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EFFECT OF FUNGICIDES ON MYCOSIS PROGRESSION AND POTATO YIELDS

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ABSTRACT. The efficiency of crop cultivation technologies, including potatoes, can decrease under the influence of pests, especially in the case of untimely or low-quality protective measures. Pathogens parasitizing the vegetative surface of plants have a significant impact on the quality and yield of potato tubers. Such pathogens are fungi *Phytophthora infestans* (Mont) de Bary, *Alternaria solani* Sorauer and *Alternaria alternata* Keis, which are the causative agents of late blight and early blight. Early manifestation and significant development of these diseases during the growing season can lead to losses, which are estimated at 4 billion euros per year. Studies by many scientists reveal a significant positive result from the use of fungicides during the growing season of plants, harvesting and storage of crops. This article investigated the efficacy of fungicides against late blight and early blight and their effects on yield and tuber quality of the early maturing potato variety Bellarosa. The research was conducted from 2018 to 2020 at the PE Zherm of the Zhytomyr region Ukraine. The experiment scheme consisted of the following variants: Control – spraying of plants with water; Variant 1. Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxyl M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference variant; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}. It has been established that the application of fungicides in the potato plantings against late blight and early blight reduces the spread of the leaf spot by 1.4–2.0 times at the end of the vegetation period, and its development – by 1.8–2.9 times in comparison with the Control variant. An increase in yield of potato tubers of Bellarosa variety due to the application of fungicides against leaf spot disease was within 4.5–10.9 t ha^{-1} in comparison with the Control variant. Among the studied preparations, the best indicators were obtained when using the fungicide Infinito 61 SC, 68.75% in potato plantings against late blight and early blight. Application of this preparation helped to reduce the spread of the studied diseases by 2.0 times, the development of diseases by 2.9 times, and increase the yield by 1.4 times compared to the variant without fungicides application. Application of fungicides also contributed to the improved quality of the tubers; in particular, we observed an increase of the dry matter content in tubers by 0.1–0.6%, ascorbic acid – by 0.2–1.1 mg% 100 g^{-1} compared to the variant without using the preparations.

Introduction

The effectiveness of any crop cultivation technology, including potatoes, can be reduced due to significant damage by pests, high incidence of diseases and weeds of crops, especially if the elements of the crop protection system against pests were not observed (Andrivon *et al*., 2003; Shpaar, 2004).

Cultivation of varieties resistant to pests and pathogens is ecologically important and contributes to

increasing crop yields. However, varieties with increased resistance reduce their tolerance during several growing seasons, and then it is necessary to apply additional protection measures. One of the highly effective measures contributing to the maximum elimination of pests is the use of chemical preparations (Bukolova *et al*., 1997; Holiachuk, Kosylovych, 2018).

The science and practice proved significant effectiveness of chemical preparations against pathogens in potato plantings, the use of which is based on an integrated approach to solving the problem. The pathogens developing on the vegetative surface of plants cause a significant influence on the yield and quality of tubers. Such pathogens are fungi – pathogens of late blight *Phytophthora infestans* (Mont) de Bary) and early blight (*Alternaria solani* Sorauer and *Alternaria alternata* Keis.) (Zan, 1962; van der Waals *et al*, 2001; Raichuk, 2010; Filippov, 2012). The global losses in yield due to the development of these diseases and the costs associated with protection measures against them amount to about four billion euros per year. The damage of these diseases grows by early manifestation and rapid development during the growing season. The use of fungicides in potato plantings during the growing season is aimed primarily at destroying the pathogens of late blight and early blight. Vegetative surface protection of plants against these pathogens helps to maximize the preservation of tuber yields (Wastie, 1991; Plotnytska *et al.*, 2009; Brurberg, 2011; Kalenska, Knap, 2012*;* Tsedaley, 2014; Holiachuk, Kosylovych, 2018).

