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Evaluation of different potato cultivars and fungicide combinations for potato late blight (*Phytophthora infestans*) control in central part of Romania

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ABSTRACT

National Institute of Research and Development for Potato and Sugar Beet Brasov is working constantly to create new potato cultivars adapted to changing climatic conditions, with high yield and resistance to diseases, suitable to the quantitative and qualitative demands of consumers. Field experiments were carried out in the years 2018 - 2019 using a complete randomized block design with four replicates. Planting was made on 19 April 2018 and on 4 April 2019. In all cases, cultivation and maintenance was in line with current good agricultural practice. Eight Romanian potato cultivars ('Castrum', 'Sarmis', 'Marvis', 'Braşovia', 'Sevastia', 'Christian', 'Asinaria' and 'Cezarina') were examined regarding the foliage and tuber susceptibility to late blight and the disease development during the season. Late blight appeared on July 3, 2018, relatively late compared to previous years. The significant quantities of rainfall and the favourable temperatures of June, when an average of 18.1°C was recorded, provided the necessary conditions for the onset of the late blight epidemic. In 2019 the first late blight spots were observed very early, on May 30 to the 'Brasovia' cv. The relatively high volume of rainfall in May and June, together with the optimum temperatures, led, in addition to the development of plants, to the attack of foliar diseases, whose control was relatively difficult. In 2018, 'Christian' cultivar showed the lowest level of foliage resistance, followed by 'Brasovia', 'Castrum' and 'Sarmis' cultivars presented a medium level of resistance. The cultivars 'Sevastia', 'Asinaria' and 'Marvis' were situated towards the upper limit of the resistance. In 2019 from the studied cultivars, 'Asinaria' and 'Cezarina' have the lowest attack level, followed by 'Braşovia', 'Castrum' and 'Sarmis. Sevastia, 'Marvis' and 'Christian' cultivars were the most susceptible to late blight.

Keywords*:* potato, late blight (*Phytophthora infestans*), fungicides, cultivars, yield

INTRODUCTION

Regarding potato diseases by far the most destructive one is late blight caused by *Phytophthora infestans.* The disease has reached epidemic proportions in Europe, Russia and North America, due to the development of resistance to phenylamide fungicides in the populations of the pathogen and the widespread occurrence of new genotypes (Deahl *et al.,* 1991; Fry *et al.,* 1997). Late blight is considered a re-emerging disease encouraged by the increasing globalization of trade and climatic change (Servici *et al.,* 2017).

Despite the considerable amount of knowledge that has been accumulated about this disease, late blight continues to be one of the main limiting factors for potato production in the world. If the disease is not controlled, losses can reach 100%. Even with low infection levels, the crop may be unsuitable for storage (Fernandez *et al.,* 2000). Over the years the role of fungicides in controlling potato late blight increased and now, spraying is a normal and routinely practice all over the world. In Europe in years with severe blight attacks, in some countries up to 25 sprays were used per season (Hansen, 2009). Nearly $ 4 billion is invested in the control of this pathogen (Judelson and Blanco, 2005; Haldar *et al.,* 2006) and around € 9 billion per year is associated with production losses of these crops (Haverkort *et al.,* 2016; Lucca *et al.,* 2019). Fungicides have a negative impact on the environment due to the pollution of groundwater, energy costs for application and negative effects on human health (Haverkort *et al.*, 2008; Pacilly, 2018). Chemical control of this disease is still playing a vital role in potato production as resistant cultivars are being less available. Fungicides encourage the development of resistance in *Phytophthora infestans* and the pathogen requires higher doses of fungicides in controlling the disease, which disturbs the cost benefit ratio and environment.

If weather conditions are the essential elements of epidemic development, it is imperative to take into account the evolution of the pathogen. For several years new strains have evolved (Duvauchelle and Ruccia, 2015).

