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Research article / Научная статья

Impact of fungicides on potato pathogens in the Tambov region of the Russian Federation

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Abstract. Fungicide application has been reported to effectively manage fungal disease that causes 10 to 80 % of the average annual estimated loss, including management costs to potatoes during the production cycle in Russia. The annual agricultural losses caused by these pathogens are highly significant. A field experiment was conducted for two consecutive years (2022 and 2023), using a potato varietal line and two fungicides (Zummer and Shirlan) to assess the efficiency of newly introduced and previously used fungicides on potato disease *Phytophthora infestans* (potato blight), *Rhizoctonia solani* (Black scurf), *Streptomyces scabies* (Common scab), and *Fusarium* spp. (Fusarium dry rot). The experiment was arranged in a randomized complete block design with four replicates. Generally, treatment 5 exhibited the highest pathogen severity population and lowest fresh tuber yield of potatoes. Treatments 2 and 4 (Zimmer and Shirlan at 0.4 L/ha) concentrations had the lowest pathogen severity population and highest fresh tuber yield of the crop studied in the experiment. Both treatments 2 and 4 had a statistically similar high tolerance to the disease pressure, contributing to an increase in fresh tuber yield of 10.25 t/ha. Treatment 5, which had the highest pathogen population, exhibited the lowest fresh tuber yield of 9.36 t/ha. This research demonstrated that the fungicides Zimmer and Shirlan significantly lowered the severity and interaction of all potato diseases studied. Therefore, the study confirmed that the application of Zimmer and Shirlan fungicides at four spraying intervals at a concentration rate of 0.4 L/ha within the developmental stages (budding, beginning of flowering, flowering, and end of flowering) effectively reduces disease development, damage caused by these potato diseases, and increases yield.

Keys words: *Phytophthora infestans*, fluazinam, potato tubers, fungicide, haulms

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Introduction

Potato belongs to the Solanaceae family. It is grown for its starched edible parts called tubers; it is a valuable food crop cultivated worldwide. The raw potato contains 2 % protein, 17 % carbohydrates (88 % of which are starch), 79 % water, and very little fat. Potatoes also have essential nutrients, including vitamins C, B6, potassium, magnesium, and iron [1–3]. Most potato starch comprises amylopectin, a branched chain glucose polymer, and amylose, a straight chain glucose polymer, in a comparatively constant 3:1 ratio. Russian Federation is the third-largest potato producer in the world, after China and India [4]. However, potato yields in Russia remain low compared to other European countries.

One of the main reasons for the decline in yields in all potato-growing regions of Russia is the massive damage to potato plants due to the pathogens *Phytophthora infestans* (Late blight or Potato blight), *Rhizoctonia solani* (Black scurf and Stem canker), *Streptomyces scabies* (Common scab), and *Fusarium spp.* (Fusarium dry rot) [5–7]. According to the Ministry of Agriculture of the Russian Federation, potato yield losses from this complex of pests amount to 50 % of the gross yield, which is 1.5 times higher than losses of grain crops [8]. The lack of resistant varieties also promotes the spread of these diseases. In this regard, potato productivity's biological and economic potential still needs to be utilized.

P. infestans affects the vegetative part of plants and leads to a significant decrease in assimilating surface of leaves, which affects the process of formation and tuber development [9]. On leaves and stems, the symptom appears in the form of dark brown, oblong spots. On the affected tubers, slightly depressed, sharply delimited brown spots form, the flesh under which has a rusty-brown color. Infection of tubers is possible from the earliest stages of their formation until harvesting. In recent years, there have also been cases of pathogen spore formation on the surface of tubers and their re-infection in storage [7, 8]. In field conditions that are under the epiphytotic development of late Blight, yield losses can reach 80.0 % in Belarus [9] and more than 20 % in Russia [6]. The main danger of phytophthora lies in its plasticity, ability to form dormant structures (oospores) that persist for long periods, and the evolution of *P. infestans* strains [10].

R. solani affects tubers, sprouts, stems, stolons, and, less commonly, the roots of adult plants. The disease manifests itself in the form of black scab, deep (pitted) spotting and reticulated necrosis of tubers, rotting of eyes and sprouts, death of stolons and roots, as well as dry rot of the underground part of the stem in the form of brown ulcers of various sizes on “rotten wood” and “white leg” stems [11–13]. In the Russian Federation, *R. solani* on potato plantings recorded 31.99 thousand hectares in 2017 and 26.06 thousand hectares in 2018. *P. infestans* developed on 9.60 thousand hectares in 2017 and 4.16 thousand hectares in 2018[1].