Fungicides, which are chemical preparations against pathogens, are subdivided, depending on their purpose, into preparations for seed dressing, plant treatment during vegetation and soil treatment. Earlier studies have revealed a significant positive result from the use of fungicides in the growing season of plants, harvesting and storage of crops. The use of fungicides helps to protect potato plants from the most common diseases, in particular late blight and early blight, and increase tuber yields (Ghorbani *et al.*, 2004; Shpaar, 2004; Nielsen *et al.*, 2010).

Studies on the use of chemicals against late blight began in the XIX century in France after the invention of the Bordeaux liquid, which combined the action of compounds of copper and lime. However, the effectiveness of this preparation began to decline over time, and this contributed to the search for the most effective means of protection against pathogens. Currently, preparations with contact and systemic action can be used to protect potatoes from spot disease. Contact fungicides do not penetrate the plant and remain on its surface, and their main action is to suppress the reproductive organs of fungi so that the plants are not overinfected. The effectiveness of contact action preparations depends on the duration of contact with the treated surface and decreases with precipitation, and the protective effect lasts no longer than eight days. The effectiveness of contact fungicides against late blight and early blight pathogens is confirmed only if they are used in a timely and repeated manner (Polozhenets *et al*., 2011).

Systemic action fungicides penetrate the plant and, together with the cell sap, are transferred to the untreated parts of the plant. They have not only a protective but also a therapeutic effect. Active substances of systemic fungicides penetrate the plant within the first thirty minutes after application, and their effectiveness is not reduced by precipitation and can be stored for 10–14 days. Application of systemic phenylamide fungicides (Ridomil, Sandofan) against *Ph. infestans* pathogen initially contributed to the reduction of the disease development, but mass application led to pathogen mutation, formation of resistant strains of the pathogen, in turn, required an increase in consumption rates and multiplicity of drugs application (Schepers van Soesbergen, 1995; Lazarchuk, 2015).

Now practical application as fungicides has received about 20 active substances, of which only 15 are the most widely used. The following active substances are the most common for protection against late blight: metalaxil, mancozeb, mephenoxam, propamocarb, fluopicolide, dimethomorph, *etc.*. Previously, contact preparations based on dithiocarbamates, copper and chlorothalonil preparations and azoxystrobin were mainly used to protect against early blight. However, an increase in the disease's harmfulness brought difenoconazole- and mandipropamide-based preparations to the market (Martynenko, 2003; Holiachuk, Kosylovych, 2018).

The number of potato plantings treatments with fungcides during vegetation season may reach 10–15 times, and 4–8 times in our country. When planning protective measures and selecting fungicides, the resistance of varieties grown in specific conditions to leaf spot pathogens, such as late blight and early blight, should be taken into account primarily. Plant protection during the growing season should be planned to take into account the preventive treatments carried out before the disease emergence. The duration of preventive treatments is calculated based on the forecast and meteorological conditions of the season. Untimely preventive treatments and late application of fungicides when 3–5% of leaves are infected result in 4–5 times more yield losses (Bondarchuk *et al*., 2009).

A considerable number of scientists and practitioners in all areas of culture cultivation deal with the problem of developing effective measures to protect potatoes from leaf spots by using fungicides. Even a single application of fungicides against late blight rot and early blight spot helps to reduce the development of pathogenic agents considerably. An increase in the number of fungicides treatments of potato plantations within a season, use of growth-promoting factors and micro fertilizers help not only to decrease the development of spot diseases of potato but also reduce affection of potato tubers by fusarium dry rot (Schepers, van Soesbergen, 1995; Martynenko, 2003; Nielsen *et al*, 2010; Polozhenets *et al*., 2011; Frost *et al*., 2013).

The constant development of new, more effective chemical preparations, and adjustment of application rates for active ingredients considering the degree of affection, may partially reduce the number of treatments during the season; nevertheless, it is impossible to exclude fungicides entirely from the system of potato protection from spot diseases of leaves. The effectiveness of preparations largely depends on weather conditions and growing conditions, it is necessary to consider specific conditions of soil and climate when developing a system of potato protection from pests (Brasovean *et al*., 2009).