The study of the effects of climatic conditions and their influence on potato production is becoming more and more important as regards the adaptogenic capacity of the plants to environmental conditions (Rosenzweig *et al.,* 2002; Rymiza *et al.,* 2015). Survival of *P. infestans* inoculum in order to initiate epidemic can be reduced through avoidance of introducing late blight into a field by planting only disease-free seed tubers, preferably certified, destroying all cull and volunteer potatoes, avoid frequent or night-time overhead irrigation and good soil coverage (Draper *et al.,* 1994). The main cultivars grown in Romania are susceptible to late blight, especially on foliage. Disease control requires regular application of fungicides at high rates and short intervals throughout the growing season. To obtain this information it is necessary to test the efficacy of all new fungicides to control disease in the presence of the new isolates of *P. infestans*.

MATERIALS AND METHODS

Trial was performed in the experimental field of the Technology and Good Agricultural Practice Laboratory at the National Institute for Research and Development for Potato and Sugar Beet Brasov. The experimental design was a randomized block with a factorial arrangement. The treatments were replicated three times. The plot size was 3.0 m × 8.4 m with 0.75 m and 0.3 m between rows and plants respectively. The experiment included two factors: potato cultivars and fungicides. The same eight Romanian potato cultivars created to NIRDPSB Brasov were planted in both years: 'Christian', 'Marvis', 'Sarmis', 'Sevastia', 'Cezarina', 'Castrum', 'Brasovia' and 'Asinaria'. Planting was made in 19 April 2018 and in 4 April 2019. In all cases, cultivation and maintenance was in line with current good agricultural practice. In 2018 the first treatment was with Lieto (0.45 kg/ha) on 5 June, followed by Ridomil Gold Mz 68 WG (2.5 kg/ha) on19 June and 13 July, continued with Consento 450 SC (2.0 l/ha) on 3 July, Infinito 687,5 SL (1.4 l/ha) on 23 July, Drago 76 WP (2.0 kg/ha) on 31 July, Acrobat Mz (2.0 kg/ha) on7 August and lastly with Banjo 500 SC (0.4 l/ha) on 20 August. In 2019 the first treatment was with Polyram DF (1.8 kg/ha) on 29 May, followed by Infinito 687,5 SL (1.4 l/ha) on 7 June, Ridomil Gold Mz 68 WG (2.5 kg/ha) on 13 June, Equation Pro (0.4 kg/ha) on 24 June, Consento 450 SC SC (2.0 l/ha) on 3 July, Bravo 500 SC (2.0 l/ha) on 22 July, Carial Star 250g/l (0.6 l/ha) on 30 July and lastly with Shirlan

500 SC (0.4 l/ha) on 7 August. Each fungicide was applied using a manually-pumped knapsack sprayer of 10-liter capacity.
Plots were assessed for the extent of blight spots on the leaves. Disease severity was scored as follows 1: None or very few lesions on the leaflets (0% foliage affected), 2: (3% foliage affected), 3: (10% foliage affected), 4: (25% foliage affected),5: (50% foliage affected), 6: (More than 50% but less than 75% stem and foliage affected), 7: More than 75% but less than 90% affected), 8: Only very few green areas of stem and leaf (much less 10%) and 9: 100% foliage destroyed. Each plot is assessed as a whole for percentage disease severity using a standard accepted severity key. (Anonymous, 1947; Cruickshank, 1982). Harvest observations (17 September 2018 and 16 September 2019) mentioned the number and the weight of tubers with blight and yield. The produce was hand-picked and stored at a temperature of over 10^0C for two weeks to allow tuber blight symptoms to develop. The tubers was graded into the following grades: < 35 mm, 35-60 mm, > 60 mm, blighted tubers and other diseases. After grading the tubers were weighed and the yields were expressed in tons per hectare.
Data were subjected to statistical analysis by M-STATC software, the differences among means were performed using the least significant difference (LSD) at a 5% level.

RESULTS AND DISCUSSIONS

Late blight incidence depends on environmental conditions. In the Brasov Depression area, the average annual temperatures have an uneven distribution, due to the influence of local factors (altitude, land forms, exposure, slope gradient and degree of vegetation cover). Compared to the multiannual average, the temperatures recorded sometimes differ quite a lot, both compared to the average and from one year to another.

