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Effectiveness of *Rhodococcus erythropolis* strain OPI-01 on the fungal development in winter wheat

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Abstract. *Behzad A, Diakite S, Astarkhanova TS, Pakina EN, Allen D, Mohammadi PM, Diarra O, Saquee FS. 2024. Effectiveness of* Rhodococcus erythropolis *strain OPI-01 on the fungal development in winter wheat. Biodiversitas 25: 1063-1070.* One of the means of sustainable wheat production is using bacterial pesticides, which can synthesize phytohormonal substances with antibacterial and antifungal action. Therefore, the work aimed to study the effect of different doses of a new growth regulator Restart, ZH (*Rhodococcus erythropolis* D strain OPI-01) on winter wheat yield. The findings of field experiments on the effect of plant growth regulator *R. erythropolis* strain OPI-01 method of pre-sowing treatment of seeds (at 0.1 L/t and 0.2 L/t), and soil spraying just before sowing (-0.5 l/ha) revealed that on average, during the 2020-2021 and 2021-2022 seasons, the number of productive stems increased by a margin of 23-30, the number of grains in 1 ear increased in the experimental units by 16.2-19.4%, and the length of the ear by 0.3-0.7cm, gluten varied from 32.3 to 33.8%, yield increased from 27.8-33.0% relative to the control. Disease severity and incidence of powdery mildew, brown rust and Septoria disease in plots amended with*R. erythropolis* strain OPI-01 was 2-fold less than in the control plots. Research trials show the efficacy of *R. erythropolis* strain OPI-01 under field conditions as a plant growth regulator and a potential microbial fungicide against some foliar diseases of winter wheat. It would be exciting to study the mechanism of *R. erythropolis* on wheat pathogens in vitro and in planta which are still less developed in the literature.

Keywords: Growth regulator, sustainable production, wheat, yields

INTRODUCTION

Wheat ranks first among all grain crops in Russia and occupies about 36% of the total area of cereals. It is also the most susceptible crop to numerous biotic factors (e.g., fungal, bacterial, and viral diseases) or abiotic factors (e.g., drought or nutrient deficiencies) stresses (Sanin 2016). In the Moscow region, root rot and rust, powdery mildew, and Septoria leaf blotch disease are among the leaf and stem diseases that predominate in wheat fields. Yield losses from leaf pathogens are associated with decreased grain weight, and reduced number of grains, transpiration of plants, which leads to desiccation and infection by other fungi, decreased leaf area, and reduced photosynthesis, which leads to shriveling of grains, resulting in lodging. Root rot pathogens are also the most common on cereal crops recently (Kekalo 2021). In terms of total wheat grain losses from pathogens, leaf and stem diseases account for 30-60%, spike infections 10-20%, and root and root rots 15-25% in Russia (Sanin 2016). One of the sources of the early appearance of fungal diseases in wheat is the use of infected seeds (Figueroa et al. 2018). The average annual infestation of wheat and barley seed with root rot in the region exceeds the 15% threshold of harmfulness.

Therefore, pesticides and fertilizers are used to reduce fungal diseases in large quantities for large-scale wheat production, resulting in the release of nutrients into the environment and other negative consequences such as reduction of soil microbiota, contamination of drinking water, and eutrophication of freshwater systems and coastal areas (Kuhl et al. 2021; Thakur et al. 2023a; Sharma et al. 2024). For example, between 2002 and 2018, the global population increased by about 21 percent and cereal production by about 44 percent, while pesticide use per hectare of farmland increased by about 30 percent and inorganic fertilizer use per hectare increased by about 23 percent for nitrogen, 13 percent for phosphorus, and 56 percent for potassium (UNEP 2021).

Many studies have also shown that environmental pollution by heavy metals such as Cd, Co, Cu, Pb, Zn, Ni, and Ag can reduce the yield of wheat and all major crops worldwide (Rizvi et al. 2020; Thakur et al. 2023b). Cd and Zn had similar inhibitory effects and reduced relative growth rate and CO_2 assimilation rate by 50% and 30%, respectively, in the second-developed leaf of wheat seedlings (Paunov et al. 2018). Metals inhibit plant mass growth and reduce photosynthetic activity and nutrient uptake.

