The influence of fungicides and plant growth regulators on the susceptibility of apple trees (*Malus domestica* (Suckow) Borkh.) to fungal diseases

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Abstract. The study was conducted during the 2024-2025 growing seasons on the territory of the Fruit Crops Department of the V.I. Edelstein Educational, Scientific and Production Center for Horticulture and Vegetable Growing of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy in Moscow. The experiment was laid out in three summer plantings of the Rozhdestvenskoye and Honey Crisp apple varieties. The field experiment included treatments with the fungicides Skor, KE (250 g / l difenoconazole), Horus, VDG (750 g / kg cyprodinil), as well as options with separate use of plant growth regulators Obereg, P (0.15 g / l arachidonic acid), AgroStimul, VE (50 g / l dihydroquercetin). During the growing season, the biological effectiveness of the treatments in reducing fungal diseases (powdery mildew and Alternaria blight) and their impact on apple shoot growth were assessed. It was found that the combined use of these growth regulators and fungicides resulted in the best results in reducing fungal disease development and increasing apple shoot growth throughout the growing season. Over the course of two years of research, it was found that the separate use of these growth regulators also significantly reduced the development of fungal diseases and contributed to increased shoot growth in the current year compared to the control.

1 Introduction

The use of plant growth regulators in modern agriculture is becoming a fairly common practice for cultivating most crops. Growth regulators are also widely used in fruit growing [1-2]. Some registered plant growth regulators are recommended for use during the growing season on apple trees not only to increase yield but also to enhance the crop's resistance to various fungal diseases [3]. The use of plant growth regulators is a promising area in fruit growing, as it allows for increased plant productivity without increasing pesticide loads.

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All registered growth regulators are classified as moderately hazardous or low-hazard to human health [3]. Naturally occurring growth regulators pose the least hazard to humans. The use of growth regulators is not associated with the risk of accumulation of toxic pesticide residues in the crop, yet it can significantly increase apple yield and quality. Some researchers point to the ability of growth regulators to reduce the level of pesticide residue contamination in the yield of certain agricultural crops when used in conjunction with chemical plant protection products [4]. To reduce direct labor costs on apple trees, growth regulators can be used in a tank mix with fungicides, as the application times for these types of products often overlap [1-2, 4]. It should be noted that plant growth regulators have low application rates, which also positively impacts their cost-effectiveness.

Currently, in the Central Region of the Russian Federation, a fungal disease, *Alternaria* mali Roberts, is significantly developing on apple tree plantings. A number of researchers have noted the particularly high severity of this disease on young apple trees of various varieties [5]. Finding ways to improve the effectiveness of disease control measures is a popular topic in apple tree protection in the Central Region of the Russian Federation. The use of growth regulators to combat this harmful disease is a relevant research topic.

The combined use of growth regulators and fungicide treatments to protect apple trees from harmful fungal diseases is an important area of research, as the use of growth regulators in this case will not only increase yield and improve crop quality but can also enhance the biological efficacy of the fungicides themselves by boosting plant immunity. It should be noted that the greatest positive effect of growth regulators is possible with the use of effective plant protection products. Therefore, studying the combined use of fungicides and growth regulators in apple tree crops is a relevant topic for research.

2 Materials and Methods

The experiment was conducted during the 2024-2025 growing seasons at the Fruit Crops Department of the V.I. Edelstein Educational, Scientific, and Production Center for Horticulture and Vegetable Growing of the Russian State Agrarian University – Moscow Timiryazev Agricultural Academy in Moscow.

The trials were conducted over two years in a super-intensive orchard of three-year-old apple trees, using combined support structures. The varieties used were Honey Crisp and Rozhdestvenskoye, both included in the State Register and known for their late ripening. Each treatment, including the control, included at least 16 plants of the same variety. Both varieties were grafted onto the semi-dwarf rootstock 62-396. In the experiment, we used preparations approved for use in the territory of the Russian Federation on apple tree plantings: the fungicide Skor, EC (250 g/l difenoconazole) (Syngenta, Russia) at a consumption rate of 0.35 l/ha (in the pink bud and petal fall phase) and Horus, VDG (750 g/kg cyprodinil) (Syngenta, Russia) at a consumption rate of 0.2 kg/ha (in the end of flowering phase and 10 days after the first treatment). Plant growth regulator Obereg, P (0.15 g/l arachidonic acid) (OOO ORTON), 1st application at the beginning of flowering, 2nd application one month after the first; plant growth regulator Agrostimul, VE (50 g/l dihydroquercetin) (OOO AGRUSHIM), 4.0 ml/10 l of water, 1st application at the "pink bud" stage, 2nd application at the "walnut fruit" stage.

