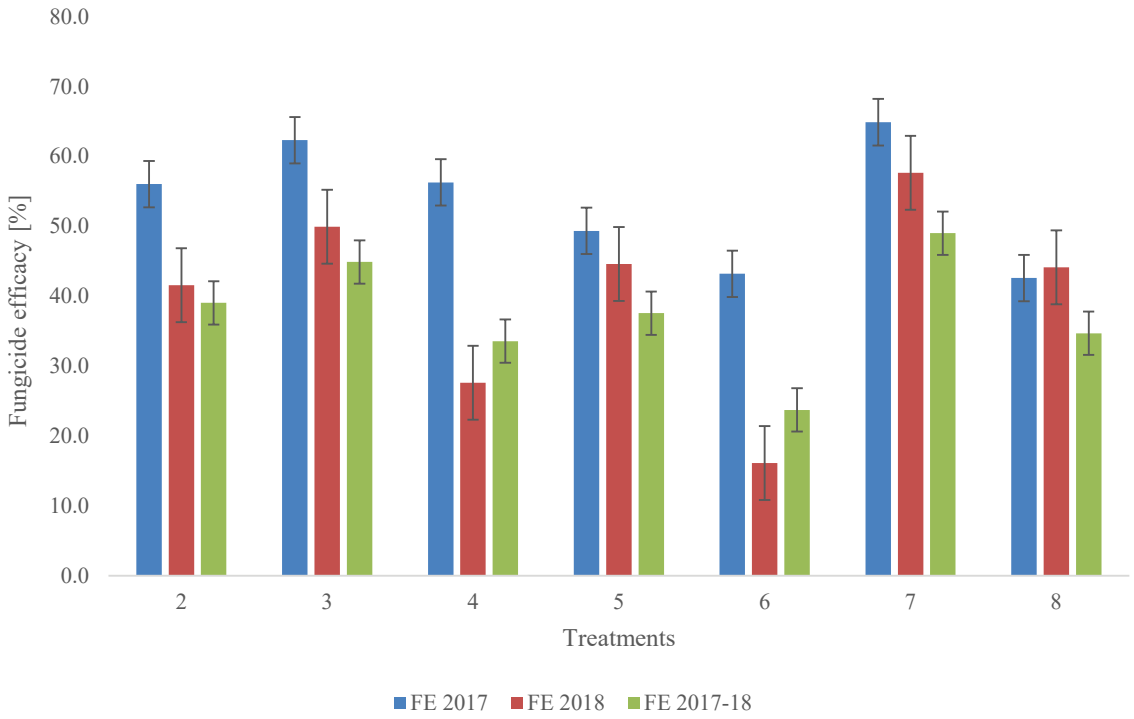


Figure 1. Average fungicide efficacy (of T1 and T2 treatment).
Note: FE 2017 – in 2017, FE 2018 – in 2018, FE 2017–18 – average of 2017 and 2018
Treatment No 2: Amistar Xtra + Score; 3: Juwel + Score; 4: Sfera 535 SC + Eminent 125 ME; 5: Bumper Super + Eminent 125 ME; 6: Acanto + Eminent 125 ME; 7: Juwel + Eminent 125 ME; 8: Plan Tonic + Plan Tonic.

T a b l e 6

The sum of monthly rainfall in 2017 and 2018

Year	Precipitation [mm]					
	April	May	June	July	August	September
2017	42.8	12.4	23.6	31.5	72.3	48.0
2018	12.3	24.8	109.0	43.1	87.3	55.3
Long-term average	39.0	61.0	66.0	52.0	61.0	40.0

T a b l e 7

The average monthly temperatures in 2017 and 2018

Year	Average monthly temperature [°C]					
	April	May	June	July	August	September
2017	9.8	17.1	21.9	22.3	19.8	17.7
2018	16.0	19.3	21.0	22.1	22.3	18.6
Long-term average	10.1	15.2	17.9	19.8	18.9	16.1

