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Rozwój chorób grzybowych oraz wielkość plonu bulw w zależności od intensywności ochrony ziemniaka

Development of potato fungal diseases and the amount of tuber yield depending on the scope of protection

Milena Pietraszko

Instytut Hodowli i Aklimatyzacji Roślin -Państwowy Instytut Badawczy, Oddział w Jadwisinie,ul. Szaniawskiego 15, 05–140 Jadwisin,
m.pietraszko@ihar.edu.pl

W latach 2014-2016 w Instytucie Hodowli i Aklimatyzacji Roślin Oddział w Jadwisinie przeprowadzono doświadczenie mające na celu ocenę wpływu różnej intensywności ochrony chemicznej na porażenie roślin ziemniaka przez *Phytophthora infestans* i *Alternaria* spp. oraz wielkość plonu bulw. Badano odmiany różnej wczesności i odporności na zarazę. Porównywano trzy warianty ochrony fungicydowej: obiekt kontrolny (bez ochrony), ochrona ograniczona (1-3 zabiegi) i ochrona intensywna (4-5 zabiegów). Udowodniono wpływ lat badań, ochrony i odmian na rozwój chorób grzybowych oraz wysokość plonu bulw. Średnio dla lat badań, najniższy stopień porażenia roślin alternariozą oraz najwolniejsze tempo szerzenia zarazy i jednocześnie największy plon bulw odnotowano w kombinacji z ochroną intensywną. Wzrost plonów spowodowany działaniem fungicydów wyniósł średnio 19%. Największy średni wzrost plonu – 21,3%, uzyskano dla wariantu ochrony intensywnej w porównaniu do obiektu kontrolnego. Istotne zróżnicowanie pomiędzy ochroną intensywną a ograniczoną pod względem rozwoju chorób i wielkości plonu było uzależnione od presji patogenów w danym roku badań.

Słowa kluczowe: badania polowe, choroby grzybowe, plon, ochrona fungicydowa, ziemniak

In the years 2014-2016 at the Plant Breeding and Acclimatization Institute in Jadwisin, an experiment was carried out to assess the impact of various levels of chemical protection on the infestation of potato plants by *Phytophthora infestans* and *Alternaria* and the size of tuber yield. Cultivars of different earliness and resistance to late blight were tested. The following levels of fungicidal protection were compared: control (without protection), limited protection (1-3 treatments) and intensive protection (4-5 treatments). The influence of years, protection levels and cultivars on the spread of fungal diseases and the size of tuber yield was proved. On average, for the years of research, the lowest degree of plant infestation with alternaria and the slowest rate of spread of late blight and the highest tuber yield were recorded for intensive protection. The mean increase in yields caused by the application of fungicides was 19%. The highest mean yield increase (21.3%) was achieved between control and intensive protection. Significant differences between intensive and limited protection in terms of disease spread and yield size depended on pathogen pressure in the year of the study.

Key words: field experimentation, fungicidal protection, plant diseases, potato, yield

Introduction

Potato blight caused by fungus-like pathogen *Phytophthora infestans* (*P. infestans*) (Mont.) de Bary) is the most important disease of potato crops. This disease has a significant negative effect on the yield and tuber quality, and increases losses during storage. Losses in the quality and size of yield due to the destruction of foliage depend on the time and scale of infection, which is mainly related to weather conditions and the susceptibility of potato cultivars. Early infection of plants and weather conditions favourable for the spread of disease are associated with greater losses in yield. Infection is promoted by high humidity and air temperature within the range of 12-15°C. The further spread of the disease is rapid at temperatures above 18°C and persistent high humidity on the field. Losses in yield on unprotected plantations can be as high as 70% (Hoffman, Schmutterer, 1983; Kapsa, 2001; Kapsa and Sawicka 2001; Keskse, 2013).

Protection of potato plantations against *P. infestans* relies on preventive measures, e.g. destruction of infection sources, early planting, greensprouting or stimulation of seed tubers, and cultivation of resistant cultivars. In addition to the above-mentioned agrotechnical and breeding methods, chemical protection with foliar fungicides registered for the control of potato blight is widely used. Several factors

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determine the effectiveness of chemical protection, and the most important of them are the date of first treatment, the dates of subsequent treatments, and the type and sequence of fungicides used, depending on the plant's growth stage and the pressure of the pathogen.

