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Biocontrol potential of an endophytic *Pseudomonas* sp. strain GEOT11 against phytopathogenic bacteria

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Abstract *Pseudomonas* species are promising objected for the creation of biological preparations. The growth-stimulating and antagonistic activity of *Pseudomonas* sp. strain GEOT11 was investigated. This strain proved to be expressed the ability to synthesize phytohormone, solubilize inorganic phosphate, and synthesize siderophores. Inoculation of *Phaseolus vulgaris* with *Pseudomonas* sp. GEOT11 stimulated and increased in the wet weight of plant organs and their linear size. Antagonistic activity of *Pseudomonas* sp. strain GEOT11 against phytopathogenic bacteria was demonstrated. *Pseudomonas* sp. GEOT11 effectively inhibited the growth of *Pseudomonas siringae* and *Clavibacter michiganensis* upon contact and by releasing volatile compounds, while the growth of *Erwinia carotovora* was only inhibited by the synthesis of volatile compounds. Co-inoculation of *Phaseolus vulgaris* with phytopathogenic bacteria and the studied strain led to be the healthy plants without signs of bacterial damage. Thus, the obtained data gave an evidence of the perspective use of the *Pseudomonas* sp. GEOT11 in agriculture to increase plant productivity and biocontrol of plant diseases.

Keywords: Phytopathogens, Antagonism, *Pseudomonas*, Biological preparations, Plant protection

Introduction

Currently, many plant diseases caused by phytopathogenic bacteria are known. Crop losses from various infections are at least 20-40%, which causes great harm to the economy and leads to food problems (Ali *et al*., 2018). Chemical methods of controlling phytopathogenic pests lead to the accumulation of harmful substances in food, in the environment, and cause the death of useful endophytic microorganisms. Another disadvantage of this control method is that many phytopathogens can become tolerant to some

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agrochemicals (Dutta *et al*., 2020). A need to use a less toxic method–the method of biological control, arises from this fact.

Microbial biopreparations are a cost-effective and environmentally friendly way to increase plant productivity. Biopreparations are good because they are highly selective and effective in combating phytopathogens, favorable for the soil, and do not harm biodiversity. Biopreparations can help to increase the yield and improve the quality of the product (Shternshis, 2012).

The basis for the creation of biological products is bacteria that have antagonistic activity against specific phytopathogenic organisms. Antagonism is a type of non-symbiotic relationship in which one of the interacting organisms suppresses the vital activity of another organism using different mechanisms. This activity is caused by three main mechanisms: the induction of systemic resistance in plants, competition, and allelopathy, in other words, the effect on competitors with metabolic products (bacteriocins, siderophores, antibiotics, enzymes) (Syed *et al*., 2018).

One of the most promising bacteria for the creation of biological preparations is the bacteria of the genus *Pseudomonas* due to its ability to actively colonize plants and excrete a large range of biologically active substances necessary to protect against phytopathogens (Shcherbakov *et al*., 2017).

The bacteria of the genus *Pseudomonas* excrete many active metabolites: phenazines, antibiotics, cyclic lipopeptides, siderophores, and lytic enzymes (cellulases, glucanases, proteases, and chitinases) (Priyanka *et al*., 2017; Syed *et al*., 2018). Pseudomonads excrete many active volatile metabolites, such as ammonia, hydrogen cyanide, and prussic acid, which are antimicrobial compounds involved in the biological control of root diseases (Islam, 2018; Doornbos *et al*., 2012).

The present study was undertaken to explore the antibacterial activity of the *Pseudomonas* sp. strain GEOT11 as representative of one of the most promising species for the creation of biological preparations that protects the plants from phytopathogens.

Materials and methods

Bacteria strains and growth conditions

Pseudomonas sp. GEOT11 was isolated from the endosphere of *Dactylorh ́za incarnata* (L.) So ́ (Orchidaceae Juss.). The antagonistic activity was assessed using phytopathogenic bacteria, *Clavibacter michiganensis, Erwinia carotovora, Pectobacterium carotovorum,* and *Pseudomonas syringae*,

which were obtained from the collection of the Institute of Molecular Genetics of the Russian Academy of Sciences, Moscow.