The study aimed to investigate the effectiveness of fungicides against late blight, and early blight and their effect on the yield and quality of tubers of early maturing potato varieties.

Materials and Methods

Field researches in 2018–2020 were conducted in conditions of Ukraine housed by the private company Zherm in the Zhytomyr region, located in the northwestern part of Ukraine (50°31′ N 28°45′ E). The climate of the region, where the research took place, is moderate continental, mild and damp. Precipitation during the spring-summer period is approximately 300 mm and in autumn-winter – over 200 mm. Average annual precipitation is within 600–670 mm. The average annual temperature is +6... +8 °C and the temperature in summer approaches +17... +20 °C.

The soil cover of the research field is presented by sod-podzolic soils that are characterized by low content of nutrients and have an acid reaction to the soil solution. In general, soil-climatic conditions of the region of the private company allow the growing of most of the crops, including potatoes.

Cultivation technology of potatoes in the experiment was generally accepted for the Polissia zone of Ukraine. The early maturing variety of potatoes Bellarosa, included in the "State Register of plant varieties suitable for distribution in Ukraine" was planted in the experiment. We investigated the effectiveness of fungicides against major mycoses (late blight and early blight). We determined the effect of chemical and biological preparations on the development of potato mycoses according to the following scheme:

Control – spraying of plants with water;

Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference;

Variant 2 – Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1};

Variant 3 – Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}.

The area of the experimental plot was 25 m^2 in four replications. Plants were sprayed with the investigated fungicides three times: during the phase of budding, at the appearance of disease symptoms, and 14 days after the second spraying.

Spread and development of late blight and early blight spot was noted during vegetation of potato plants every 7 days starting from the seedling stage by examining 40 plants in each plot in all replicates.

The progress of diseases studied was calculated by the Formula (1).

$$R = \frac{n \times 100}{N}, \quad (1)$$

where R – progress of the disease (%);

n – number of affected plants in samples;

N – total number of accounted plants (healthy and affected).

Progress of diseases characterizing the relation of the affected leaf surface to the total area of the leaf on the field was calculated by the Formula (2).

$$P = \frac{(n \times b) \times 100}{N \times K}, \quad (2)$$

where P – progress of the disease, %;

$(a \times b)$ – figures of the sum of multipliers of the number of affected plants (n) to the corresponding grade of affection (b);

N – total number of accounted plants;

K – the highest grade on the accounting scale.

Visual inspection of the degree of affection by late blight rot and early blight spot was done according to the following scale in grades: 9 – very high resistance (absence of spots), and 1 – very low resistance (affected more than 75% of leaves of the sample) (Trybel, 2001; Kononuchenko *et al*., 2002).

The results of the study were statistically processed by using MS Excel 2016 and Statistica 6.0. The analysis of variance was used to find statistical differences ($P < 0.05$).

Results and Discussion

The development of pathogens *Phytophthora infestans* (Mont) de Bary and *Alternaria solani* Sorauer, causing late blight and early blight of potato, depends largely on the weather conditions of the growing season and growing conditions. The years of the study were not particularly favourable for the spread of these pathogens on potato plants. Our research suggests that the fungicides studied have sufficiently high efficiency in protecting potatoes from pathogens of late blight and early blight.

At the beginning of the growing season, the symptoms of mycosis on potato plants could be distinguished visually. However, beginning from the blossoming phase, the studied pathogens jointly began to parasitize on the vegetative surface of potato plants, and it was quite difficult to distinguish them visually by the available symptoms (Fig. 1). The common pathological process of fungi *Phytophthora infestans* (Mont) de Bary and *Alternaria solani* Sorauer led to the rapid damage of potato plants.

A B

Figure 1. Symptoms of mycosis on potato plants: A – tillering phase; B – after blossoming (Bellarosa variety, 2019)

Visual records and calculations of the spread and development of late blight and early blight in the field conditions were carried out by assessing their joint parasitization on the vegetative surface of potato plants.