Fusarium dry rot is caused by several species of *Fusarium spp*., of which *F. avenaceum, F. oxysporum, F. solani,* and *F. culmorum* are the most harmful and have broad adaptive features to unfavorable environmental factors [14, 15]. The tubers become darker. During storage, it has a specific lilac smell [15]. Slightly affected potato tubers without visible symptomatic manifestations during planting and storage are dangerous to potato seed production. Such healthy planting material will significantly reduce the predicted yield, and storing it will lead to significant losses. According to experts, annual yield losses from fusarium blight during storage are 15 %, and if temperature and humidity are violated, they range from 25…50 % [13–15]. Unlike other pathogenic species, species of the genus *Fusarium* can accumulate large amounts of mycotoxins (Zearalenone (ZEA), fusarin C.) in potato tubers, which can cause significant harm to human and animal health [15].

Among the bacterial agents, *S. scabies* mainly affects tubers; less often, stolons and roots are the most devastating, causing economic losses to the potato-producing countries worldwide. Brown ulcers of irregular shapes and varying sizes form on the surface of the tubers. The prominent harm from this pathogen is a decrease in the quality of tubers. Tubers affected by scab have an unattractive appearance and lower taste and marketability, as they contain less starch [16].

More than twenty fungicides are currently available on the Russian market. However, Schepers et al. [10] and Kuznetsova et al. [6] indicate that not all fungicides are effective in controlling potato fungal diseases. Therefore, this research examines the effectiveness of different fungicide dosages and the application techniques in controlling Late blight, Black scurf, Common scab, and Fusarium dry rot, as well as sustainable management strategies to mitigate the disease in the Tambov region, Russian Federation (Fig. 1).

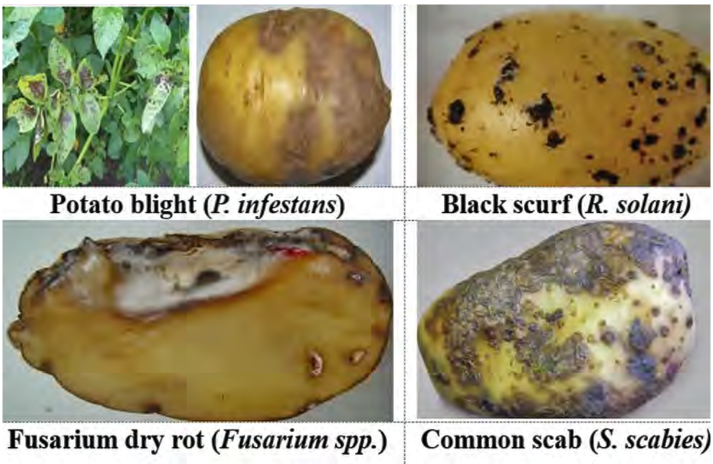

Fig 1. Symptoms of potato plant pathogens
Source: made by authors

[1] *Korneeva T.* TOP fungal and bacterial diseases of potatoes // GlavAgronom. 2020. Available from: https://glavagronom.ru/articles/TOP-gribnyh-i-bakterialnyh-boleznej-kartofelya

Materials and Methods

Description of the site. The experiment was conducted in Michurinsk at the "Roshcha" farm of Michurinsk State Agrarian University in the Tambov region (Russian Federation). The experiment was carried out for two years (2022 and 2023). The size of the experimental plots was 50 m^2, and the soil was a floodplain meadow light loamy with a pH scale ranging from 6.0 to 6.6. The soil had a thick humus horizon of 40 to 45 cm, and the humus content in the arable layer was 4.0 to 4.5 %, with a soil pH of 6.0 to 6.6.