Pseudomonas sp. GEOT11 and phytopathogenic bacteria were cultured on LA growing medium (NaCl 5 g/l, yeast extract 5 g/l, trypton 10 g/l, agar 20 g/l) at 28 ℃.

Molecular identification

Molecular genetic identification of the strain was performed using PCR method (Kuznetsova *et al*., 2013; Onishchenko *et al*., 2014). Genomic DNA was isolated from a suspension of bacteria using the ExtractDNA kit (Evrogen) following the manufacturer's protocol. PCR of the isolated fragment was performed using primers 356F (5'-ACWCCTACGGGWGGCWGC) and 1064R (5'-AYCTCACGRCACGAGCTGAC) using the HS-Taq PCR-Color (2x) BioMaster kit. The method of gel electrophoresis was used to detect the results of PCR. Electrophoresis was performed in 1.5% agarose gel. Isolation and purification of the amplified DNA fragment from the agarose gel were performed using a commercial CleanupMini kit according to standard protocols.

The sequences were identified using the BLAST program and the GenBank database. The identification of the strain was based on the analysis of the 16S rRNA gene sequence. A phylogenetic tree, based on 16S rRNA sequences, was constructed by the neighbor-joining method.

Ability to fix nitrogen

The investigated strain was sown on Jensen's selective medium (Ali *et al*., 2018). The crops were cultivated in a thermostat at 28 ℃ for 96 hours. The presence of nitrogen-fixing activity was determined by the ability to grow on this medium, that is, to form colonies.

Ability to reduce phosphate

The investigated strain was sown on agar with mineral medium, in which tricalcium phosphate was used as a source of insoluble phosphate (Ali *et al*., 2018). The cultures were cultivated in a thermostat at 28 ℃ for 72 hours. The presence of the ability to phosphate reduction was determined by the presence of clearing zones on the agar around the colonies of the strain. The efficiency of phosphate reduction was estimated by the diameter of the clearing zones around the colonies.

Ability to excrete ACC deaminase

The investigated strain was sown on a medium with the following composition: K_2HPO_4 – 4 g/l; Na_2HPO_4 – 6 g/l; $MgSO_4 \times 7H_2O$ – 0,2 g/l; $FeSO_4 \times H_2O$ – 1 mg/l; H_3BO_3 – 10 mg/l; $MnSO_4$ – 10 mg/l; $ZnSO_4$ – 70 mg/l; $CuSO_4$ – 50 mg/l; MoO_3 – 10 mg/l; glucose – 2 g/l; gluconic acid – 2 g/l; citric acid – 2 g/l; agar-agar – 12 g/l (Dutta *et al*., 2020). The cultures were cultivated in a thermostat at 28 ℃ for 96 hours. The ability to excrete ACC deaminase was determined by the ability to grow on this medium.

Ability to synthesize siderophores

The strain was sown on medium Blue Agar CAS, in which chromium azurol S (CAS) and hexadecyltrimethylammonium bromide (HDTMA) were contained as an indicator (Shternshis, 2012). The cultures were cultivated in a thermostat at 28 ℃ for 96 hours. The ability to synthesize siderophores was determined by the formation of clearing zones around the colonies or by the staining of medium near the colonies in a yellow-orange color.

Evaluation of Indolyl-3-Acetic Acid (IAA) production

IAA production was determined by the colorimetric method with Salkovsky's reagent at 540 nm (Ali *et al*., 2018). The bacterial cultures were cultivated in LB medium on an ES-20 rotary shaker (Biosan, Latvia) at 170 rpm at 28 ℃ for 144 hours. Then the samples were centrifuged for 15 minutes at 7000 rpm. After centrifugation, Salkovsky's reagent (35% $HClO_4$ and 0.5 M $FeCl_3$ solution in a 50:1 ratio) was added to 5 ml of the supernatant in a 1:1 ratio. Then the tubes were placed in a thermostat at 28 ℃ for 20 minutes. The optical density of the solutions was measured on a Unico-2802S / VIS spectrophotometer (USA) at 540 nm. The concentration of IAA in the culture liquid was calculated using the calibration curve for dilutions of a synthetic IAA solution.