Plant infestation by fungal diseases was assessed using a generally accepted phytopathological scale of five points [6]. During the growing season, the biological effectiveness of treatment with the preparations under consideration against powdery mildew and alternaria was assessed.

Also, at the end of the growing season, the growth rate in various experimental variants was assessed relative to the control (without treatment with the preparations).

Chemical treatments were carried out using a Gardena-10 l knapsack sprayer in windless weather, at an air temperature of at least 15° C, while observing all safety measures required when working with pesticides.

3 Results and Discussion

During the 2024-2025 growing seasons, powdery mildew development in apple tree orchards was observed beginning in the second ten days of May, and alternaria blight development began in the first ten days of June. Under 2024 conditions, slightly stronger alternaria blight development was observed compared to 2025. Differences in the severity of powdery mildew development on the studied apple varieties were less significant over the two years of the study. These differences in fungal disease development are most likely related to lower temperatures in May 2025 compared to the same period in 2024. Plant debris is known to be the primary source of primary alternaria blight infection in apple trees. A longer period of below-normal temperatures under May 2025 conditions could have significantly reduced the development and spread of primary alternaria blight infection, which primarily persists in plant debris.

The maximum Alternaria blight development under 2024-2025 conditions was observed in both varieties in the control variants of the experiment. Thus, the Alternaria blight development on the Rozhdestvenskoye apple variety reached 26.3% in the control variant under 2024 conditions, and 7.8% under 2025 conditions. On the Honey Crisp apple variety, Alternaria blight development in the control variant reached 23.7% and 6.4%, respectively, in 2024 and 2025 (Tables 1-4).

Arachidonic acid, the active ingredient in the growth regulator Obereg, P, is capable of not only affecting plant growth and development but also exerting an immunostimulatory effect on various plant species. Arachidonic acid is known to promote the activation of genes responsible for immunity, activate lipid and phenol metabolism, and increase the activity of peroxidases and lipoxidases. Arachidonic acid has been shown to promote the formation of phytoalexins - substances that increase local resistance to damage and pathogens. Arachidonic acid also has been shown to alter terpenoid biogenesis, which affects free sterol levels and promotes the development of specific immunity [1-2, 7-9].

The plant growth regulator Agrostimul, VE, contains the bioflavonoid dihydroquercetin as an active ingredient. Its primary effect on plants is to increase resistance to diseases and adverse environmental factors, enhance the growth of the root system and aboveground organs, and consequently improve yield and quality. The substance is a powerful antioxidant. One of its properties is the activation of anti-stress responses in plants, particularly those caused by low temperatures [2, 10-11].

The use of the plant growth regulator Obereg, R, without fungicide treatments, significantly reduced the development of fungal diseases. For example, in the Rozhdestvenskoye apple variety, in the treatment using only the plant growth regulator Obereg, R, the development of Alternaria blight decreased by 51.7% in 2024 and was 47.4% lower in 2025 than in the control (Tables 1-4). Similar efficacy against Alternaria leaf spot was achieved with the growth regulator Obereg, R on the Honey Crisp apple tree: 54.4% under 2024 conditions and 48.4% in 2025 (Tables 1-4).

In our experimental conditions, higher biological efficacy was recorded for the treatments using plant growth regulators in combination with fungicides compared to those using fungicides alone.

The active ingredient in the fungicide Skor, EC is difenoconazole. This substance is a systemic fungicide belonging to the triazole class. It has a protective and therapeutic effect on plants against a broad spectrum of phytopathogenic fungi, and is effective against fungi of the genus *Alternaria*. Another important effect of difenoconazole on plants is its ability

to have a positive effect on the growth and development of plants, as well as the ability to have an immunizing effect on the treated plant [10-11].