Treatment and experimental design. The study was arranged in a randomized complete block design (RCBD) with four replications. All plots were arranged systematically on the potato variety line. The plot size was 9 m^2. Each plot had four rows (the middle two are harvestable) with inter- and intra-row spacing of 0.75 and 0.3 m, and every plot contained ten plants per row. The spacing between blocks and plots was 1.5 and 1 m, respectively. The treatment consisted of one potato varietal line and a combination of two types of fungicides (Zummer SC 500 g/L fluazinam and Shirlan SC 500 g/L fluazinam). These fungicides were obtained from registered companies in the country. Treatments included: T1: Zummer, SC (500 g/L fluazinam) 0.3 L/ha (new fungicide); T2: Zummer, SC (500 g/L fluazinam) 0.4 L/ha (new fungicide) T3: Shirlan, SC (500 g/L fluazinam) (standard): 0.3 L/ha; T4: Shirlan, SC (500 g/L fluazinam) (standard): 0.4 L/ha; and T5: Control (untreated) plots employed for comparison. Zummer, SC, is a contact fungicide and an analog of the fungicide Shirlan (both have the same active ingredient, fluazinam). Agronomic practices were carried out, beginning from tillage, plowing to a depth of 20…25 cm, and spring harrowing before cultivation at 12 cm, with no fertilizers applied. However, a general application of insecticides and herbicides at a consumption rate of (250 g/kg and 0.05 kg/ha) were applied before crop emergence. All treatments were carried out according to the BBCH scale: at the beginning of budding (51), the beginning of flowering (61), flowering (65), and at the end of flowering (69), respectively [17]. Tuber infestation records were determined following the methods generally accepted in phytopathological studies[2].

Table 1

Experimental design

Trade names	Treatments	Application rate	Active ingredients	Manufacturer
Zimmer	T1	0.3 L/ha	Fluazinam 500 g/L	Keminova A/S company, Denmark
Zimmer	T2	0.4 L/ha	Fluazinam 500 g/L	
Shirlan	T3	0.3 L/ha	Fluazinam 500 g/L	Farmoz PTY Limited Crop Care Australasia PTY LTD
Shirlan	T4	0.4 L/ha	Fluazinam 500 g/L	
Control	T5 untreated	N/A	N/A	N/A

[2] *Dolzhenko VI.* Metodicheskie ukazaniya po registratsionnym ispytaniyam insektitsidov, akaritsidov, mollyuskotsidov i rodentitsidov v sel'skom khozyaistve [Methodological guidelines for registration tests of insecticides, acaricides, molluscicides and rodenticides in agriculture]. St. Petersburg; 2009. (In Russ.).

Data collection and analysis

Analysis of disease and yield. Based on the records of haulm infestation in the field, yield losses for each disease were calculated. Tuber quality was assessed one month after storage using the express method (the degree of tuber infestation with phytophthora in %), and tuber marketability was evaluated [5].

Analysis of variance (ANOVA) was used to examine the relevance of disease severity and tuber yield (marketable and total yield). Fisher's protected least significant difference test at a 5 % significance level (LSD) was used to separate the means. All the analyses were done using GenStat statistical software [18].

Yield of fresh Tuber. At maturity, potato tubers were harvested from each plot's three inner rows and then sorted into marketable and unmarketable tubers based on the presence or absence of tuber color, size, and shape deformation. The fresh tuber potato yield weights per treatment were also recorded for analysis.

Results

The ANOVA (general results presented in Tables 2 and 3) detected trivial significant differences between the two trades fungicides used within the two growing potato seasons in this experimental period. In both growing seasons, potato leaf blight (*P. infestans*) was quite pronounced in the control (untreated plots) in early July. Generally, treatment 5 exhibited significantly the highest severity of disease and lowest fresh root yield of potato. At the same time, treatments 2 and 4 at a concentration of 0.4 L/ha of fungicide Fluazinam 500 g/L had the lowest disease severity and highest fresh root yield of the crop, respectively (Table 2). Both treatments 2 and 4 had a statistically similar high tolerance to the disease pressure, contributing to a high fresh root yield of 10.25 t/ha. Treatment 5, which had the highest disease severity, exhibited the lowest fresh root yield of 9.36 t/ha.

Table 2

Percentage Severity of potato leaf blight at different stages and fresh tuber yield

Treatments	Haulm	Harvest	One month after storage	Fresh tuber yield (t/ha)
T1	5.1	3.1	4.2	10.20
T2	2.3	2.0	2.1	10.25
T3	5.7	3.0	4.2	10.15
T4	2.2	2.1	2.1	10.25
T5	20.5	10.3	15.1	9.36
Mean	7.2	4.1	5.5	10.04
LSD (5 %)	0.48*	0.46*	0.61*	0.04*
CV (%)	4.3	7.4	7.2	0.3

Note. CV = coefficient of variation; LSD = least significance difference; * = significant at 5 % LSD.