Ability to excrete inhibitory antibacterial compounds

In the experiment, Petri dishes with partitions were used. The growing medium was poured into both parts. After solidification, the studied strain was inoculated on one half of the Petri dish and the phytopathogenic bacterium was inoculated on the second half. Dishes with inoculations were wrapped in a parafilm and cultivated in a thermostat at a temperature of 28 ℃ for a day. The

antagonistic activity was assessed by the intensity of the phytopathogen growth compared to its growth in the control.

Ability to synthesize and isolate metabolites with inhibitory properties into the medium

In the experiment, the method of co-culturing using agar blocks was used (Sorokina *et al*., 1998). The antagonist strain was previously inoculated on a growing medium in a Petri dish. After it grew well, blocks with a diameter of 10 mm were cut out with a sterile Forstner bit. These agar blocks were placed on the surface of the growing medium previously inoculated with phytopathogenic bacteria in another Petri dish. The culture of the phytopathogenic bacterium was distributed over the growing medium with a spatula for growth in a continuous lawn. Agar blocks were placed with the antagonist strain upward, equally apart. Then, the inoculations were incubated in a thermostat at a temperature of 28 ℃ for two days. The antagonistic activity was assessed by the presence of zones where no phytopathogen growth around the agar blocks was observed.

Effectiveness of phytopathogen-inhibiting metabolites in planta experiment

The bean *Phaseolus vulgaris* was selected as a test host plant for the experiment. Before starting the biological test, the seeds were disinfected with a 20% solution of ethyl alcohol for 10 minutes, then washed with running water. Then the seeds were soaked for 24 hours in the water. Before planting, the seeds were inoculated in a suspension of the antagonist strain with an optical density of 0.5, containing about 10^5CFU ml for two hours. The soil was previously made of sand, peat, and earth in a ratio of 2:1:2 and sterilized in a dry heat oven at a temperature of 200 ℃ for 5 hours.

The finished soil was placed in seedling containers, into which a concentrated suspension of phytopathogenic bacteria was introduced further. There were 4 pots for each phytopathogenic bacterium. Then, the seeds treated with the antagonist suspension were planted and grown for 4 weeks at a temperature of 22-24 ℃ and a humidity of 50%. Repeated inoculation with a suspension of the antagonist strain was carried out on the 7^{th} and 14^{th} days after planting. For the treatment of plants, a suspension of bacteria with 10^5CFU ml at a dilution of 1:100 was used. After 28 days, the linear dimensions, dry and wet mass of the aboveground and underground parts of the plants were measured.

Statistical analysis

The obtained results were processed according to standard methods using the data analysis package of the "Microsoft Excel" program. The tables show the average values and their standard errors. One-way analysis of variance (ANOVA) was performed to determine the significance of the effects of treatments.

Results

Molecular identification of the strain

According to the results of PCR and gel electrophoresis, a sequence of a fragment of the 16S rRNA gene with a length of 627 nucleotides was isolated. The nucleotide sequence was identified, sequenced, and deposited in the GenBank database under the number MT180653.

BLAST analysis of the nucleotide sequences of the 16S rRNA gene that the strain under study belongs to the genus *Pseudomonas*. Exact species identification was not possible, since the studied strain was identified as 100% identical to *Pseudomonas yamanorum*. The phylogenetic tree was made using the neighbor-joining method (Figure 1).

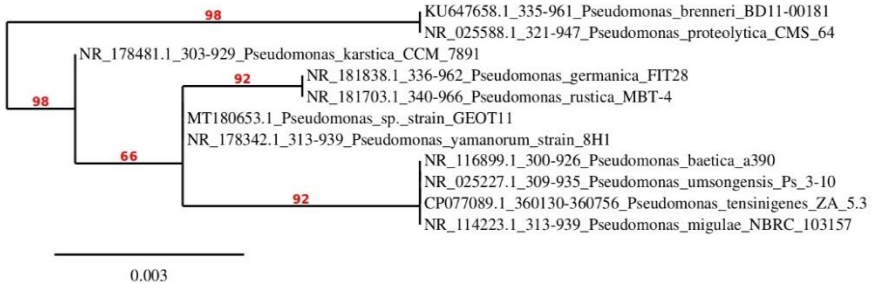

Figure 1. Phylogenetic tree of the isolated strain and reference species based on the 16S rRNA genes according to the neighbor-joining method