Table 1. Air temperature and rainfall during the experiment

Year	Month					
	May	June	July	August	September	
	Air temperature (°C)					Average
2018	16.3	18.1	18.8	20.2	14.7	17.6
2019	13.4	19.6	19.0	15.5	14.8	16.5
Multiannual average of air temperature	13.6	16.5	18.1	17.5	13.6	15.9
	Amount of rainfall (mm)					Total
2018	34.8	204.8	133.6	46.6	43.4	463.2
2019	98.6	110.0	68.6	86.2	8.9	372.3
Multiannual average of rainfall	82.0	96.7	99.8	76.4	52.5	407.4

Late blight appeared on July 3, 2018, relatively late compared to previous years. The late emergence was influenced by the initially unfavorable climatic conditions both as an evolution of the potato crop and the disease.
After March, when the amount of water added was 78.4 mm (271.3% compared to MAA), in April only 10.8 mm (21.6% compared to MaA) were achieved and in May 34.8 mm (42.4% compared to MAA), which influenced the emergence of plants and a slow start in vegetation.
In June and July, the thermo-hydric conditions became favorable for the potato crop. Water needed for plant development was provided by abundant rainfall of 204.8 mm in June (211.8% compared to MAA) and 133.6 mm in July (133.9% compared to MAA). The significant

quantities of rainfall and the favorable temperatures of June, when an average of 18.1 ° C was recorded, provided the necessary conditions for the onset of the late blight epidemic.
In 2019 the first late blight spots were observed very early, on May 30 at Braşovia' cv.
The months of March and June were characterized by higher than normal temperatures, with the monthly average exceeding 3.1°C. Between April and May, the average monthly temperatures were close to normal. In the second part of the vegetation period, in July, August and September the average monthly temperatures fluctuated, generally being around the MAA values (+ 0.9°C in July, -2.0°C in August and + 1.2°C in September).
The month of May, rich in rainfall (98.6 l / sqm) and with temperatures close to the MAA contributed to a good start for potato crops. The relatively high volume of rainfall in May and June, together with the optimum temperatures, favored, besides the development of plants, the attack of foliar diseases, whose control was relatively difficult, being applied a large number of treatments. The low level of rainfall in August caused the maturation of the plants and the end of the vegetation of the semi-early cultivars (Table 1).
For the occurrence of late blight, more important is the presence of rainy days than the amount of them, although the abundant rainfall influences the intensity of late blight attack. Being humidity conditions, the late blight appears without fail and there is an unlimited succession of secondary infections so that in a relatively short time, the attack is widespread throughout the whole potato crop (Hermeziu, 2017). Observations regarding the resistance of the cultivars to late blight attack take into account the infection pressure from the plot level starting from the moment of the installation of the epidemic everywhere when the resistance to the progression of infection even on less sensitive cultivars can be modified due to the interrelation that is created between the cultivars planted side by side.
Hence the difficulty, in this kind of tests, to measure the behavior of one cultivar without the disturbances induced by another more sensitive.

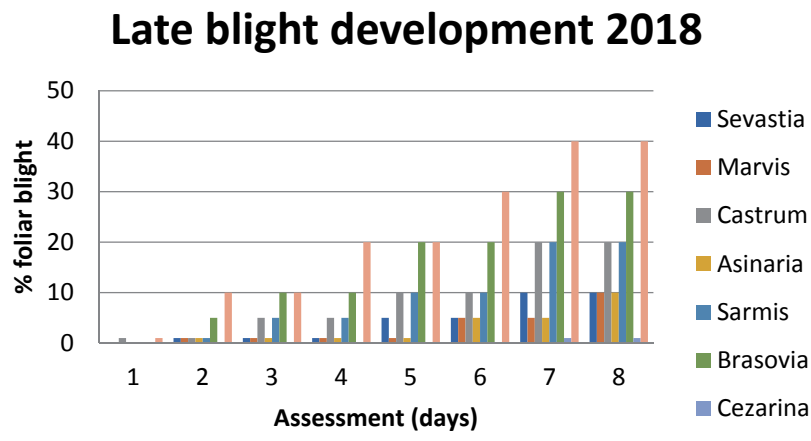

Figure 1. Late blight development on foliage 2018

In 2018, 'Christian' cv. showed the lowest level of resistance on foliage (40% attack level), followed by Braşovia' cv. (30% attack level). 'Castrum' and 'Sarmis' cultivars have an attack level of 20%.
The cultivars 'Sevastia', 'Asinaria' and 'Marvis' were situated towards the upper limit of the resistance (attack degree 10%). It should be noted to these cultivars that the time required for the epidemic install is longer, even under conditions of high infection pressure and by the timely application of systemic fungicides there is the possibility that the general pressure in the plot will decrease progressively. 'Cezarina' cv. (1% attack degree), rated according to the field resistance determinations as the most resistant, has maintained a high level of resistance on both foliage and tubers (Figure 1).