Application of the Skor, KE fungicide against apple Alternaria blight at the end of the growing season demonstrated efficacy of 70.3-66.7% (Tables 1-4) on the Rozhdestvenskoye variety and 79.7-67.2% (Tables 1-4) on the Honey Crisp variety over two years.

Combined application of the Skor, KE fungicide with the Agrostimul, VE plant growth regulator on the Rozhdestvenskoye variety reduced Alternaria blight development by 85.6% and 82.1% (Tables 1-4), respectively, in 2024-25. On the Honey Crisp variety, the reduction in Alternaria blight development in this variant amounted to 89-81.3% over the two years of the study. Thus, based on a comparison of biological efficacy data on two different varieties, it can be concluded that the combined application of the plant growth regulator Agrostimul, VE and the fungicide Skor, EC was more effective than when either fungicide was applied separately.

The combined application of the plant growth regulator Obereg, R and the fungicide Skor, EC was 87.1-89.7% effective on the Rozhdestvenskoye variety and 94.1-87.5% effective on the Honey Crisp variety (Tables 1-4). Thus, when the fungicide treatment was supplemented with the growth regulator Obereg, R, an increase in the biological efficacy of treatments against apple Alternaria was recorded.

The fungicide Horus, VDG, with the active ingredient cyprodinil, used in the trials, is a systemic fungicide belonging to the aniline pyrimidine class. It is a fungicide with therapeutic and systemic action, effective against a number of widespread fungal pathogens of apple trees, including apple alternaria [2, 10-11].

Application of the Horus, VDG fungicide against apple Alternaria blight at the end of the growing season demonstrated an efficacy of 71.9-71.8% (Tables 1-4) on the Rozhdestvenskoye variety and 78.1%-68.8% (Tables 1-4) on the Honey Crisp variety over two years.

Combined application of the Horus, VDG fungicide with the plant growth regulator Agrostimul, VE on the Rozhdestvenskoye variety reduced the development of Alternaria by 83.3% and 88.5% (Tables 1-4), respectively, in 2024-25. On the Honey Crisp variety, the reduction in Alternaria development in this variant amounted to 85.7-89.1% over the two years of the study. Thus, based on a comparison of biological efficacy data on two different varieties, it can be concluded that the combined application of the plant growth regulator Agrostimul, VE and the fungicide Horus, VDG was more effective than when either fungicide was applied separately.

The combined application of the plant growth regulator Obereg, R and the fungicide Horus, VDG was 84-85.9% effective on the Rozhdestvenskoye variety and 86.9-79.7% effective on the Honey Crisp variety (Tables 1-4). Thus, when the growth regulator Obereg, R was added to the fungicide treatment, an increase in the biological efficacy of treatments against apple Alternaria was recorded.

In the variants using the fungicide Horus, VDG, an increase in the biological efficacy of chemical treatments was also recorded when the fungicide and the studied growth regulators were combined.

Based on two years of data on the Rozhdestvenskoye variety, compared to the isolated application of Skor, EC, its effectiveness increased by 21.8-23.1% with two additional treatments with the plant growth regulator Agrostimul, VE, and by 23.9-34.5% with an additional two-fold treatment with Obereg, R. On the same variety, the effectiveness of the fungicide Horus, VDG increased by 15.9-23.3% with the use of Agrostimul, VE, with two additional treatments with the plant growth regulator Agrostimul, VE, and by 16.8-19.6% with an additional two-fold treatment with Obereg, R.

Table 1. The effect of treatment with fungicides and plant growth regulators on the development of the current year's growth and susceptibility to Alternaria of the Rozhdestvenskoye apple tree variety, 2024.