The application of investigated fungicides has allowed reducing the distribution of pathogens of late blight and early blight on potato plants. The conducted surveys showed an increase in the index of mycosis spread on potato plants during the growing season (Fig. 2). In particular, in the Control variant, this indicator ranged from 5% in the primary recording to 72.1% in recording at the end of the growing season. The use of the studied fungicides reduced the spread of leaf spot disease at the end of the growing season by 1.4–2.0 times compared with the variant without fungicides. The best result, in which the spread of the evaluated diseases was 2.0 times lower than in the Control variant and 1.5 times lower than in the reference variant, was obtained in Variant 2 with the active substances fluopicolide and propamocarb hydrochloride (Infinito 61 SC, 68.75%).

A similar dependence was obtained in the study of disease development. Starting from the third ten-day period of June, the Control variant recorded a fairly rapid increase in disease development from 5.0% in the second recording to 10.5% in the third recording (Fig. 3).

The development of late blight and early blight pathogens in potatoes during the growing season in the variant without the use of fungicides was within 73.3%.

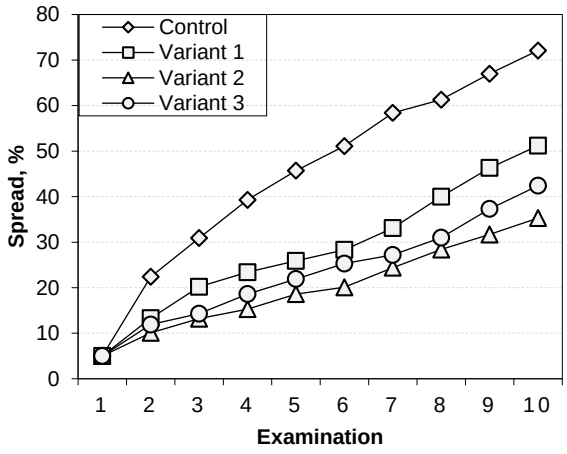

Figure 2. Dynamics of late blight and early blight spread when using fungicides, 2018–2020 (Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

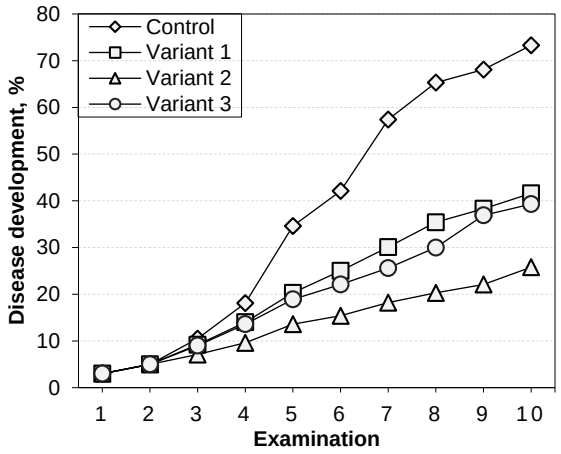

Figure 3. Dynamics of late blight and early blight development when using fungicides, 2018–2020 (Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

The use of fungicides reduced the development of diseases in the variants with the use of preparations by 1.8–2.9 times compared with the control one. The development of the studied potato mycoses when using the preparation Quadris TOP 325 SC, 32.5% (Variant 3) at the end of the study was 32.5%, which was 1.9 times lower than in the Control variant. The lowest rate of disease development amounted to 25.8% at the last count was recorded in Variant 2 with the application of the preparation Infinito 61 SC, 68.75%. In this variant, we observed a decrease in the development of leaf spot disease by 2.9 times compared with the Control variant and by 1.6 times compared with the reference preparation Ridomil Gold MC 68 WP (Variant 1).

Research carried out in different soil-climatic areas showed, that use of fungicides helps to decrease the spread and development of spot diseases in potato leaves and for potato sorts with high resistance to pathogenic agents it is possible to reduce chemical preparations application rate to 30% (Nielsen *et al.*, 2010; Polozhenets *et al.*, 2011).