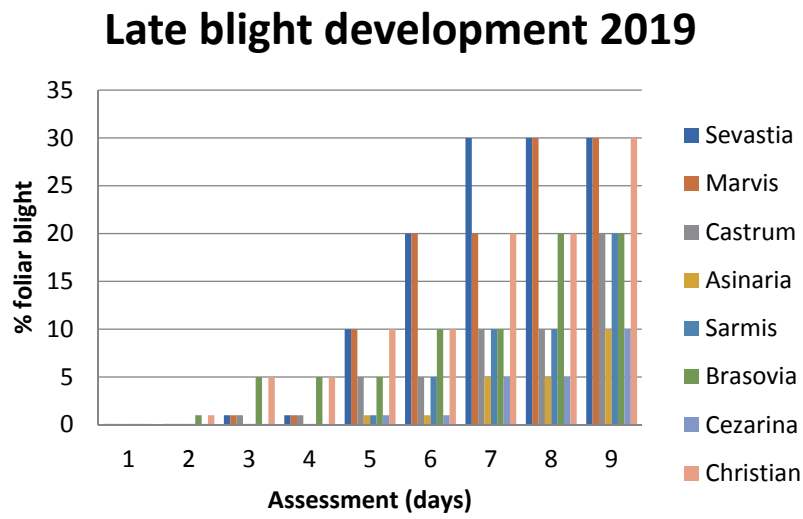

Figure 2. Late blight development on foliage 2019

From figure 2 can be observed the slow evolution of the attack, even if the climatic factors during June and July were favorable for the epidemic development. Among the studied cultivars, 'Asinaria' and 'Cezarina' cvs. have the lowest level of attack, followed by ' Braşovia', 'Castrum' and 'Sarmis' cvs., and 'Sevastia', 'Marvis' and 'Christian' cvs. presented a higher level of attack.

The reading of the graphs shows a very contrasting behavior according to the year for some cultivars. This is the case of 'Sevastia' and 'Marvi', which in 2018 showed resistance to infection, and in 2019 once infected, their resistance decreased dramatically. Analyzing 'Cezarina' cv., from the point of view of resistance in vegetation, but also in the longer term, such a cultivar allows the entrance with one or two protective treatments at the beginning of the season and can withstand without annoying consequences less intensive treatment strategies, such as 14 days between treatments.

Table 2. Number of tubers (Brasov, 2018)

No.	Cultivar	Total no. tubers	from which:				
			> 60 mm	35-60mm	<35 mm	Tubers with blight	
		tub/sqm					%
1	'Sevastia'	14.8 g	7.1 de	5.2 h	2.5 h	0.0 c	0.1 c
2	'Marvis'	40.4 cd	12.0 c	17.8 cde	10.4 cd	0.2 c	0.4 c
3	'Castrum'	30.2 ef	8.4 d	14.5 def	7.1 efgh	0.1 c	0.5 c
4	'Asinaria'	31.1 ef	15.3 ab	11.2 fg	4.6 gh	0.0 c	0.0 c
5	'Sarmis'	27.4 f	9.2 d	13.3 efg	4.6 gh	0.2 c	0.9 c
6	'Braşovia'	37.5 cde	14.1 abc	18.1 cde	5.2 gh	0.1 c	0.2 c
7	'Cezarina'	34.4 def	16.4 a	13.0 efg	5.0 gh	0.1 c	0.2 c
8	'Christian'	30.5 ef	13.2 bc	13.1 efg	4.0 gh	0.3 c	0.9 c
Average		*36.9*	*10.7*	*17.6*	*8.0*	*0.6*	*1.5*
(CV %)		*10.6*	*13.8*	*18.1*	*21.2*	*58.4*	*76.1*
LDS 5%		*6.5*	*2.4*	*5.3*	*2.8*	*0.5*	*1.9 %*