The second disease of potato plants is early blight caused by *Alternaria* spp. fungi (*Alternaria solani, Alternaria alternata).* The harmfulness of alternaria as a yield-reducing factor is much lower than that of late blight, and is therefore somewhat underestimated by farmers. However, due to the observed climate warming, alternaria is gaining more and more importance. According to Reinoch (1974) and Fry (1994), yield losses caused by alternaria range from 20 to 30%, and in particularly susceptible cultivars they may exceed 50%. According to more recent reports, yield losses are estimated at 5 to 78% (Waals et al., 2004; Pasche et al., 2004, 2005). The spread of early blight is promoted by warm and dry weather, when periods of drought alternate with moderate but frequent rainfall. *Alternaria* spreads more easily on potatoes grown in light soils, poor in nutrients, on plants with nitrogen deficiency, weakened, insufficiently fertilized, ageing or previously attacked by other pathogens (Kapsa, 2004, Osowski, 2007). The prevention and control of alternaria on plants relies on adequate agricultural practices, the use of resistant cultivars, and the application of various chemical fungicides.

The aim of the study was to assess the impact of various levels of chemical protection on the infestation of potato plants by *P. infestans* and *Alternaria* spp. and the size of tuber yield in potatoes of different earliness and resistance to these pathogens.

Material and Methods

The study was carried out in 2014-2016 at the Plant Breeding and Acclimatization Institute in Jadwisin. Potatoes were grown on light soil, with the grain size composition of light loamy sand. Potatoes were produced in a conventional system. Agrotechnical treatments are presented in Table 1. Due to prolonged drought throughout June 2015, potato plants required irrigation. On the experimental field, irrigation was performed four times, in a total dose of 80 mm. The field experiment was designed in a system of three blocks, and a different variant of fungicidal protection was used for each block:

— no protection (control);
— limited protection that started after the onset of potato blight symptoms (1-3 treatments);
— intensive protection that started with a preventive treatment against potato blight and included 4-5 treatments (Tab. 2, Tab. 2.1).

In each experimental block the research material consisted of 11 potato cultivars from different groups of earliness and different levels of resistance to *P. infestans*. Types of earliness and resistance of potato cultivars are presented in Table 3. Plants were inspected for disease symptoms every seven days. The degree of infestation in potato plants was determined using a 1-9 scale, where 9 means no symptoms of disease, and 1 means total destruction of foliage. The infestation with blight was expressed by the rate of disease spread calculated

Tabela 1
Table 1

Zabiegi agrotechniczne zastosowane na polu doświadczalnym. Jadwisin 2014–2016

Agronomic inputs in experimental field. Jadwisin 2014–2016

	Płodozmian i zabiegi agrotechniczne / *Crop production practice*
Nawożenie *Fertilization*	ok. 5 t słomy pszennej na przyoranie + 1 kg azotu mineralnego na 100 kg słomy + międzyplon z gorczycy białej *Plowed rye straw + 1 kg mineral nitrogen per 100 kg straw + catch crop,* N: 100 kg·ha^{-1}, P: 53 kg·ha^{-1}, K: 150 kg·ha^{-1}
Nawadnianie w 2015 *Irrigation on 2015*	80 mm
Zwalczanie chwastów *Weed control*	Linurex 500 SC – 1,8 l·ha^{-1} Titus 25 WG + Trend 90 EC – 60g + 100ml·ha^{-1}
Zwalczanie stonki *Colorado potato beetle control*	Insektycydy chemiczne 2–3 razy w sezonie *Chemical insecticides 2–3 times per season* Actara 25 WG – 40 g·ha^{-1}; Calypso 480 SC – 75 ml·ha^{-1}

Tabela 2
Table 2

Zabiegi przed chorobami grzybowymi w zależności od intensywności ochrony

Treatments of fungicides depending on scope of protection

Ochrona fungicydowa *The fungicides protection*	Lata badań / *Years*					
	2014		**2015**		**2016**	
	Preparat *Chemical preparation*	Liczba zabiegów *Number of treatments*	Preparat *Chemical preparation*	Liczba zabiegów *Number of treatments*	Preparat *Chemical preparation*	Liczba zabiegów *Number of treatments*
Brak ochrony *No protection*	–	0	–	0	–	0
Ograniczona *Limited*	Ekonom MC 72,5 WP – 2 kg·ha^{-1} Revus 250 SC – 0,6 l·ha^{-1}	2	Pyton Consento 450 SC – 2 l·ha^{-1}	1	Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Cabrio Duo 112 EC – 2,5 kg·ha^{-1} Revus 250 SC – 0,6 l·ha^{-1}	3
Intensywna *Intensive*	Pyton Consento 450 SC – 2 l·ha^{-1} Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Pyton Consento 450 SC – 2 l·ha^{-1} Revus 250 SC – 0,6 l·ha^{-1}	4	Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Pyton Consento 450 SC – 2 l·ha^{-1} Pyton Consento 450 SC – 2 l·ha^{-1} Revus 250 SC – 0,6 l·ha^{-1}	5	Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Ridomil Gold MZ 67,8 WG – 2,5 kg·ha^{-1} Banjo 400 SC – 0,8 l·ha^{-1} Cabrio Duo 112 EC – 2,5 kg·ha^{-1} Revus 250 SC – 0,6 l·ha^{-1}	5