Fungicide treatment in 2018 resulted in an increase in root yield (up to 19.34%) and yield of sugar (up to 23.83%). The yield of sugar was significantly higher in all treatments in comparison with the untreated control in 2018. The highest yield of sugar beet roots was achieved by treatment No. 5 (117.40 kg), where the sugar content was the highest (16.31%), too. The lowest yield of roots was measured in treatment No. 7, and the lowest sugar content in treatment No. 1 – untreated control. The fungicide applications in 2018 had a positive influence on sugar content in all treatments (Table 4). It is in agreement with the results of Kristek *et al.* (2006), who claimed that fungicide application leads to an increase of root yield by 11.07 t/ha (14.8%), sugar content by 1.00% (relative 7.1%) and white sugar yield by 2.08 t/ha (23.0%) in comparison with untreated check. The highest sugar yield was recorded in treatment No. 5 (Bumper Super + Eminent 125 ME) at 14.50 t/ha, which is in agreement with the results of Tedford *et al.* (2019).

The average FE of T1 and T2 applications in 2018 are shown in Figure 1. The highest FE was achieved in treatment No. 7 (Juwel + Eminent 125 ME) as of 2017, followed by treatments No. 3 (Juwel + Score), No. 5 (Bumper Super + Eminent 125 ME), No. 8 (Plan Tonic + Plan Tonic), No. 2 (Amistar Xtra + Score), No. 4 (Sfera 535 SC + Eminent 125 ME), and No. 6 (Acanto + Eminent 125 ME).

The average FE for both treatments and both years is outlined in Figure 1. The results obtained here showed that treatment No. 7 – Juwel (T1) + Eminent 125 ME (T2) achieved the highest FE against CLS. According to the FRAC, the fungicides epoxiconazole and tetraconazole (DMi) belong to the group of active ingredients with a middle risk of resistance development. DMI fungicides are broadly used in the fungicide treatment of sugar beet against CLS. While FRAC considers the DMi fungicides (e.g., tetraconazole) as a middle-risk group of resistance development, other authors found an increase in less susceptible strains of *C. beticola* in the field (Hudec *et al.* 2020). *Cercospora beticola* isolates originated from treated plots are usually less sensitive to the fungicides than those that originated from untreated plots. However, the resistant sugar beet cultivars are not able to eliminate the resistant strains of *C. beticola*, it could decrease the occurrence of all isolates (Karaoglanidis *et al.* 2003). Bolton *et al.* (2012) confirmed the increase of EC_{50} values to the tetraconazole for *C. beticola* in the USA.

The second highest FE was measured in treatment No. 3 (Juwel + Score), followed by treatments No. 2 (Amistar Xtra + Score), No. 5 (Bumper Super + Eminent 125 ME), No. 8 (Plan Tonic + Plan Tonic), and No. 4 (Sfera 535 SC + Eminent 125 ME). Treatment No. 6 – Acanto + Eminent 125 ME achieved the lowest FE in the two-year average. Karaoglanidis *et al.* (2003) found that 60% of *C. beticola* isolates were resistant to the difenoconazole (Score). It could be caused by the fact that the application of difenoconazole might potentially lead to the selection of high frequencies of DMI-resistant strains (Karaoglanidis & Bardas 2006). With the increased use of tetraconazole in agricultural practice, the prevalence of resistant strains of *C. beticola* has recently increased (Bolton *et al.* 2012). Karaoglanidis *et al.* (2001) mentioned that towards the end of the vegetation, the occurrence of the resistant isolates decreased. Multi applications of the same fungicides, by using full or reduced doses, usually lead to the selection of resistant strains of *C. beticola* (Karaoglanidis *et al.* 2001). The fungicide efficacy is usually higher by preventive treatment, especially for trifloxystrobin, difenoconazole, and epoxiconazole (El Housni *et al.* 2023). For better CLS management, the using of tank-mixes of different fungicides is needed (Khan & Smith 2005). Therefore, the combination of knowledge about certain fungicide efficacy and pathogen biology is very important for creating fungicide resistance management strategies and successful management of Cercospora leaf spot (Rosenzweig *et al.* 2020).