Significant differences in the number of tubers per plant were noticed among the cultivars. The total number of tubers varied very much, with statistically assured differences between 40.4 tubers/sm on 'Marvis' cv. (the highest number of tubers/square meter) and 14.8

tubers/sm on 'Sevastia' cv. (the lowest number of tuber/square meter). The other cultivars in descending order of the number of tubers are 'Braşovia' (37.5), 'Cezarina' (34.4), 'Asinaria' (31.1), 'Christian' (30.5), ' Castrum' (30.2) and 'Sarmis' (27.4). For the majority of cultivars can be observed a high number of tubers and good protection due to the applied fungicides (Table 2).

Table 3. Number of tubers (Brasov, 2019)

No.	Cultivar	Total no. tubers	from which:				
			> 60 mm	35-60 mm	<35 mm	Tubers with blight	
		tub /sqm					%
1	'Sevastia'	24.17d	3.11d	13.42e	7.64c	0.00c	0.00c
2	'Marvis'	49.42ab	4.94cd	27.36bc	17.08a	0.02c	0.12c
3	'Castrum'	38.08c	6.64bc	19.50d	11.92bc	0.02c	0.22c
4	'Asinaria'	38.22c	8.25b	16.11de	13.83ab	0.02c	0.06c
5	'Sarmis'	43.17bc	12.17a	20.75d	10.11bc	0.14c	0.35c
6	'Brasovia'	49.58ab	8.81b	26.53c	14.14ab	0.11c	0.23c
7	'Cezarina'	53.39a	9.08b	31.89ab	12.39ab	0.03c	0.08c
8	'Christian'	57.97a	9.06b	34.19a	14.72ab	0.00c	0.00c
Average		*44.25*	*7.76*	*23.72*	*12.73*	*0.08*	*0.13*
(CV %)		*12.69*	*28.44*	*18.81*	*25.24*	*186.86*	*201.87*
LDS 5%		*8.255*	*5.91*	*4.49*	*1.18*	*0.124*	*0.404*

From table 3 can observed the presence of a large number of tuber /sqm, the values being between 57.97 tubs. / sqm to 'Christian' cv. and 24.17 tubs. /sqm to 'Sevastia' cv.
The good environmental conditions, temperature and rainfall, were reflected in a large number of count tubers to the almost cultivars. The other cultivars in descending order of the number of tubers were 'Cezarina' (53.39), 'Brasovia' (49.58), 'Marvis' (49.42), 'Sarmis' (43.17), 'Asinaria' (38.22), 'Castrum' (38.08). The difference between cultivars is natural and varies with the genotype, physiological age of seed, number of stems per hill and environmental conditions during the initiation phase of growth (Mihovilovich *et al.,* 2008; Tufa *et al.,* 2019). Based on these factors can be determinate the productive potential of a cultivar and its final destination. By example, 'Christian' cv. is recommended for summer-autumn consumption and for french fries processing and 'Sevastia' is a cultivar in which the tuber remains whole, being suitable for salads and cooking with water and steam.