The effect of different fungicide treatments applied on potato varietal lines shows highly significant differences among pathogens observed, and in comparing treatment five, the control (untreated plots) exhibited significantly the highest severity of disease than all other treatments.

Whereas treatments 2 and 4 at a concentration of 0.4 L/ha of fungicide Fluazinam 500 g/L had the lowest disease severity at harvest and storage (1.0 %) for Fusarium dry rot and Black scurf, the severity was 3.0 % at harvest and storage as well as Common scab (Table 3).

Table 3

The effect of different potato tuber diseases at harvest and storage

Treatments	Harvest			One month after harvest		
	Fusarium dry rot	Common scab	Black scurf	Fusarium dry rot	Common scab	Black scurf
T1	1.1	3.00	3.40	1.2	2.90	3.30
T2	1.0	3.20	3.00	1.0	3.20	3.10
T3	1.1	3.30	3.20	1.3	3.10	3.20
T4	1.0	2.8	3.00	1.1	3.00	3.10
T5	1.3	3.50	3.60	1.3	3.60	3.80
Mean	1.1	3.16	3.24	1.2	3.16	3.30
LSD (5 %)	0.44*	0.46*	0.61*	0.4*	0.45*	0.54*
CV (%)	26.0	9.50	12.30	21.3	9.30	10.60

Note. CV = coefficient of variation; LSD = least significance difference; * = significant at 5 % LSD.

In general, the mean yield advantage of the fungicides sprayed plots has a marketable value for treatment with the Zummer at two application rates: 0.3 L/ha was 57.0 % for (food) and at 0.4 L/ha, was 58.1 % for (food). Shirlan at the same application rates: 0.3 L/ha was 57.6 % for (food), and at the rate of 0.4 L/ha was 57.5 % for (food) and in control: was 55.0 % for (food) (Fig. 2).

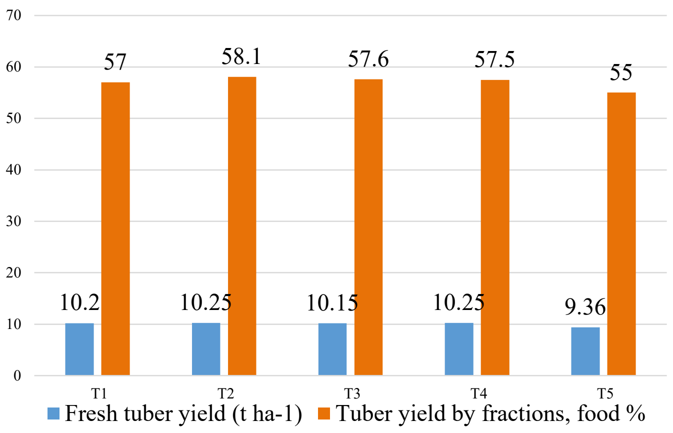

Fig. 2. Fresh tuber yield and tuber yield by fractions, food

Source: made by authors

Discussion

All fungicides applied in the trial substantially reduced foliage and potato tuber infection and increased yield effectively. The Effectiveness of fluazinam at 0.4 L/ha was superior to that of 0.3 L/ha in terms of overall efficacy. These results are in agreement with a previous study that evaluated fluazinam treatment on the pathogenic *P. infestans* population, indicating that Fluazinam was effective at a dose of 0.4 L/ha consisting of 100 % EU_33_A2 genotype [10]. In addition, Mukalazi et al. [19] and Xue et al. [20] also observed that the incidence and severity of Late blight on potato cultivars could significantly reduce the severity of most potato pathogens. The efficacy of this fungicide can be attributed to the fact that Fluazinam suppresses the respiration process by inhibiting energy metabolism in pathogen cells, inhibiting zoospore formation, appressorium formation, and pathogen hyphae growth [10, 21–24]. This fungicide also reduces the production of *F. graminearum* mycotoxin (deoxynivalenol) by disrupting peroxisome formation [23]. After one month's storage, both fungicides showed high efficacy in all amended tubers at the application rate of 0.4 L/ha. Considering the general effectiveness of the two fungicides, Late blight severity was highly reduced and significant, compared to other potato diseases in this study. These results are similar to those of Sedlák et al. [25], in which the application of Altima 500 SC (Fluazinam 500 g/L) at 0.4 L/ha was more effective against Late blight than Common scab, Black scurf, and Silver scurf. As a result, fungicides must be utilized to control disease in moderately resistant types.