Tabela 2.1
Table 2.1

Rodzaje substancji aktywnych stosowanych preparatów

Types of active substances of the preparations used

Preparat / *Chemical preparation*	Substancja aktywna i jej ilość / *Active substance and its amount*
Banjo 400 SC	Fluazynam/Fluazinam – 20%, Dimetomorf/Dimethomorph – 20%
Cabrio Duo 112 EC	Dimetomorf/Dimethomorph – 6,9%, Piraklostrobina/Pyraclostrobin – 3,8%
Ekonom MC 72,5 WP	Mankozeb/Mancozeb – 68%, Cymoksanil/Cymoxanil – 4,5%
Pyton Consento 450 SC	Chlorowodorek propamokarbu/Propamocarb hydrochloride – 33,30% Fenamidon/Fenamidone – 6,66%
Revus 250 SC	Mandipropamid/Mandipropamid – 25%
Ridomil Gold MZ 67,8 WG	Metalaksyl M/Metalaxyl M – 3,8%, Mankozeb/Mancozeb – 64,0%

as the regression coefficient of infestation over time. The following formula was used to calculate the rate of spread for late blight:

· [L_n of final infestation – L_n of initial infestation]

where:

t1 – number of days from date zero to the onset of the first symptoms,

t2 – number of days from date zero to the date when the degree of infestation assessed on the subsequent date of inspection was not higher than that on the previous date (Roztropowicz, 1999).

The size of tuber yield was assessed after harvest for each protection variant. Data were analysed using ANOVA and the STATISTICA 13.3 software. The significance of differences was verified with Tukey's test at $\alpha_{0.05}$.

Results

Weather conditions during the growing season and dates of the first symptoms of diseases

Data on temperature and rainfall in the individual months of the growing season are presented in Table 4. Dates of the first symptoms of fungal diseases in potato plants are shown in Table 5.

The growing season in 2014 was characterized by higher air temperatures and drought between May and July. During this period, the level of rainfall was about 74 mm lower compared to the multi-year data for 1967-2013. In the second ten days of July, rainfall was moderate and followed

Tabela 3
Table 3

Grupy wczesności odmian i odporności na zarazę (*Phytophthora infestans*)

Characteristics of potato cultivars

Grupa wczesności *Maturity group*	Odporność roślin na P. infestans *Resistance to P. infestans*	Liczba badanych odmian *Number of cultivars*
Bardzo wczesna *Very early*	2–3	2
Wczesna *Early*	3–4	3
Średnio wczesna *Middly early*	3,5–6	4
Średnio późna *Middly late*	5	2

Tabela 4
Table 4

Suma opadów atmosferycznych i średnia temperatura powietrza w okresie wegetacji ziemniaka w latach badań (2014–2016) w Jadwisinie

Total monthly rainfall (R) and mean monthly temperatures (T) during the vegetative growth period in the years 2014–2016 for Jadwisin

Rok/miesiąc *Year/month*	Średnia temperatura powietrza (°C) *Mean air temperature (°C)*						
	IV	V	VI	VII	VIII	IX	IV-IX
2014	10,3	14,1	15,8	21,4	18,3	14,7	15,8
2015	8,3	12,9	17,5	19,6	22,5	15,1	16,0
2016	9,3	15,3	18,7	19,6	18,4	15,7	16,2
Średnia wielolecia *Multi-year average* 1967–2013	7,9	13,7	16,6	18,5	17,9	13,2	14,6
	Suma opadów (mm) *Sum of rainfall (mm)*						
2014	61,1	41,3	69,8	23,5	79,2	11,9	286,8
2015	27,8	39,5	15,4	62,6	8,6	36,6	190,5
2016	31,4	92,2	85,4	103,6	61,4	9,5	383,5
Średnia wielolecia *Multi-year average* 1967–2013	36	56	76	77	60	49	354,0

by favourable conditions for the spread of *P. infestans* infection. The first symptoms of late blight were noted on July 22 in the control plots (without protection) and in the plots with limited protection, but the drought in the following days of July inhibited the further spread of the disease. Before that there were symptoms of infection with alternaria on the potato plantation. The first symptoms of alternaria were noted on June 16 on early potato cultivars, on all plots compared in the study.

In 2015, weather during the growing season was characterized by prolonged drought. The total rainfall was only 190.5 mm and was more than 163 mm lower than the multi-year average. The greatest water deficit was recorded in June and August. Air temperature was also higher than the multi-year average. These weather conditions did not promote the spread of fungal diseases. Despite the irrigation of crops, no symptoms of infection caused by *P. infestans* were found on potato plants. The first symptoms of alternaria were noted on June 22 on the unprotected plants and on the plot where limited protection was used, and as late as on July 20 on potatoes where intensive fungicidal protection was applied.