Table 4. Yield obtains in 2018 to NIRDPSB Brasov

No.	Cultivar	Total yield	Size categories:				
			> 60 mm	35-60 mm	<35 mm	Tubers with blight	Commercial yield
		t/ha				%	t/ha
1	'Sevastia'	23,93 i	14,1 ef	7,9 gh	1,9cdef	0,0 a	22,0 h
2	'Marvis'	44,79cd	28,2 c	14,3 def	2,2cde	0,1 a	42,5 cd
3	'Castrum'	31,76 gh	17,4 def	12,5 def	1,5efg	1,0 a	29,9 fg
4	'Asinaria'	49,40 bc	38,2 ab	9,9 gh	1,3fgh	0,0 a	48,1 bc
5	'Sarmis'	33,74 fg	21,8 d	10,3 fg	1,4fgh	0,9 a	32,1 efg
6	'Braşovia'	50,19 bc	32,2 c	16,5 de	1,4efg	0,2 a	48,7 bc
7	'Cezarina'	56,91 a	43,5 a	12,0 fg	1,3fgh	0,2 a	55,5 a
8	'Christian'	39,52def	28,3 c	10,2 fg	0,8gh	0,5 a	38,5 de
Average		*41,3*	*24,6*	*14,3*	*2,0*	*1,3*	*38,9*
(CV %)		*(8,9)*	*(12,9)*	*(16,9)*	*(23,4)*	*(95,3)*	*(10,0)*
LDS 5%		*6,1*	*5,3*	*4,1*	*0,8*	*2,0 %*	*6,5*

From table 4 it appears that the total production is correlated with the commercial production. Very good commercial production was obtained to 'Cezarina' cv. (56.91 t/ha). In descending order are registered the cultivars 'Braşovia' (50.19 t/ha), 'Asinaria' (49.40 t/ha), 'Marvis' (44.79 t/ha), 'Christian' (39.52 t/ha), 'Sarmis' (33.74 t/ha), 'Castrum' (31.76 t/ha) and 'Sevastia' (23.93 t/ha).
It is observed that the cultivar as a biological resource is an important factor in obtaining high yields, but adequate technology is meant to provide conditions for the production and quality of the initial qualities of the cultivar.

Table 5. Yield obtains in 2019 to NIRDPSB Brasov

No.	Cultivar	Total yield	Size categories:				Commercial yield
			> 60 mm	35-60 mm	<35 mm	Tubers with blight	
		t/ha				%	t/ha
1	'Sevastia'	16.83e	5.01e	10.06c	1.77b	0.0b	15.06d
2	'Marvis'	31.08bcd	9.24de	18.03ab	3.78a	0.02ab	27.28bc
3	'Castrum'	27.17d	10.71cde	13.27c	3.16a	0.03ab	23.98cd
4	'Asinaria'	28.41cd	13.96bcd	10.63c	3.81a	0.02ab	24.58cd
5	'Sarmis'	44.06	26.26a	14.87bc	2.77ab	0.17a	41.12a
6	'Brasovia'	38.25abc	16.57bc	18.27bc	3.32a	0.09ab	34.84ab
7	'Cezarina'	43.30a	17.51b	22.70a	3.04a	0.04ab	40.21a
8	'Christian'	39.61ab	13.88bcd	21.99a	3.74a	0.00b	35.87ab
Average		33.59	14.14	16.23	3.17	0.046	30.37
(CV %)		*19.79*	*28.44*	*18.81*	*25.24*	*203.25*	*20.91*
LDS 5%		*9.774*	*5.914*	*4.487*	*1.179*	*0.139*	*9.337*

It should be noted also the different number of tubers in terms of size fractions may be an indicator of what would be the final destination of a potato cultivar. The large number of tubers from the 35-60 mm size is observed in the 'Cezarina', 'Christian', 'Marvis' and 'Brasov' cultivars. A large number of tubers in the size > 60 mm were obtained to 'Asinaria' and 'Sarmis' compared to the one registered in the 35-60 mm size.
It is worth noting the small percentage of tubers attacked by different diseases (late blight and dry rot) observed during harvest, due to the fact that the attack of the diseases in the vegetation was very well controlled.

CONCLUSIONS

Due to the large number of treatments (8-9 treatments/season), through the timely application and the use of active substances with different mode of action, the evolution of the attack was slow and the cultivars taken in the study had a good and very good evolution.
Results on the investigation of the effectiveness of fungicides to minimize the disease incidence of late blight in two years of field trials in 2018 and 2019 indicated that all the fungicides significantly reduced the disease incidence and increased yield. Among the eight tested cultivars, in both years, 'Cezarina' cv. produced maximum yield.
It should be emphasized once again that the potato late blight is an evolving, complex disease, which under the current climatic conditions when global warming takes place and the extreme phenomena are accentuated (torrential rain, short duration, large quantities of water in a short period) has the ability to be dynamic and to continue to pose serious problems to both researchers and farmers.

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