Growth-stimulating properties of the Pseudomonas sp. GEOT11

Result revealed that the studied strain is shown nitrogen-fixing and ACC-deaminase activity which capable of producing siderophores. These properties are important for improving the mineral nutrition of plants. In addition, this strain demonstrated high phosphate-mobilizing activity - the diameter of the

clearing zone on the medium with insoluble phosphate was 13 mm. It was found that *Pseudomonas* sp. GEOT11 is capable of producing IAA, a phytohormone of the auxin class. The IAA concentration in the culture liquid of *Pseudomonas* sp. GEOT11 was 5 μg / ml after 6 days of cultivation. The obtained data indicated that *Pseudomonas* sp. GEOT11 proved to be the growth promoting properties.

The efficiency of antibacterial metabolites in contact with phytopathogens

In vitro experiment, *Pseudomonas* sp. GEOT11 proved to be the potential in suppressing the growth of the phytopathogens, *Pseudomonas siringae* and *Clavibacter michiganensis.* Transparent zones were observed around agar blocks with the antagonist strain, in which there was no growth of phytopathogenic bacteria. The growth inhibition zone in the case of *P. siringae* was 4±0.3 mm (Figure 2A). In *C. michiganensis*, the growth inhibition zones were larger and amounted to 6±0.5 mm, therefore, the tested pathogen showed more sensitive to specific compounds of *Pseudomonas* sp. GEOT11 (Figure 2C). Phytopathogenic bacteria, *Erwinia carotovora* and *Pectobacterium carotovorum in vitro* experiments were tolerant to the action of the antagonist strain and no visible growth inhibition zones were observed.

Accordingly, *Pseudomonas* sp. GEOT11 synthesized and released to the environment as active metabolites to inhibit the growth and reproduction of some dangerous phytopathogens of agricultural crops.

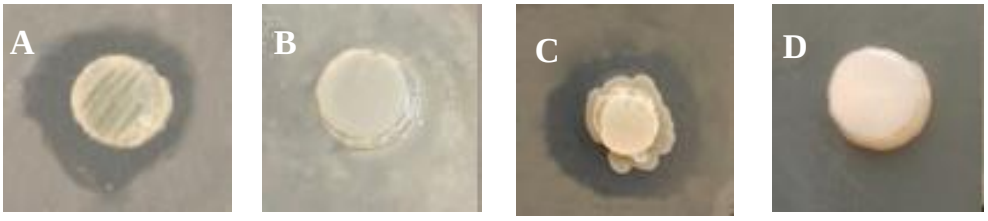

Figure 2. Suppression of phytopathogen growth using the mechanism of synthesis of active secondary metabolites in the environment: A – *Pseudomonas siringae*; B–*Pectobacterium carotovorum;* C–*Clavibacter michiganensis*; D –*Erwinia carotovora.* Zones of lack of growth are presented in figures A and C

The efficiency of volatile antibacterial metabolites

The strain showed the ability to suppress some phytopathogens with the help of volatile antibacterial compounds. *In vitro* experiment, it was proved that

the growth of *E. carotovora* and *P. siringae* was noticeably slowed down as compared to the control (Figure 3). In the control, the colonies of phytopathogenic bacteria grew intensively in the growing medium and therefore their inocula were very dense. In the experimental option with an antagonist, the colonies of phytopathogens were sparsed. Based on this fact, it concluded that *E. carotovora* and *P. siringae* are exposed to influence of volatile compounds released from *Pseudomonas* sp. GEOT11.