The growing season in 2016 was wet and warm. Between May and the end of August the level of rainfall was higher than the multi-year average. The sum of rainfall for the entire growing season was 383.5 mm and was approx. 30 mm higher than the multi-year average, but rainfall was irregular. The average air temperature for the whole growing season was 16.2°C and was 1.6°C higher than the multi-year average. The mean daily air temperature reached 25°C in July and August, and even 27.5°C in June. Despite the significant amount of rainfall, the number of hours with high relative humidity was small due to the high temperature. Hot weather caused the plants to dry up quickly on the field. Despite that, the first symptoms of blight were noted on July 19 on unprotected plots (early potato cultivars), and two days later symptoms of disease were also found on plots with limited protection. On plots where preventive treatment was applied the onset of disease was late (July 29) and no further spread was observed. The first symptoms of alternaria were found on June 20 on all plots regardless of the type of protective treatment.

*Spread of early blight of potato (Alternaria **spp.)***

Weather in the study years had a significant effect on the degree of plant infestation (Tab. 6). The severity of alternaria was significantly lowest in 2015 (6.7 in the 1-9 scale) and highest in 2014 (5.7). Differences in the degree of infestation of plants between 2014 and 2016 were not statistically significant. Analysis revealed significant differences in the spread of disease depending on the level of fungicidal protection. The degree of infestation was highest in potatoes grown without protection, lower on plots with limited protection, and lowest on plots with intensive protection. The spread of alternaria also depended on the earliness of cultivars, and there were significant differences between early cultivars and those of other types of earliness. The significantly highest degree of infestation was found for early potato cultivars.

Spread of late blight (P. infestans)

Data on the rate of spread for late blight are presented in Table 7. There was a significant correlation between the rate of spread and all other analysed factors, but air temperature and rainfall during the study years had the strongest effect. Potatoes were affected by late blight during two out of three analysed seasons and its spread was fastest in 2016. The mean rate of spread for study years was highest for unprotected potatoes, lower on plots with limited protection, and lowest on plots with intensive protection. In 2014 the pressure from the pathogen was the lowest and no symptoms of late blight were noted on the plots with intensive protection. There were considerable differences between plots in the rate of disease spread.

Tabela 5
Table 5

Terminy wystąpienia pierwszych objawów chorób grzybowych roślin ziemniaka

Dates of first symptoms of fungal disease

Ochrona fungicydowa *The fungicides protection*	Choroba / *Disease*; Lata badań / *Years*					
	Alternarioza/*Early blight*			Zaraza ziemniaka/*Late blight*		
	2014	2015	2016	2014	2015	2016
Brak ochrony / *No protection*	16.06	22.06	20.06	22.07	X	19.07
Ograniczona / *Limited*	16.06	22.06	20.06	22.07	X	21.07
Intensywna / *Intensive*	16.06	20.07	20.06	X*	X	29.07

*- Objawy choroby nie wystąpiły / *no symptoms*

Tabela 6
Table 6

Najwyższy stopień porażenia roślin ziemniaka przez *Alternaria* spp w zależności od zakresu ochrony, wczesności odmian i lat

Maximum degree of infestation by *Alternaria* depending on the scope of protection, cultivar earliness and years

Grupa wczesności *Earliness*	Rok badań / *Year* /; Ochrona fungicydowa / *The fungicides protection*									Średnio *Mean*
	2014			2015			2016			
	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	
Bardzo wczesna *Very early*	5,3	7,0	7,5	7,0	7,0	7,0	6,3	5,0	6,8	6,5 b**
Wczesna *Early*	4,5	4,8	6,5	6,3	6,0	7,0	3,8	6,0	5,5	5,5 a
Średnio wczesna *Middly early*	4,7	5,8	6,7	5,7	7,0	7,1	5,6	7,1	6,5	6,2 b
Średnio późna *Middly late*	4,8	5,0	6,0	6,5	7,5	7,3	6,3	5,5	7,3	6,2 b
Średnia dla ochrony *Mean for protection*	4,8 a*	5,6 abc	6,6 cd	6,3 bcd	6,9 cd	7,1 d	5,5 ab	5,9 bcd	6,5 bcd	X
Średnia dla lat *Mean for years*		5,7 a*			6,7 b			6,0 a		X

**- Średnie w wierszach oznaczone z tymi samymi literami nie różnią się między sobą istotnie (P < 0.05)*
Means in lines marked with the same letter do not differ statistically (P < 0.05)
***- Średnie w kolumnie oznaczone z tymi samymi literami nie różnią się między sobą istotnie (P < 0.05)*
Means in column marked with the same letter do not differ statistically (P < 0.05)

In 2016 the pressure from the pathogen was high and the disease on unprotected plants spread more than two-fold faster compared to plants that were treated with chemical agents after the onset of potato blight symptoms, and more than eight-fold faster compared to plants that were protected before the onset of disease. The earliness of cultivars and their resistance to late blight were also of great importance. Nevertheless, as with alternaria, differences were only found for early cultivars less resistant to potato blight, where the rate of disease spread was highest, and medium-early and medium -late cultivars with higher resistance, where the rate of spread was lowest.