One of the means of sustainable wheat production is the use of microbial preparations, representatives of which can synthesize substances of phytohormonal nature that have antibacterial and antifungal effects (Thakur et al. 2023b; Sharma et al. 2024). Wheat can interact with many plants' growth-promoting rhizobacteria, which are both phytoprotective and phytostimulatory (Mavrodi et al. 2018). Currently, some pure microbial strains such as members of the genus *Rhodococcus* have been described in the literature as capable of increasing the resistance of wheat to various stresses as well as reducing the accumulation of fungicides belonging to the benzothiazole class in the environment (Kuhl et al. 2021). *Rhodococcus erythropolis* is a Gram-positive actinobacterium with a great ability to control plant diseases by inhibiting N-lactone acyl-homoserine signaling molecules (Latour et al. 2013). Seed pretreatment is one of the main methods of controlling plant diseases during the initial period of plant development and allows the formation of healthy and vigorous seedlings, which are the key to good yields (Kekalo 2021; Mulk et al. 2022). There is little data in the literature on the effectiveness of *R. erythropolis* effectiveness in the crop under field conditions, so the work aims to study the effect of the dose of a new growth regulator Restart, ZH of different spectrum of action on the formation of winter wheat yields in the background.

METHODS AND MATERIALS

Experimental site

The research was conducted during the growing seasons 2020-2021 and 2021-2022, following all agronomic procedures of D.N. Pryanishnikov Russian Research Institute of Agrochemistry, located in the Domodedovo Micro District, Barybino Microdistrict, Moscow Region, Russia

Agrochemical characteristics of the soil

Experimental sites were located at the zone of sod-podzolic, heavy loams. The amount of humus in the layer 0-10 cm does not exceed 4.5%, in the layer 30-40 cm - 2.3%, and in the horizon, 70-80 cm was 0.9%. Soil boils under the humus horizon at a 30-50 cm depth. Absorption capacity in the humus horizon was 25-30 mg-eq. per 100 g of soil. The upper middle loam horizons and clay interlayer, which lies at a depth of 0.97-1.1 m, where non-saline. The amount of hydrolyzable nitrogen was average.

The amount of phosphorus was very low, and the amount of mobile potassium was medium. Soils were slightly alkaline in the upper horizons. Before sowing winter wheat, soil samples were taken to determine soil pH, the content of easily hydrolyzable nitrogen, mobile phosphorus and exchangeable potassium in the soil layer of 0-0.8 m, as presented in Table 1.

Meteorological data

The climate of the Moscow Region is moderately continental with an average annual air temperature of about 4°C. Weather conditions during the 2020-2021 and 2021-2022 seasons did not differ from each other and were generally characterized as favorable for winter wheat (Figure 1). Average daily air temperatures ranged from -2 to 11°C from September to November. Plants went into winter in good condition. Snow cover was established in December with fluctuations of average daily air temperature from -3.7 to -6.0°C. The winter months (January and February) were snowy. Precipitation amounted to 114.2 mm during the months. The maximum amount of precipitation in the form of snow was recorded in February - 60.4 mm. The snow layer was 1.5 m high in March. Snow completely melted during the first 10 days of April. The mean monthly air temperature in April was 2°C above the mean summer temperature. The vegetation of plants resumed in the second decade of April. Air temperatures in May, June and July were higher and averaged was 14-23°C. Precipitation was recorded on average. Monthly precipitation amounted to 74.6 mm in April and 85.7 mm in May. Temperatures were higher in June and July, and precipitation was lower (30-60 mm) than the multiyear average data (75-86 mm). The duration of the period with positive temperatures was about 215 days. The average annual precipitation was 550-600 mm. According to long-term observations in Barybino settlement average annual air temperature is 3.3°C, and average multiyear precipitation varies within the range of 500-600 mm. In general, weather conditions are typical for south-eastern areas of the Moscow Region, where the sum of average daily temperatures during the growing season is 1900-2100°C and the hydrothermal coefficient is 1.3-1.4. The weather conditions in 2020-2021 and 2021-2022 allowed us to identify the biological effectiveness of Restart, Zh.