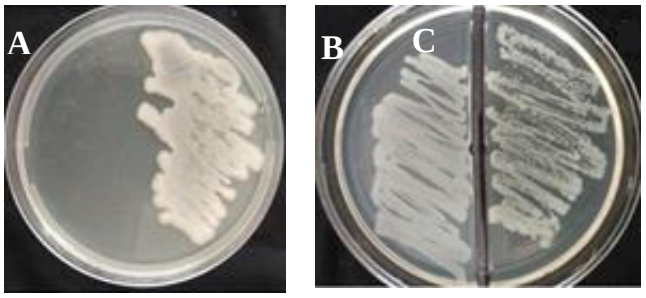

Figure 3. Suppression of phytopathogen growth by the synthesis of volatile inhibiting compounds: A – Growth of *Erwinia carotovora* (control); B – *Pseudomonas* sp. strain GOT11; C – Supression of *Erwinia carotovora* growth

The efficiency of the antibacterial compounds Pseudomonas sp. strain GEOT11 in the experiment in plant

The results of the *in planta* experiment are presented in Table 1. The experience was conducted in 10 options. The growth of *Phaseolus vulgaris* in the control (experiment option 1) without treatment with phytopathogens and an antagonist is characterized by developed shoots and roots, large leaves of deep green color. The shoots were erect, strong, and the roots were strong.

Inoculation of beans with *Pseudomonas* sp. GEOT11 (experiment option 2) stimulated an increased in the wet weight of plant organs and their linear size. Hence, *Pseudomonas* sp. strain GEOT11 synthesized special substances that showed a positive effect on plants. The most significant parameters were the wet weight of roots and shoots and their linear dimensions.

The tested plants were infected with phytopathogens, morphological changes were noticeable from the moment of germination compared to the control. The infected beans with *P. siringae* (experiment option 3), the leaves were black and irregular shapes, the rootsand shoots were undeveloped and the leaves were absent.

The infected beans with *E. carotovora* (experiment option 4) revealed a lag in the development of shoots and roots and grayish color of the leaves was visually observed, and with *P. carotovorum* (experiment option 5) the absence of deep green color was noted. In the case of both options, the plants withered, the shoots were weak.

In the case of *C. michiganensis* (experiment option 6), a clear sign of the lesion was yellowing of the leaves, and in some cases showed their necrosis.

The infected beans with phytopathogens and additionally treated with *Pseudomonas* sp. GEOT11 (experiment options 7, 8, 9, 10) showed signs of the lesions but lesser extent than in experiment options 3, 4, 5, 6. The shoots and roots were developed as normal size, the leaves were not wilted, and the color was deep green. Hence, the strain *Pseudomonas* sp. GEOT11 showed slowly down and in some cases completely stopped the growth of phytopathogenic bacteria.

The studied strain had the greatest effect on *P. siringae* as an antagonist of phytopathogens. In the control group of plants that were infected with this phytopathogen (experiment option 3), the length of roots and shoots and their weight were less than in the control group about 3, 5, 7 and 6 times, respectively. In the group of plants in which inoculation with the antagonist strain was carried out (experiment option 7), positive dynamics of the growth of aboveground and underground organs and the accumulation of the wet weight were observed. The wet weight of the shoots was about 4 times higher compared to the inoculated plants, the wet weight of the roots were not significantly differed, the length of the shoots and roots were 4 and 2 times longer, respectively. The strain of *Pseudomonas* sp. GEOT11 can be successfully used as plant protection against disease caused by *P. siringae.*

In experiment options 8, 9, 10 with plants infected with other phytopathogens (*P. carotovorum, C. michiganensis, E. carotovora)* and treated with the strain *Pseudomonas* sp. GEOT11 compared to plants that were treated only with phytopathogens (experiment options 4, 5, 6) showed positive changes in the wet weight and length of shoots. The studied strain proved to stimulate the aboveground part of plants, which is confirmed by an increase in the weight of shoots and length. The root system could not be protected from the influence of phytopathogens with this strain.