The technical effectiveness calculation of the investigated fungicides during the observation period confirmed the data obtained earlier (Fig. 4). Weather conditions of the growing seasons at the beginning of the observation period were not contributing to the development of diseases, and the applied preparations showed primarily a preventive effect. The effectiveness of the studied preparations was recorded starting from the third recording, and a gradual decrease in the index of technical effectiveness of fungicides was recorded throughout the observation period.

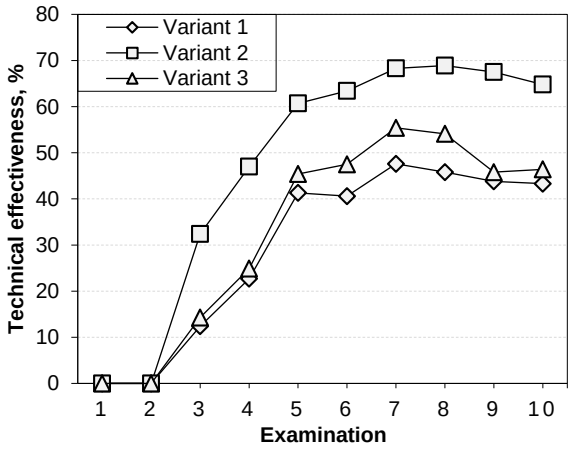

Figure 4. Technical effectiveness of fungicides against late blight and early blight, 2018–2020 (Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1})

The efficacy of any preparations is determined by their ability to maintain the therapeutic effect over a long period. The technical efficacy of the reference preparation Ridomil Gold MC 68 WP, with mancozeb and methylaxyl at the end of the observation period was 43.3%, Quadris TOP 325 SC, 32.5% (azoxystrobin + difenoconazole) was 46.4%, and Infinito 61 SC, 68.75% (fluopycolide + propamocarb hydrochloride) – 64.8%. The highest technical efficiency indicator against late blight and early blight of potatoes during the whole period of the study was obtained when using the preparation based on active substances fluopicolide and propamocarb hydrochloride (Variant 2).

Several factors influence the degree of affection by pathogenic agents of late blight and early blight spot and harvest yield of potato tubers, in particular, the intention of potato crops rotation, application of organic and mineral fertilizers, planting sorts resistant to pathogenic agents and use of fungicides during vegetation. The researchers ascertained, that each element of potato protection against spot diseases has a positive effect, but, to achieve the maximum result it is necessary to use a complex approach to solving this problem (Garrett *et al.*, 2001; Makarov *et al.*, 2005; Plotnytska *et al.*, 2009; Frost *et al.*, 2013; Eric Mosota Rosana *et al.*, 2017*).*

Positive dynamics on reduction of spread and development of late blight and early blight of potatoes due to the use of preparations affected the yield of potato tubers (Table 1).

During the study, small fluctuations in the yield of potato tubers over the years were observed. The highest yields were obtained in 2020 for all variants of the experiment, which is primarily due to the weather conditions of the growing seasons.

Table 1. The yield of Bellarosa variety potatoes due to the use of fungicides, t ha^{-1}

Variant	Years				Difference,
	2018	2019	2020	average	± Control
Control	26.0	25.8	26.8	26.2	–
Variant 1	31.4	28.9	31.8	30.7	4.5
Variant 2	36.9	36.7	37.7	37.1	10.9
Variant 3	32.4	31.4	33.1	32.3	6.1
$LSD_{0.05}$	0.7	1.2	1.1		

Control – spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}

The yield of potato variety Bellarosa for 3 years of research on average in the Control variant without application of preparations was 26.2 t ha^{-1}. Applying fungicides against leaf spot in the potato plantings of this variety allowed obtaining an increase in tuber yield in the range of 4.5–10.9 t ha^{-1} compared to the Control variant. Spraying of potato plants in Variant 1 with the preparation Ridomil Gold MC 68 WP, which was the reference one, increased the tuber yield by 4.5 t ha^{-1} up to the level of 30.7 t t ha^{-1}. The highest increase in potato tuber yield was obtained in Variant 2 with the use of Infinito 61 SC, 68.75%. This variant of the experiment resulted in a yield of 37.1 t ha^{-1}, which was 1.4 times more compared to the Control variant and 1.2

times more compared to the reference Variant 1 with the preparation Ridomil Gold MC 68 WP.