Restart, Zh- Is a liquid plant growth regulator with antidote properties containing biomass of live microorganisms in *R. erythropolis* cultivation medium strain OPI-01. The total number of viable bacterial cells in the finished product is not less than 1.5×10^9 CFU/ml. Seed pre-sowing treatment, spraying the soil just before sowing to establish the biological efficiency of winter wheat, helps to overcome temperature stress, mobilizes the immune system of plants, and increases germination energy and germination. The microorganisms in this preparation have a high ability to biodegrade chemical herbicides.

Table 1. Compositional analysis of the meadow medium loamy soil

Sampling depth (cm)	Humus (%0	pH	N hydrolyzable (mg/kg)	P_2O_5, mg/kg	K_2O (mg/kg)
0.0-10	4.19	7.2	48.6	24.3	350.0
10-20	3.83	7.2	41.7	19.6	310.0
20-30	3.58	7.2	35.9	15.2	290.0
30-40	2.46	7.1	32.0	12.6	230.0
70-80	0.92	7.1	23.2	9.2	170.0

Variety Duplet- It is a pedigree Line 94-247a655-1 x Moskvich, included in the State Register for the North Caucasus (6) region by the organization of the federal state budgetary scientific institution 'National Grain Center named after P.P. Lukyanen' in 2018. The average yield of this variety in the region is 58.1 c/ha. The growing season of Duplet is 219-286 days. It is resistant to lodging, *Septoria* leaf blotch, and moderately resistant to powdery mildew and brown rust. Duplet is also susceptible to *Fusarium* head blight and hardhead disease (https://reestr.gossortrf.ru/sorts/8559198/).

Experimental design and treatment applications

Tillage was carried out using the plough PN-4-35 at a depth of 20-25 cm, early spring harrowing with BZTS-1,0 harrow in 2 tracks at a depth of 3-5 cm and 5 tillage of fallow (cultivator KPIR-7,2 at a depth of 10-12 cm before sowing of winter wheat. Apre-sowing tillage at a depth of 6-8 cm using cultivator KPIR-7,2 and rolling of crops was adopted.

Fertilizer application. At sowing, complex fertilizer was applied in a dose of N16P16K16 (Azofoska, 1.0 c/ha). Nitrogen fertilization was carried out in spring with a dose of N35 (Ammonium nitrate, 1.0 cwt/ha).

The scheme of the experiment is presented in Table 2. The precursor was pure fallow. Sowing was carried out by SZ-5,4 seeder at a seed rate of 5.5 million/ha. The experimental plots where treated with herbicide Ametil VRK, 1 l/ha (500 g/l 2-methyl-4-chlorophenoxyacetic acid) in all variants (T0, T1 and T2). Pre-sowing treatment of seeds with the growth regulator Restart, Zh was carried out by semidry treatment using a machine for seed dressing and with a sprayer. Plants were sprayed using a Solo sprayer. The area of experimental plots was 100 m², and the area of registration plots is 50 m^2. All treatments were replicated four times, using Randomized Complete Block Design (RCBD).

Data collection

The onset of the main phases of plant development was noted, and the prevalence and intensity of disease were assessed. The prevalence and intensity of common root rot in wheat were carried out in the germination stage and wax ripeness stage. The total sample of selected plants was 100 plants from each plot. To determine the intensity of common root rot, seedlings are analyzed by grouping them according to the defeat scores: 0-no symptom of the disease; 0.1-10% of the organ surface is affected; 1-11-25% of the organ surface is affected; 2-26-50% of the organ surface is affected; 3-51-75% of the organ surface is affected. 4-75% of the organ surface is affected (Kekalo et al. 2017). The intensity of powdery mildew, brown rust, and Septoria leaf blotch was determined by the percentage of leaf and stem area covered with symptoms, according to the illustration scales: 0: no signs of damage; 1: up to 10% of leaf surface affected; 2: 11 to 25% affected; 3: 26 to 50% affected; 4: more than 50% of leaf surface affected (Figure 2) (Kekalo et al. 2017).