Tuber yield

There was a significant relationship between tuber yield and all analysed factors (Tab. 8). Tuber yield was highest in 2016 and lowest in 2015 (more than two-fold lower compared to 2016). The mean tuber yield for three years was 32.7 t·ha^{-1} for the variant without fungicidal protection, 37.8 t·ha^{-1} for the variant with limited protection, and 39.1 t·ha^{-1} for the variant with intensive protection. However, differences in tuber yield between individual variants of protection depended on the study year. In 2014 there were significant differences in yield between all protection variants. In 2015 and 2016 significant differences in yield were only found between the variant without protection and other variants. The yields of tubers harvested from fields with limited and intensive protection did not differ significantly in these study years. In 2014 and 2016, when the pressure from fungal pathogens of potato was strongest, the difference in tuber yield between the variant without fungicidal protection and the variant with intensive protection was 10.3 t·ha^{-1} and 7.4 t·ha^{-1}, respectively. The loss in yield in these two years was 44.2% and 14.3%, respectively. In 2015, when the pressure from the pathogen was low, this difference was 1.3 t·ha^{-1}, which accounted for 5.5% of loss in yield. Tuber yield was highest for medium-early cultivars, and lowest for very early cultivars. There were significant differences between medium-early cultivars and other groups of earliness.

In the two years when blight affected potato, the highest mean rate of disease spread and the lowest tuber yield were noted for the variant without fungicidal protection. In contrast, the lowest rate of disease spread and highest tuber yield were noted for the variant with intensive protection (Fig. 1). This negative correlation between the rate of disease spread and tuber yield was not statistically

Tabela 7
Table 7

Tempo szerzenia zarazy ziemniaka w zależności od zakresu ochrony, wczesności odmian i lat

Rate of late blight development depending on the scope of protection, cultivar earliness and years

Grupa wczesności *Earliness*	Rok badań / *Year*/ ; Zakres ochrony fungicydowej / *Scope of protection*									Średnio *Mean*
	2014			2015			2016			
	Brak ochrony *No protection*	Ograniczona Limited	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	
Bardzo wczesna *Very early*	0	0	0	0	0	0	0,363	0,100	0,039	0,056 ab**
Wczesna *Early*	0	0	0	0	0	0	0,357	0,141	0,016	0,073 b
Średnio wczesna *Middly early*	0,061	0,018	0	0	0	0	0,182	0,072	0,041	0,041 a
Średnio późna *Middly late*	0	0	0	0	0	0	0,116	0,110	0,024	0,027 a
Średnia dla ochrony Mean *for protection*	0,015 a*	0,004 a	0 a	0 a	0 a	0 a	0,254 c	0,105 b	0,031 a	X
Średnia dla lat *Mean for years*		0,006 a			0 a			0,128 b		X

*- *Średnie w wierszach oznaczone z tymi samymi literami nie różnią się między sobą istotnie (P < 0.05)*
Means in lines marked with the same letter do not differ statistically (P < 0.05)
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Means in column marked with the same letter do not differ statistically (P < 0.05)

Tabela 8
Table 8

Plon bulw (t/ha) w zależności od zakresu ochrony, wczesności odmian i lat

Tuber yield depending on the scope of protection, cultivar earliness and years

Grupa wczesności Earliness	Rok badań / *Year* /; Zakres ochrony fungicydowej / *Scope of protection*									Średnio *Mean*
	2014			2015			2016			
	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	Brak ochrony *No protection*	Ograniczona *Limited*	Intensywna *Intensive*	
Bardzo wczesna *Very early*	20,2	25,9	27,7	25,2	28,8	26,5	47,3	49,5	54,1	33,9 a**
Wczesna *Early*	20,3	23,6	30,4	23,9	29,8	27,8	49,6	54,8	56,1	35,1 a
Średnio wczesna *Middly early*	25,3	30,6	36,5	23,2	27,6	24,2	54,2	62,4	62,9	38,5 b
Średnio późna *Middly late*	24,7	30,3	35,8	20,8	21,8	20,1	51,9	59,8	57,5	35,8 a
Średnia dla ochrony *Mean for protection*	23,3 a*	28,4 b	33,6 c	23,3 a	27,1 ab	24,6 ab	51,6 d	58,1 e	59,0 e	X
Średnia dla lat *Mean for years*		28,5 b*			24,9 a			56,3 c		X