The highest sugar yield (Figure 2) was recorded in treatment No. 5 (Bumper Super + Eminent 125 ME) 12.40 t/ha, followed by treatments No. 3 (Juwel + Score), No. 2 (Amistar Xtra + Score), No. 4 (Sfera 535 SC + Eminent 125 ME), No. 6 (Acanto + Eminent 125 ME) and No. 8 (Plan Tonic + Plan Tonic). The lowest sugar yield was recorded in the untreated control. The results showed the relationship between yield and leaf protection against CLS during the vegetation period. Our results are in agreement with the findings of Kristek *et al.* (2015), who found out, that leaf damage caused by CLS in untreated check is in relation with fungicide treated variants. The yield of roots could be increased by 15.92 t/ha (20.64%), sugar content by 1.61% (rel. 10.37%) and white sugar yield by 3.07 t/ha (30.67%) (Kristek *et al.* 2015). The fungicide application could increase the content of sucrose and white sugar. Therefore, the fungicide application recommendations advice shortening the spraying interval, but this does not necessarily lead to higher sucrose yield (Tedford *et al.* 2019).

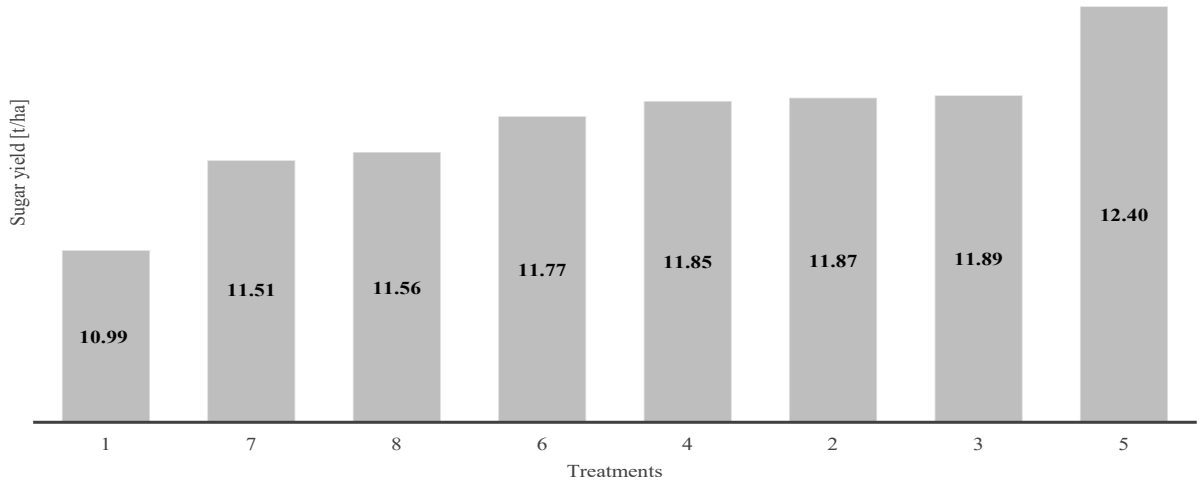


Figure 2. Average sugar yield for years 2017 – 2018.
Note: [1]Treatment No 1: Untreated check; 2: Amistar Xtra + Score; 3: Juwel + Score; 4: Sfera 535 SC + Eminent 125 ME; 5: Bumper Super + Eminent 125 ME; 6: Acanto + Eminent 125 ME; 7: Juwel + Eminent 125 ME; 8: Plan Tonic + Plan Tonic