Table 2. Experimental design

Variant code	Treatments
T0	Control
T1	Background+ *Rhodococcus erythropolis* strain OPI-01. Seed pre-sowing treatment, Restart, Zh consumption - 0.1 l/ha of seeds, working solution consumption - 10 l/ha. Soil spraying just before sowing, agrochemical consumption - 0.5 l/ha, working solution consumption - 300 l/ha.
T2	Background+ *Rhodococcus erythropolis* strain OPI-01. Seed pre-sowing treatment, the rate of agrochemical - 0.2 L/t seed, the rate of working solution - 10 L/t. Soil spraying just before sowing, Restart, Zh consumption - 0.5 l/ha, working solution consumption - 300 l/ha.

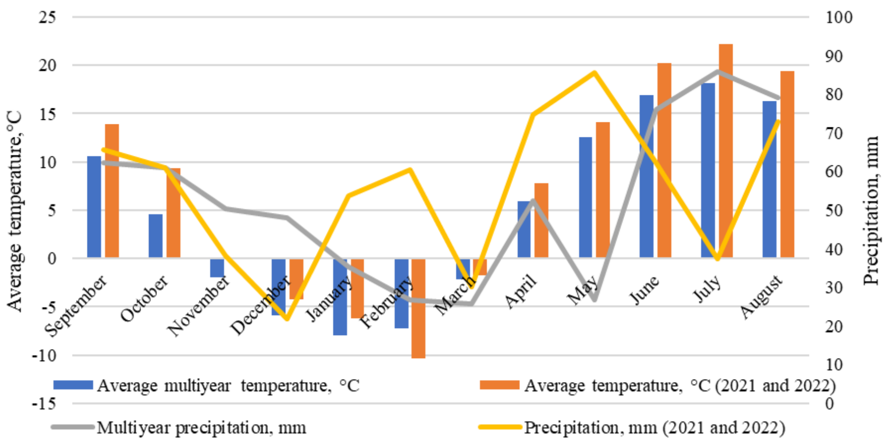

Figure 1. Meteorological data of Barybino, Russia. The planting material used in this study was soft winter wheat Duplet and a new growth regulator Restart, Zh

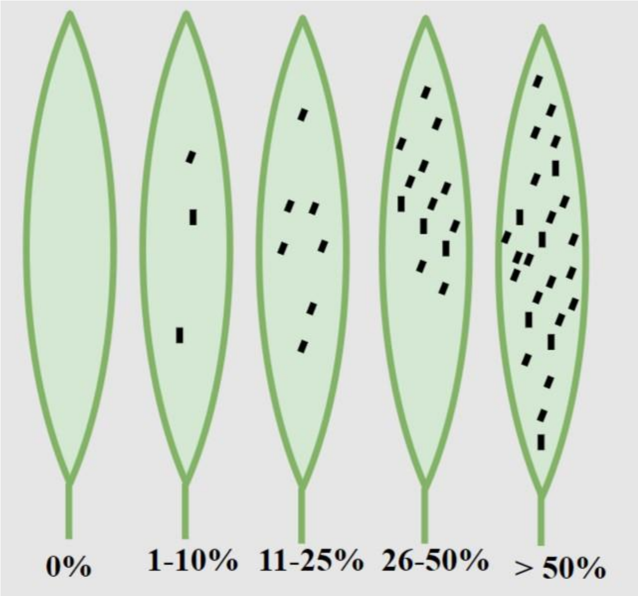

Figure 2. Scale for assessing wheat disease intensity

Disease prevalence was calculated using the formula (Aseeva et al. 2020; Feng et al. 2022): $P = \frac{n}{N} \times 100$, where P is disease prevalence (%); n is the number of diseased plants; N is the total number of counted plants.

The intensity of disease development in percentage was calculated by the formula (Aseeva et al. 2020; Feng et al. 2022): $R = \frac{\sum(a \times b)}{N} \times 100$, where R is the intensity of disease development (%); (ab) is the sum of the products of the number of plants (a) with the corresponding % symptoms (b); N is the total number of plants counted.