*- *Średnie w wierszach oznaczone z tymi samymi literami nie różnią się między sobą istotnie (P < 0.05)*
Means in lines marked with the same letter do not differ statistically (P < 0.05)
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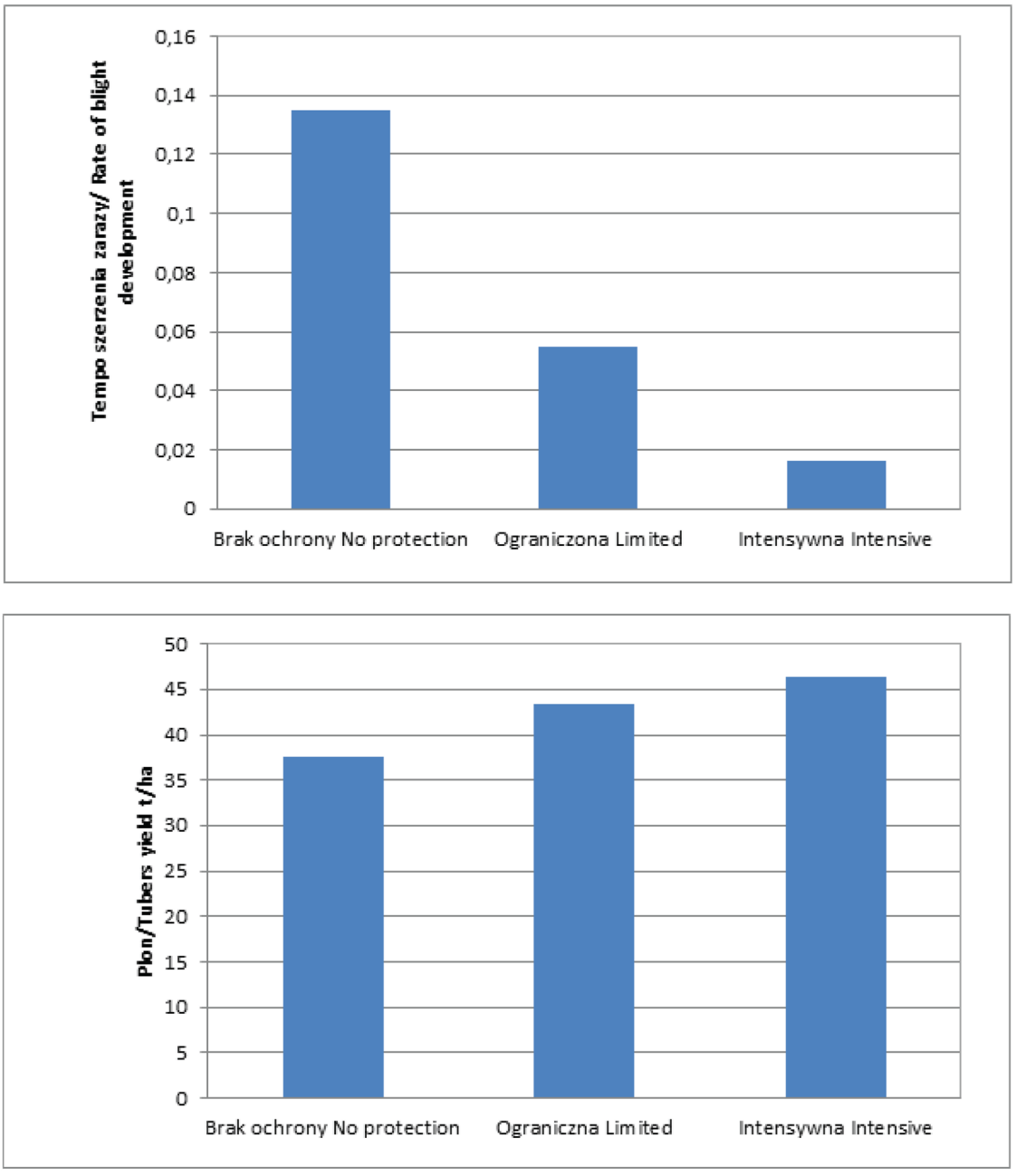
Means in column marked with the same letter do not differ statistically (P < 0.05)

significant (p=0.1120), and the correlation coefficient was low (r=-0.1133).

Discussion

Late blight and alternaria are the most common diseases affecting potato during the growing season. Destruction of the aboveground parts of plants inhibits the growth of tubers and significantly reduces yield. The most popular strategy for the control of fungal diseases relies on fungicidal treatments. However, in the era of green agriculture, efforts are made to minimize or optimize the use of plant protection products. Our study provided information on the effects of different levels of fungicidal protection on the spread of late blight and alternaria in potato plants, and increase in yield associated with this protection.