In addition to the effectiveness of the two fungicides studied, findings by Xue et al. agree with our result that to effectively decrease the occurrence of Fusarium dry rot of potatoes in storage, a registered chemical synthetic fungicide and post-harvest treatment can be effective [15]. According to Xue et al. (2013) [20], more than 85 % of potatoes should be stored for 3–6 months as a vegetable, seed, and industrial material, and the losses due to disease during storage are significant. Fungus, bacteria, and viruses can cause post-harvest disease. Among these is *Fusarium* spp. infection of potato tubers, which can cause severe dry rot during storage, resulting in not only quality decline but also a reduction in marketable yield.

Also, in reducing common scab potatoes, several effects have been made by [21, 22] to control common scab disease potatoes through seed treatment with chemical fungicides Fluazinam, Mancozeb, and Benzothiazole and all proved to be effective in suppressing the disease. Thus, their findings are in agreement with our result stating that the application of fungicide Fluazinam 500 g/L at a concentration of 0.4 L/ha reduces disease severity at harvest and storage for Fusarium dry rot (1.0 %), Black scurf at (3.0 %) as well as Common scab (3.1 %) respectively.

Conclusion

Based on the result of this experiment, the two fungicides used in this experiment were effective in reducing all potato diseases studied in the field and at the storage; these chemicals applied at 0.4 L/ha effectively reduced all disease development and increased yield in all treatment plots as compared to the control plot. In General, the application rates and techniques employed during the vegetative phases, harvesting, and storage of the potato variety line in the Tambov region (2nd soil-climatic zone of Russia) were key. It is, therefore, evidence that the use of fungicides with the active ingredient Fluazinam at four developmental stages of the potato can be effective in the fight against *P. infestans*, on haulm and tubers, and at harvesting and during storage. Based on the qualitative and quantitative characterization of the tuber yield, Zummer and Shirlam fungicides at the rate of 0.4 L/ha had the best advantage over 0.3 L/ha, and the least was evidence at all control plots. Therefore, the selected fungicides can be recommended for incorporation into the package as a significant input for potato disease control and production in the Tambov region of the Russian Federation.

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Влияние фунгицидов на развитие болезней картофеля в Тамбовской области Российской Федерации

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Аннотация. Применение фунгицидов позволяет эффективно бороться с грибными заболеваниями картофеля, на долю которых в России ежегодно приходится от 10 до 80 % всех потерь. На протяжении всего производственного цикла патогены наносят весьма значительный ущерб сельскохозяйственной культуре. Полевые исследования по изучению эффективности фунгицидов Зуммер (500 г/л флуазинам) и Ширлан (500 г/л флуазинам) в отношении патогенов картофеля *Phytophthora infestans*, *Rhizoctonia solani*, *Streptomyces scabies* и *Fusarium* spp. проводили в 2022–2023 гг. Эксперимент организовали в виде рандомизированных полных блоков с четырьмя повторениями. В варианте 5 наблюдали самое сильное повреждение растений картофеля грибными болезнями и получили самый низкий урожай свежих клубней — 9,36 т/га. Максимальный урожай клубней отмечен в вариантах 2 и 4 при использовании фунгицидов Зуммер и Ширлан в концентрации 0,4 л/га, где повреждение патогенами было наименьшим. В вариантах 2 и 4 наблюдали статистически одинаковую высокую устойчивость к повреждению грибными болезнями, что способствовало увеличению урожая свежих клубней до 10,25 т/га. Результаты исследования показали, что фунгициды Зуммер и Ширлан значительно снижают степень поражения всех изученных болезней картофеля. Таким образом, четырехкратное опрыскивание фунгицидами Зуммер и Ширлан в концентрации 0,4 л/га на стадиях развития картофеля (бутонизация, начало цветения, цветение и конец цветения) эффективно снижает развитие болезней, повреждение растений и повышает урожайность картофеля.

Ключевые слова: *Phytophthora infestans*, флуазинам, клубни картофеля, фунгицид, ботва

Заявление о конфликте интересов: Авторы заявляют об отсутствии конфликта интересов. Все препараты приобретались на рынке.

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