Yield accounting by harvester (test digging). After the harvest grain quality was determined according to the relevant standards: weight of 100 grains, mass fraction and quality of gluten according to GOST 1358.1-68, and protein according to GOST 10846-91.

Statistical data analysis

The data collected were subjected to analysis of variance (ANOVA) using the GENSTAT statistical program (GENSTAT, 15th release, Rothampstead, UK). The Least Significance Difference (LSD) was used to compare treatment means using a significance level of $\alpha = 0.05$. The residuals of the parameters studied were first checked for normality and homogeneity using the Shapiro-Wilk and Bartlett's tests to ensure that data were normally distributed (Saquee et al. 2023).

RESULTS AND DISCUSSION

Phenological phase of winter wheat

Phenological observations showed that the growing season of winter wheat variety is 265 days: sowing - seedlings is 10-13 days, seedlings - bushing is 12-13 days, tillering - leaving the tube is 12-13 days, leaving the tube - earing is 8-11 and earing - maturation (full ripeness) is 40-45 days.

Effectiveness of *Rhodococcus erythropolis* strain OPI-01 on the development of fungal diseases on wheat crops

The effects of *R. erythropolis* strain OPI-01 on fungal development at different growth and development stages in winter wheat crop are presented in Tables 1-4. Growth regulator treatments significantly ($p<0.05$) affected the disease prevalence and intensity of winter wheat sampled at the wax ripeness stage, while at the germination stage, only disease prevalence exhibited significant variation among treatments. Winter wheat grown under non-amended growth regulator plots had higher fungal disease prevalence and intensity scores than those amended with growth regulator, *R. erythropolis* strain OPI-01 (Table 3). At the germination stage, non-amended treatment 0 L/ha RES OPI-01 (T0) exhibited the highest prevalence and intensity of 12.3 and 9.1%, respectively, whereas treatments 0.2 L/ha RES OPI-01 (T2) and 0.1 L/ha RES OPI-01 (T1) had the lowest values of 11.8 and 8.7%, respectively. At the wax ripeness stage, treatment 0 L/ha RES OPI-01 (T0) had the highest prevalence and intensity of 25.5 and 13.7%, while treatment 0.2 L/ha RES OPI-01 (T2) had the lowest values of 8.1 and 5.9%, respectively. The disease severity in the experimental units was 2.4 and 1.8 times lower than the severity observed in the control plants.

The incidence and severity of powdery mildew, brown rust, and Septoria leaf blotch developments in plots amended with 0.1 L/ha RES OPI-01 and 0.2 L/ha RES OPI-01 were significantly ($p<0.05$) lower than the control, indicating the immune action of *R. erythropolis* - OPI-01. However, no significant differences were found in the effect of increasing doses from 0.1 L/ha RES OPI-01 to 0.2 L/ha RES OPI-01 (Table 4).

Table 3. Percent prevalence and intensity of common root rot assessed at the germination and wax ripeness stages in wheat

Treatment	Germination stage		Wax ripeness stage	
	Prevalence (%)	Intensity	Prevalence (%)	intensity
0 L/ha RES OPI-01 (T0)	12.3	9.1	25.5	13.7
0.1 L/ha RES OPI-01 (T1)	14.2	8.7	9.3	7.7
0.2 L/ha RES OPI-01 (T2)	11.8	9.0	8.1	5.9
Least significant difference (5%)	1.0	1.2	1.4	0.5
CV(%)	4.5	8.1	5.6	3.5
F pr.	0.002	0.7	<.001	<.001

Note: RES OPI-01: *Rhodococcus erythropolis* strain OPI-01; CV: coefficient of variation

Effect of *R. erythropolis* - strain OPI-01 on winter wheat yield components

The number of productive stems and reproductive traits (average spike length, average spikelet number per ear, average grain weight per ear and average number of grains per ear) of winter wheat significantly ($p<0.05$) increased with increasing application of plant growth regulator (Table 3). For all measured traits, treatment 0.2 L/ha RES OPI-01 (T2) significantly produced the highest number of productive stems, longest average spike length, highest average spikelet number per ear, heaviest average grain weight per ear and highest average number of grains per ear, whereas the control treatment had the lowest values of 255.0 stems, 6.5 cm spike, 9.7 spikelet per ear, 0.9g grain weight per ear, and 22.0 grains per ear (Table 5).