Alternaria was the first to attack plants, before the symptoms of late blight were noted. Our study confirmed previous findings reported by Zarzyńska and Szutkowska (2012). The role of weather in the onset and spread of late



Rys. 1. Tempo szerzenia zarazy w zależności od zakresu ochrony fungicydowej (średnio dla lat badań 2014 i 2016) i plon bulw (t·ha^{-1})

Fig. 1. Rate of late blight development depending on scope of protection (mean for years 2014 and 2016) and tuber yield.

blight has been emphasized by Harrison (1992) and Kapsa (2007), who reported higher rates of disease spread in wet and cold weather. Our study provided evidence for a significant effect of meteorological conditions on the occurrence of infection, its spread, and size of tuber yield. Precipitation had the strongest impact on differences between the analysed variables. Because of drought in 2015, no symptoms of infection with *P. infestans* were recorded on potato plants, and the degree of infection with alternaria was moderate. A lower water deficit in 2014 promoted the occurrence of alternaria, but had a moderate effect on the spread of late blight on the potato plantation. In 2016, rainfall was above the multi-year average, and this weather had the strongest effect promoting the spread of late blight and, to some extent, alternaria. There was also a positive correlation between the level of rainfall and tuber yield. Correlations identified in our study are consistent with those reported by other researchers (Kapsa, 2004; Zarzyńska, Szutkowska, 2012; Rakotonindraina, 2012).

In the study years, the mean degree of infection of potato plants by *Alternaria* spp. and the mean rate of spread of *P. infestans* (mean for two years of research when the pathogen was noted) were highest on the control plots without fungicidal protection. A significantly lower degree of infection with fungal diseases was observed for plants growing on plots with limited protection, where the first fungicidal treatment was applied after the symptoms of blight were noticed. In these plots one to three treatments were applied across the season, depending on the pressure from the pathogen in a given year. The control of alternaria and late blight was most effective on intensively protected plots, where preventive treatment was applied before the onset of late blight. For this variant 4 or 5 chemical treatments were applied. Many authors have reported that fungicidal protection significantly reduces the severity of fungal diseases on plants compared to untreated controls (Dowley et al., 2008; Mantecón, 2007; Kapsa, 2004). Their studies also demonstrated significant differences in the severity of infection depending on the type of fungicidal product. Our research, focused instead on the frequency of treatments, revealed that differences in the rate of blight spread between plots with limited protection and intensive protection were significant only in 2016, when the pressure from the pathogen was stronger.

Fungicidal treatments inhibited or prevented the spread of fungal infections and resulted in a significant increase in tuber yield. The mean increase in yield for three study years associated with the use of fungicides was 19%. The mean increase in yield was highest (21.3%) between the control plots and intensively protected plots. About a 17% increase in yield was found for plots with limited protection compared to unprotected controls. The difference in yield between plots with limited protection and intensive protection was 6.5%. The greatest differences in tuber yield between study plots were recorded in 2014, when weather was more favourable for the occurrence of alternaria than late blight. Plots with intensive protection were free from late blight. Our present findings are very similar to those reported previously by other researchers. Losses in yield caused by the infestation of potato plantations with alternaria on plots unprotected in field experiments ranged from 6 to 45% (Pietraszko, 2016). Mantecón (2007) in a 10-year study investigated the effects of selected fungicides on the size and quality of tuber yield and reported a 17.9% mean increase in yield associated with the use of fungicides for the control of alternaria. The use of products for the control of late blight in their study was associated with a 33.8% increase in yield. Dowley et al. (2008) analysed yield losses caused by late blight in potato crops in Ireland across 25 seasons and reported that there was an average increase of 10.1 $t \cdot ha^{-1}$ in yield from the use of fungicidal protection. In our study the mean increase in yield compared to control plots was 5.1 $t \cdot ha^{-1}$ for limited protection and 6.4 $t \cdot ha^{-1}$ for intensive protection. These findings indicate that in the years with moderate pressure from fungal pathogens, chemical protection implemented immediately after the onset of the first symptoms of late blight on the field ensured a satisfactory tuber yield, only slightly lower than the tuber yield from plots with intensive protection.

The study revealed a clear relationship between resistance of potato cultivars to pathogens and the spread of disease. The rate of spread for late blight was higher in very early and early cultivars with low resistance compared to more resistant later cultivars. This correlation was also reported by Kapsa (2005), Visker (2003) and Rakotonindraina (2012). Similar relationships were also noted with

respect to alternaria. Early and faster-ageing potato cultivars are more susceptible to alternaria, which was also confirmed in our study.