It is known that the biochemical composition of potato tubers can vary depending on varietal characteristics, cultivation technology and protective measures (Bukolova *et al*., 1997)

After harvesting, we conducted a study to determine the quality indicators of potato tubers' yield of Bellarosa variety due to the use of the fungicides (Table 2).

Table 2. Effect of fungicides on tuber quality parameters of the potato variety Bellarosa (mean, 2018–2020)

Variant	Content of		
	dry matter, %	starch, %	ascorbic acid, mg% 100 g^{-1}
Control	21.5	15.3	23.5
Variant 1	21.7	14.8	23.7
Variant 2	22.1	15.0	24.6
Variant 3	21.6	14.9	24.0

Control– spraying of plants with water; Variant 1 – Ridomil Gold MC 68 WP, (mancozeb, 640 g kg^{-1} + metalaxil M, 40 g kg^{-1}) – 2.5 kg ha^{-1} – the reference; Variant 2. Infinito 61 SC, 68.75% (fluopycolide, 62.5 g L^{-1} + propamocarb hydrochloride, 625 g L^{-1}) – 1.5 L ha^{-1}; Variant 3. Quadris TOP 325 SC, 32.5% (azoxystrobin, 200 g L^{-1} + difenoconazole, 125 g L^{-1}) – 0.8 L ha^{-1}

The content of dry matter in tubers, which was obtained in the Control variant without the use of preparations, amounted to 21.5%, starch – 15.3%, and ascorbic acid – 23.5 mg% 100 g^{-1}. Variants with fungicide use showed an increase of tubers' dry matter content by 0.1–0.6% and ascorbic acid content by 0.2–1.1 mg% 100 g^{-1} compared to the variant without fungicides. Starch content in the variants with the use of fungicides was 14.8–15.0%. The decrease in starch content due to the use of fungicides was in the range of 0.3–0.5% compared to the Control variant. The content of ascorbic acid in tubers, depending on the variant of research, was within the limit of 23.7–24.6 mg% 100 g^{-1} and was by 0.2–1.1 mg% 100 g^{-1} higher than in the Control variant.

Conclusion

Using fungicides in potato plantings against late blight and early blight reduces the spread of leaf spot disease at the end of the growing season by 1.4–2.0 times, and its development – by 1.8–2.9 times in comparison with the Control variant.

The increase in yield of potato tubers of Bellarosa variety due to the application of fungicides against leaf spot disease was within 1.2–1.4 times in comparison with the Control variant.

Among the studied preparations, the best indicators were obtained when using the fungicide Infinito 61 SC, 68.75% in potato plantings against late blight and early blight. Application of this preparation helped to reduce the spread of the studied diseases by 2.0 times, the development of diseases by 2.9 times, and to increase the yield by 1.4 times compared to the variant without fungicides application.

Application of fungicides also contributed to the improvement of quality indices of tubers; in particular, we observed an increase in the content of dry matter in tubers by 0.1–0.6% and ascorbic acid by 0.2–1.1 mg% 100 g^{-1}compared to the variant without fungicides.

Further studies will be aimed at determining the effect of preparations and their mixtures on the development of some potato mycoses during the growing season and postharvest period, yields and quality indicators of potato tubers.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

RT – a study of the concept and design, drafting the manuscript;
OS – author of the idea, who led the research;
OO – data analysis and interpretation, the corresponding author;
RT, NP – data collection, drafting the manuscript;
RT, NP – conducted analysis and discussion of data from the research literature;
OS, OO – critical revision and approval of the final manuscript.
All the authors have read and approved the final manuscript.

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