Growth regulator treatments significantly ($p<0.05$) affected the grain yield, mass of 1000 seeds and food quality traits (protein and gluten) of winter wheat (Table 4). Treatments 0.2 L/ha RES OPI-01 (T2) (4.8 t ha^{-1}) and 0.1 L/ha RES OPI-01 (T1) (4.7 t ha^{-1}) had significantly ($p<0.05$) higher seed yield than the control 0 L/ha RES OPI-01 (T0) (4.1 t ha^{-1}). Treatment 0.2 L/ha RES OPI-01 (T2) had significantly ($p<0.05$) the heaviest mass of 1000 seeds (50.8g) and highest protein content (14.5%), while Treatment 0 L/ha RES OPI-01 (T0) had the lowest values of 47.1g and 13.3%, respectively. Treatment 0.2 L/ha RES OPI-01 (T2) had significantly ($p<0.05$) the highest gluten content (33.8%), followed by 0.1 L/ha RES OPI-01 (T1) (33.6%), while 0 L/ha RES OPI-01 (T0) had the lowest of 32.3% (Table 6).

Table 4. Percent prevalence and intensity of fungal diseases in wheat

Treatment	Powdery mildew		Brown rust		Septoria blotch	
	Prevalence (%)	**Intensity**	**Prevalence (%)**	**intensity**	**Prevalence (%)**	**intensity**
0 L/ha RES OPI-01 (T0)	21.10	11.9	23.9	12.80	31.7	18.9
0.1 L/ha RES OPI-01 (T1)	12.1	7.2	7.9	5.50	12.9	7.4
0.2 L/ha RES OPI-01 (T2)	11.9	8.5	8.6	5.30	11.9	6.8
Least significant difference (5% level)	1.5	1.3	1.1	1.1	2.6	0.9
CV (%)	6.1	8.5	5.1	8.6	8.0	5.0
F pr.	<.001	<.001	<.001	<.001	<.001	<.001

Note: RES OPI-01: *Rhodococcus erythropolis* strain OPI-01; CV: coefficient of variation

Table 5. Effect of plant growth regulator *Rhodococcus erythropolis*-strain OPI-01 on the number of productive stems and reproductive traits of winter wheat

Treatment	Average number of productive stems (pcs/m^2)	Average spike length (cm)	Average spikelet number per ear	Average grain weight per ear (g)	Average number of grains per ear
0 L/ha RES OPI-01 (T0)	255.0	6.5	9.7	0.9	22.0
0.1 L/ha RES OPI-01 (T1)	278.0	6.8	10.2	1.0	26.0
0.2 L/ha RES OPI-01 (T2)	285.0	7.2	11.1	1.1	27.0
Least significant differences of means (5% level)	10.1	0.08	0.1	0.08	0.8
CV (%)	2.2	0.7	0.6	4.7	1.9
F pr.	<.001	<.001	<.001	0.003	<.001

Note: RES OPI-01: *Rhodococcus erythropolis* strain OPI-01; CV: coefficient of variation

Table 6. Effect of plant growth regulator *Rhodococcus erythropolis*-strain OPI-01 on winter wheat grain yield and quality traits

Treatment	Yield (t ha^{-1})	Mass of 1000 seeds (g)	Protein (%)	Gluten (%)
0 L/ha RES OPI-01 (T0)	4.1	47.1	13.3	32.3
0.1 L/ha RES OPI-01 (T1)	4.7	48.5	13.8	33.6
0.2 L/ha RES OPI-01 (T2)	4.8	50.8	14.5	33.8
Least significant difference (5% level)	0.3	0.2	0.2	0.2
CV (%)	4.7	0.3	0.8	0.5
F pr.	0.008	<.001	<.001	<.001