In our previous works (Hudec *et al.* 2020; Hudec *et al.* 2022), the lowest occurrence of resistant strains of *C. beticola* was recorded after treatments with Juwel and Eminent. It strongly corresponds with the results of the field experiment, where this combination achieved the highest FE. On the contrary, in laboratory tests, the fungicide Score demonstrated the lowest inhibition effect on the mycelial growth of *C. beticola* and resulted in total strain resistance (Hudec *et al.* 2020). In the field experiment, the treatment of Score + Juwel achieved the second-highest FE. It could be caused by using a combination with the fungicide Juwel, which resulted in a very low resistance in *C. beticola* strains monitoring. In laboratory experiments, the highest inhibition effect on *C. beticola* mycelium growth was found after using Eminent 125 ME and Bumper Super (Hudec *et al.* 2020). It strongly corresponds with the field experiment, where the highest yield of sugar was achieved even with this combination. Based on the comparison of these results we can confirm that the occurrence of fungicide resistance in *C. beticola* population has a substantial impact on FE in field conditions. The relationship between coefficients of virulence and the production of *C. beticola* spores indicates that the level of resistance to DMI fungicides affected the fitness of the resistant strains (Karaoglanidis *et al.* 2001). Reduction of the number of fungicide spraying by DMI fungicides and their use only by favourable weather conditions for CLS development is an appropriate strategy for effective resistance management (Karaoglanidis *et al.* 2003).

The calculation of the economic effectiveness coefficient (CEE) of certain treatments is shown in Table 5. The highest CEE was achieved by using Bumper Super + Eminent 125 ME, followed by Plan Tonic + Plan Tonic. The CEE of the following treatments was lower or similar to each other: Sfera 525 SC + Eminent 125 ME, Acanto + Eminent 125 ME, Amistar Xtra + Score, Juwel + Score, and Juwel + Eminent 125 ME.

CONCLUSIONS

The presented study showed the results of a 2-year field trial focused on the effectiveness of fungicide control of sugar beet against *Cercospora beticola* and its impact on the yield of crop and quality. The infection pressure of Cercospora leaf spot (CLS), expressed as leaf area attacked, was higher in 2018, both in the time of T1 application (2017 – 8.63% of, 2018 – 9.50%) and T2 application (2017 – 22.63%, 2018 – 52.33%). An average fungicide efficacy (FE) was higher after T1 treatment (27.89 – 79.3%) than after T2 treatment (0.96 – 65.32%), because of the increasing CLS severity in August. In the year with higher infection pressure of CLS, the FE was lower. Despite the year and weather specification, the average fungicide efficacy for both treatments and both years showed, that the treatment of Juwel (T1) + Eminent 125 ME (T2) achieved the highest FE. The second highest FE was measured in the treatment by Juwel + Score, followed by Amistar Xtra + Score, Bumper Super + Eminent 125 ME, Plan Tonic + Plan Tonic, and Sfera 535 SC + Eminent 125 ME. The treatment by Acanto + Eminent 125 ME achieved the lowest FE in the two-year average. The positive effect of fungicide treatment on root yield and sugar yield was higher in the year with higher occurrence and severity of CLS. The appropriate fungicide treatment of sugar beet can save root yield by up to 19.34%, and sugar yield by up to 23.83% in comparison to the untreated control. The highest sugar yield was recorded in the treatment of Bumper Super + Eminent 125 ME, followed by Juwel + Score, Amistar Xtra + Score, Sfera 535 SC + Eminent 125 ME, Acanto + Eminent 125 ME, and Plan Tonic + Plan Tonic. The highest CEE was recorded by using Bumper Super + Eminent 125 ME, followed by Plan Tonic + Plan Tonic. The results obtained during this experiment showed a demand to continue with the fungicidal resistance monitoring of *C. beticola* in Slovakia, concerning anti-resistance strategy in field conditions. Reduction of the number of fungicide spraying and their use only by favourable weather conditions for CLS development is an appropriate strategy for effective resistance management.

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