Findings from our study indicated that a very good tuber yield can be obtained if the frequency and timing of fungicidal treatments is adjusted to weather conditions and resistance of potato cultivars to late blight.

References

Dowley, L. J. Grant, J., Griffin, D. (2008). Yield losses caused by late blight (Phytophthora infestans (Mont.) de Bary) in potato crops in Ireland. Irish J. Agric. Food Res., (47), 69-78

Fry, W. E. (1994). Role of early blight suppression pest management. W: G. W. Zehder, M. L Powelson, R. K. Jansson, K.V Raman. Advance in potato pest biology andmanagement (166-177). APS Press, Am. Phytophath. Soc. St. Paul. Minnesota USA

Harrison, J. G. (1992). The effect of aerial environment on late blight of potato foliage - a review. Plant Pathology 41: 384 - 416. In: Leonard, K. J. & Fry, W.E. (eds.): Plant Disease Epidemiology, Vol. 2. MacMillan, New York, 3-37

Hoffman, G. M. & Schmuterer, H. O. (1983). Parasitäre Krankheiten und Schädlinge an landwirtschaftlichen Kulturpflanzen. Verlag Eugen Ulmer, Stuttgart, 488

Kapsa, J. (2001). Zaraza (*Phytophthora infestans*/Mont./ de Bary) występująca na łodygach ziemniaka. Monografie i Rozprawy Naukowe IHAR 11, 7-10

Kapsa, J. (2004). Early blight (*Alternaria spp*.) in potato crops in Poland and results of chemical protection. J. Plant Prot. Res. 44 (3), 231-238

Kapsa, J. (2005). Wykorzystanie odporności odmian w ochronie przed zarazą. Ziem. Pol. (4), 20-23

Kapsa, J. (2007). Effect of climatic conditions on infection pressure of Phytophthora infestans and harmfulness of the pathogen to potato crops. J. Plant Protection Res. 47 (4), 357-366

Keskse, D. (2013). Overview of epidemiology and management of late blight (Phytophthora Infestans (Mont.) on potato and tomato crops. IJRAS. Volume 6, Issue 4, ISSN (Online): 2348-3997

Mantecón, J. D. (2007). Potato yield increases due to fungicide treatment in Argentinian early blight (*Alternaria solani*) and the late blight (*Phytophthora infestans*) field trials during the 1996-2005 seasons. Plant Health Prog. doi: 10.1094/PHP-2007-0202-01-RS

Osowski, J. (2007). Termin wystąpienia pierwszych objawów alternariozy ziemniaka w zależności od roku i województwa. Prog. Plant Prot. 47 (2), 216-233

Pasche J.S., Wharam C.M., and Gudmestad, N.C. (2004). Shift in sensitivity of *Alternaria solani* in response to Q (0) I fungicides. Plant Dis. 88, 181-187

Pasche, J.S., Piche, L.M. and Gudmestad, N.C. (2005). Effect of the F129L mutation in *Alternaria solani* on fungicides affecting mitochondrial respiration. Plant Dis. 89, 269-278

Pietraszko, M., Zarzyńska, K. (2016). Wpływ alternariozy na porażenie roślin i plon ziemniaka w zależności od zakresu ochrony i systemu uprawy. Ziem. Pol. (3), 28-34

Rakotonindraina, T., Chauvin, J. E., Pellé, R., Faivre, R., Chatot, C., Savary, S., Aubertot, J. N. (2012). Modeling of yield losses caused by potato late blight on eight cultivars with different levels of resistance to *Phytophthora infestans*. Plant Dis. (96), 935-942

Rienoch, M. (1974). Alternarioza ziemniaka. Z Prac Inst. Ziemn.1(2), 19-28

Roztropowicz, S. (1999). Metodyka obserwacji, pomiarów i pobierania prób w agrotechnicznych doświadczeniach z ziemniakiem. Instytut Hodowli i Aklimatyzacji Roślin, Oddział w Jadwisinie, 24

Sawicka, B., Kapsa, J. (2001). Effect of varietal resistance and chemical protection on the potato late blight (*Phytophthora infestans* [Mont.] de Bary) development. Potato Res. 44 (3), 303-304

Waals, J.E., Korsten L., Slippers, B. (2004). Genetic diversity among *Alternaria solani* isolates from potatoes in South Africa. Plant Dis.88, 959-964

Visker, M.H.P.W., Keizer, L.C.P., Budding, D.J., Van Loon, L.C., Colon L.T., Struik P.C. (2003). Leaf position prevails over plant age in reflecting resistance to late blight in potato. Phytopathology (93), 666-674

Zarzyńska, K., Szutkowska, M. (2012). Rozwój chorób grzybowych oraz plon bulw w uprawie ekologicznej i konwencjonalnej. J. Res. Appl. Agric. Engin. 57 (4): 205-210