Note: RES OPI-01: *Rhodococcus erythropolis* strain OPI-01; CV: coefficient of variation

Discussion

To limit the development of fungi, a commercial organic growth regulator restart ZH was utilized, thus reducing the use of fungicides. The present study aimed to protect the quality of winter wheat in the field, by using a commercial organic growth regulator Restart ZH, and the result obtained indicated that *R. erythropolis* - strain OPI01 during the germination phase did not influence the development of common root rot of wheat caused by infection of *Bipolaris sorokiniana* (teleomorph *Cochliobolus sativus*). Notwithstanding, during the developmental phase at maturity, specific to the wax stage, a reduction of the percentage of diseased plants ranging from 40-55% depending on the treatments, as compared to the control reduces its severity by 1.8%. In vitro experiments, it was observed that *R. erythropolis* B43 reduced wheat root rot caused by *Rhizoctonia solani* AG8. This bacterium can produce volatile substances that inhibit the growth of *R. solani* AG8 (Yin et al. 2022). Other bacterial strains have been reported to be effective in controlling the root rot of wheat due to *B. sorokiniana*. Fermentation supernatant of *Bacillus halotolerans* strains isolated from wheat rhizosphere soil had reduced the incidence of root rot by 72.06% in pot experiments (Kang et al. 2023).

The present study showed that *R. erythropolis* - strain OPI-01 used as seed and soil treatment before sowing, obtained a reduction of up to 50% on average by the prevalence and severity of powdery mildew, brown rust, and Septoria leaf spot on wheat plants. This suggests that *R. erythropolis* - strain OPI-01 can act as an inducer of systemic resistance to affected wheat plants by the presence of these microorganisms or by their secondary metabolites in the rhizosphere. The objective of plant protection stimulators is to enhance the natural defense mechanisms of the plant and to make it more difficult to bypass the fungus. This concept is based on host/pathogen interactions and more precisely on plant resistance mechanisms. The mechanism of *R. erythropolis* on fungal pathogens of wheat is less documented, few studies have shown that this bacterium controls potato tuber soft rot caused by *Pectobacterium atrosepticum* through the γ-lactone catabolic pathway (the QsdA lactonase) (Barbey et al. 2013; Latour et al. 2013; Chane et al. 2019). *Streptomyces rimosus* LMG 19352 and *Rhodococcus sp*. R-43120 reduced symptoms of Fusarium wilt in wheat and mycotoxin (deoxynivalenol, DON) production by *F. graminearum* (Tan et al. 2021). Fungicide suppression of *F. graminearum* mediated by *Rhodococcus sp.* was associated with archetypal salicylic acid and jasmonic acid defense pathways (Tan et al. 2021). Hu et al. 2023 also observed that *R. erythropolis* could also reduce zearalenone through the expression of the zenR gene (Hu et al. 2023). According to McLeod et al. 2006 the metabolic diversity of *Rhodococcus* species was also due to the presence and mobilization of large linear plasmids and multiple enzymatic homologs in catabolic pathways (McLeod et al. 2006). Therefore, the remarkable metabolic diversity of *Rhodococcus* makes them ideal contenders for enhancing bioremediation of contaminated sites and as biocatalysts for a wide range of biotransformations (Afordoanyi et al. 2023). It was also evident in the experiment by Afordoanyi et al. (2023) that *R. erythropolis* MGMM8 has resistance genes to magnesium (Mg), cobalt (Co), nickel (Ni), manganese (Mn), cadmium (Cd), zinc (Zn), and mercury (Hg). Thus it should be recommended that the role of *R. erythropolis* in the detoxification of mycotoxins, needs further extensive research to unlock its potential. Research by Garai et al. 2021 has shown that the product of the detoxification of aflatoxin B1 (AFB1) and toxin 2 (T-2) by the *R. erythropolis* NI1 strain was more toxic than the initial AFB1+T-2 mixture (Garai et al. 2021).