Experience options	Average growth length, cm	Increase in the average length of growth for the current year, %	Alternaria (R)*	Alternaria (BE)**
Obereg, R	30.6	37.2	12.7	51.7
Agrostimul, VE	33.1	48.4	13.3	50.6
Skor, KE	31.1	39.5	7.8	70.3
Horus, VDG	30,8	38.1	7.4	71.9
Skor, KE + Agrostimul, VE	38.0	70.4	3.8	85.6
Skor, KE + Amulet, R	30.8	38.1	3.4	87.1
Horus, VDG + Agrostimul, VE	37.5	68.2	4.4	83.3
Horus, VDG + Amulet, R	30.8	38.1	4.2	84
Control	22.3	-	26.3	-
HCP_{05}	0.31	-	0.41	-

Note: *R - disease progression, **BE - Biological effectiveness

Table 2. Effect of fungicide and plant growth regulator treatments on the development of current-year growth and the susceptibility to Alternaria in the Honey Crisp apple variety, 2024.

Experience options	Average growth length, cm	Increase in the average length of growth for the current year, %	Alternaria (R)*	Alternaria (BE)**
Obereg, R	25.0	36.6	10.8	54.4
Agrostimul, VE	24.2	32.2	11.4	51.9
Skor, KE	21.5	17.5	4.8	79.7
Horus, VDG	21.6	18.0	5.2	78.1
Skor, KE + Agrostimul, VE	23.6	29.0	2.6	89.0
Skor, KE + Amulet, R	25.0	36.6	3.1	86.9
Horus, VDG + Agrostimul, VE	25.3	38.3	3.4	85.7
Horus, VDG + Amulet, R	24.3	32.8	1.4	94.1
Control	18.3	-	23.7	-
HCP_{05}	0.23	-	0.10	-

Note: *R - disease progression, **BE - Biological effectiveness

Based on two years of data on the Honey Crisp variety, compared to the single application of Skor, EC, its effectiveness increased by 11.7-20.9% with two additional treatments with the plant growth regulator Agrostimul, VE, and by 18.1-30.2% with two additional treatments with Obereg, R. On the same variety, the effectiveness of the fungicide Horus, VDG increased by 9.7-29.5% with two additional treatments with the plant growth regulator Agrostimul, VE, and by 11.3-15.8% with two additional treatments with Obereg, R.

One of the apple tree development indicators that can be influenced by the use of plant growth regulators is the average length of the current year's growth, which we measured at the end of the growing season for two years. It should be noted that, under our study conditions, the current-year growth values varied over the two years and depended on both the age of the trees and the climatic conditions of the study year. It is important to note that

abnormally low air temperatures and increased precipitation were observed during the first half of the 2025 growing season.

The increase in current-year growth on the Rozhdestvenskoye apple variety relative to the control over the two years was 37.2% and 11.9% with the growth regulator Obereg, P, and 48.4% to 35.5% with the preparation Agrostimul, VE.

Table 3. Effect of fungicide and plant growth regulator treatments on current-year growth and Alternaria susceptibility of the Rozhdestvenskoye apple variety, 2025.

Experience options	Average growth length, cm	Increase in the average length of growth for the current year, %	Alternaria (R)*	Alternaria (BE)**
Obereg, R	33.0	11.9	4.1	47.4
Agrostimul, VE	35.8	21.4	4.8	38.4
Skor, KE	34.0	15.3	2.6	66.7
Horus, VDG	30.4	3.1	2.2	71.8
Skor, KE + Agrostimul, VE	39.7	34.6	1.4	82.1
Skor, KE + Amulet, R	40.5	37.3	1.1	85.9
Horus, VDG + Agrostimul, VE	39.3	33.2	0.9	88.5
Horus, VDG + Amulet, R	42.4	43.7	0.8	89.7
Control	29.5	-	7.8	-
HCP_{05}	0.27	-	0.13	-

On the Honey Crisp apple variety, the isolated application of the Obereg, R plant growth regulator resulted in a 36.6% and 19.4% increase in average shoot length, respectively, while the application of the Agrostimul, VE plant growth regulator increased this indicator by 32.2% and 24.7%.

The highest increases in shoot length were recorded in variants combining fungicide treatment with plant growth regulators. Thus, under 2024 conditions, the application of the Agrostimul, VE growth regulator on the Rozhdestvenskoye variety, along with the Skor, KE, and Horus, VDG fungicides, resulted in a 68.2-70.4% increase in shoot length for the current year under 2024 conditions and a 33.2-34.6% increase under 2025 conditions.