Cereal crop yield is composed of three components: productive stem density, number of grains in the ear, and 1000-grain weight, where 50% of productivity is determined by productive stem density, 25% by grain size in the ear, and 25% by 1000-grain weight (Batakova and Korelina 2017). The results of our trials revealed that *R. erythropolis* - strain OPI-01 was able to stimulate the growth and yield of winter wheat plants by increasing the growth parameters (average number of productive stems (pcs. / m^2), spike length (cm), spikelet number in an ear (pcs.), grain weight per ear (g), and number of grains in one ear (pcs.). These results agree with the study conducted by Lammas and Shitikova 2021, which shows that seed treatment with commercial biostimulator *R. erythropolis* - strain OPI-01 strain increased germination of barley up to 11%, seedling height up to 63.8% and root length up to 44.1% as compared with the control treatments. These results are similar to those of Trivedi et al. (2007), in which *R. erythropolis* MTCC 7,905 enhanced the low-temperature growth of pea (*Pisum sativum*) plants while reducing Cr6+ in the soil. It was also observed that the increase in plant growth parameters was related to enhanced mineral (P and Fe) uptake (Trivedi et al. 2007). Similarly compared to control *N. tabacum* plants, *R. erythropolis* P30 strains improved to 57% shoot dry weight of (Rosenkranz et al. 2018). The effectiveness of *R. erythropolis* - OPI-01 strain is to prevent the negative effects of herbicide residues - growth retardation, root shoot death, yellowing and general weakening of the plant (Lammas and Shitikova 2021).

Another key role of biocontrol agents is to improve the qualitative characteristics of yields (Thakur et al. 2023b; Sharma et al. 2024). In these findings, it was evident that the application of growth regulator *R. erythropolis* - strain OPI-01, aided the reduction of fungal infections, hence improved wheat yield components, and resulted in an average yield increase of 33.0% as compared to the control. The yield increase was more distinct as the concentration of the biostimulant increased. Similar results were observed by Isaychev et al. 2020 stating that the growth regulators Crezacin, Energia, Albit, Gumi, Zircon, Extrasol, compared to the control increased the yield of spring wheat from 0.17 to 0.40 t/ha (Isaychev et al. 2020). Results obtained from this experiment show that the Restart, ZH commercial plant growth regulator is a valuable stimulant and has the potential to enhance wheat production, then unlock sustainable cereal production and preservation of its organic quality.

Conclusion, based on the results of field experiments on the effect of plant growth regulator *R. erythropolis* - strain OPI-01 method of pre-sowing treatment of seeds (consumption for pre-sowing treatment 0.1 L/t and 0.2 L/t), the working solution consumption - 10 L/t and the subsequent spraying of the soil just before sowing, the agrochemical consumption - 0.5 L/ha, the working solution consumption - 300 L/ha revealed the following: the number of productive stems increased by 23-30. The most significant number of productive stems was formed from presowing treatment with the plant growth regulator *R. erythropolis* - strain OPI-01 at a dose of 0.2 L/t; the bacteria activated the growth and development of plants, increased all indicators of the yield structure of winter wheat, the number of grains in one ear increased in the studied variants by 16.2-19.4%, and the ear length by 0.3 cm-0.7 cm. -promoted the gluten content in the grain, where this index ranged from 32.3 to 33.8 %; grain with the highest quality indicators in absolute terms, respectively, 33.6% and 14.5% were formed on the background (0.2 L/ha); contributed to yield increase by 27.8-33,0 % about the control. The maximum yield of grain - 4.82 t/ha, was obtained on the option number 3 plant growth regulator *R. erythropolis* - strain OPI-01 (0.2 L/t), an increase to the control was 0.70t/ha. The lowest yield of winter wheat grain was obtained in the control variant - 4.12 t/ha; thus, when cultivating winter wheat to increase yield and grain quality, as well as to reduce fungal diseases in the Moscow region it is advisable to use the plant growth regulator *R. erythropolis,* strain OPI-01 by pre-sowing treatment of seeds and soil before sowing. This bacterium is highly promoted not only in the biocontrol of pathogenic plants but also in the bioremediation of wheat production. It would be very prospective to study the mechanisms of this bacterium on wheat pathogens *in vitro* and plants.

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