The application of Obereg, R, in combination with fungicides on the Rozhdestvenskoye variety, resulted in a 30.8% increase in current year growth under 2024 conditions and a 37.3-43.7% increase in 2025.

Under 2024 conditions, the use of the growth regulator Agrostimul, VE, in combination with the fungicides Skor, KE and Horus, VDG, on the Rozhdestvenskoye variety resulted in a 29 to 38.3% increase in current year growth under 2024 conditions and a 32.3-32.6% increase in 2025 conditions.

The application of Obereg, R, in combination with fungicides on the Rozhdestvenskoye variety, resulted in a 32.8-36.6% increase in current year growth under 2024 conditions and a 27.6-30.8% increase in 2025.

Analyzing the obtained data, it can be noted that in all experimental variants, the increase in shoot length for the current year was significant. The applied growth regulators significantly increased shoot length by the end of the growing season. This result is particularly important for young apple trees, as it ensures accelerated plant growth, faster crown formation, and productive plants.

Table 4. Effect of fungicide and plant growth regulator treatments on current year shoot development and Alternaria susceptibility of the Honey Crisp apple variety, 2025.

Experience options	Average growth length, cm	Increase in the average length of growth for the current year, %	Alternaria (R)*	Alternaria (BE)**
Obereg, R	33.3	19.4	3.3	48.4
Agrostimul, VE	34.8	24.7	3.6	43.8
Skor, KE	29.2	4.7	2.1	67.2
Horus, VDG	28.5	2.2	2.0	68.8
Skor, KE + Agrostimul, VE	37.0	32.6	1.2	81.3
Skor, KE + Amulet, R	36.5	30.8	1.3	79.7
Horus, VDG + Agrostimul, VE	36.9	32.3	0.7	89.1
Horus, VDG + Amulet, R	35.6	27.6	0.8	87.5
Control	27.9	-	6.4	-
HCP_{05}	0.34	-	0.14	-

The positive effect of the growth regulators Obereg, R, and Agrostimul, VE, associated with improved growth formation this year, is primarily explained by the ability of these growth regulators to enhance plant growth processes. It is also important to consider that meteorological conditions in 2024 and 2025 were challenging for the development of young apple trees, as both years saw significant periods of low temperatures in May, with a particularly prolonged period of low temperatures observed in May 2025. The observed increase in apple shoot growth in the variants using the growth regulators can also be attributed to the protective properties of these products, as their action is associated with increased plant resistance to various stressful conditions.

The recorded increase in the biological effectiveness of fungicide treatments with the fungicides Skor, KE and Horus, VDG when combined with plant growth regulators against apple Alternaria is explained by the ability of the stimulants in question to have a positive effect on plant immunity and increase their stress resistance.

4 Conclusion

The use of the fungicides Skor, KE, and Horus, VDG provided a relatively high biological efficacy against apple Alternaria blight.

The growth regulators Obereg, R, and Agrostimul, VE significantly reduced the development of Alternaria blight on young apple trees of the Rozhdestvenskoye and Honey Crisp varieties. The reduction in Alternaria blight in the treatments using these regulators ranged from 38.4% to 54.4%. A significant reduction in Alternaria blight development in treatments using only the growth regulators Obereg, R, and Agrostimul, VE suggests the possibility of using these products to combat this disease in combination with other protective measures.

The highest biological efficacy against apple Alternaria blight was demonstrated by the combined use of fungicides and the plant growth regulators Obereg, R, and Agrostimul, VE due to their immunizing effect and ability to reduce the negative impact of abiotic factors.

The observed positive effect of the plant growth regulators Obereg, R, and Agrostimul, VE on the current year's growth during the growing season and their ability to reduce the development of Alternaria blight suggest the possibility of incorporating these products into apple tree protection measures.

The obtained results on the effectiveness of using the plant growth regulators Obereg, R, and Agrostimul, VE, both individually and in combination with fungicides, against

Alternaria blight of apple trees indicate the need for continued research in this area. It should be noted that this issue also requires study from the perspective of the possibility of using plant growth regulators to reduce pesticide loads and mitigate the risk of apple crop contamination.

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