Table 1. The effect of phytopathogenic bacteria and the *Pseudomonas* sp. strain GEOT11on the growth of *Phaseolus vulgaris*

Experiment option	**Wet weight, g**		**Dry weight, g**		**Length, cm**	
	Shoots	Roots	Shoots	Roots	Shoots	**Roots**
Soil (control)	1.80 ± 0.1200	0.37 ± 0.0100	0.22 ± 0.0010	0.02 ± 0.0003	20.70 ± 1.4000	**11.50 ± 0.1100**
Soil + *Pseudomonas* sp. GEOT11	1.90 ± 0.1400	0.57 ± 0.0200	0.10 ± 0.0030	0.02 ± 0.0002	22.50 ± 1.7500	**13.20 ± 0.5400**
Soil + *P. siringae*	0.40 ± 0.0300*	0.05 ± 0.0010*	0.02 ± 0.0010	0*	4.20 ± 0.1200*	**4.00 ± 0.0200***
Soil + *P. carotovorum*	0.90 ± 0.1000*	0.34± 0.0100*	0.05 ± 0.0020	0.01 ± 0.0001*	17.00 ± 0.7500*	**7.00 ± 0.0500***
Soil + *C. michiganensis*	0.70 ± 0.0500*	0.30 ± 0.0010	0.04 ± 0.0020	0.02 ± 0.0003	15.80 ± 0,4300*	**10.50 ± 0,7000***
Soil + *E. carotovora*	0.40 ± 0.0400*	0.05 ± 0.0010*	0.05 ± 0.0010	0.01 ± 0.0001*	11.10 ± 0.3200*	**5.40 ± 0.2200***
Soil + *Pseudomonas* sp. GEOT11 + *P. siringae*	1.70 ± 0.0900*	0.08 ± 0.0010*	0.08 ± 0.0030	0.02 ± 0.0001*	16.20 ± 0.8000*	**10.90 ± 0.7000***
Soil + *Pseudomonas* sp. GEOT11+ P.carotovorum	1.60 ± 0.0100	0.13 ± 0.0010*	0.10 ± 0.0010	0.02 ± 0.0002	19.20 ± 1.2300	**7.50 ± 0.2800***
Soil + *Pseudomonas* sp. GEOT11 + *C. michiganensis*	1.40 ± 0.0200	0.36 ± 0.0100	0.08 ± 0.0020	0.03 ± 0.0010	20.00 ± 1.1000	**8.80 ± 0.3000**
Soil + *Pseudomonas* sp. GEOT11 + *E. carotovora*	**1.00 ± 0.0100**	**0.17 ± 0.0010***	**0.05 ± 0.0020**	**0.01 ± 0.0001**	**13.30 ± 0.2400**	**5.90 ± 0.1400***

* - signifcantly diferent compared to control (p -value < 0,05)

Based on the data obtained, *Pseudomonas* sp. GEOT11 proved to be an effective antagonist of *P. siringae* and created as biological preparation to protect plant from disease caused by phytopathogenic bacterium. For other

phytopathogens, this strain can also be used to create a biological preparation, but in combination with other strains for greater efficiency.

Discussion

Pseudomonas is actively interacted with plants, stimulating their growth and development through the synthesis of phytohormones, optimization of mineral nutrition, and acting as biocontrol agents (Zhumakayev *et al*., 2022). It acts as biocontrol activity against phytopathogenic fungi as *Sclerotium*, *Fusarium*, *Phytophthora* (De Vrieze *et al*., 2018; Liu *et al*., 2022). In particular, *Pseudomonas trivialis* effectively combats *Rhizoctonia solanin* (Berg *et al*., 2008), and *Pseudomonas cepacian* is an active antagonist against *Rhizoctonia solani, Sclerotium rolfsii,* and *Pythium ultimum* (Syed *et al*., 2018). At the same time, there are relatively few data on the antagonistic activity of *Pseudomonas* strains against phytopathogenic bacteria. It was shown that *Pseudomonas glareae*, *Pseudomonas benzenivorans*, *Pseudomonas monteilii*, *Pseudomonas plecoglossicida* have a significant antagonistic activity against the phytopathogenic bacteria, *Ralstonia solanacearum*, *Clavibacter michiganensis* subsp. *michiganensis* and *Erwinia carotovora* (Takishita *et al*., 2018; Rodr ǵuez *et al*., 2020; Zhumakayev *et al.*, 2022).

In this study, we characterized the endophytic strain of *Pseudomonas* sp. GEOT11 isolated from *Dactylorhiza incarnata* and evaluated its effect on the development of phytopathogenic bacteria *P. siringae*, *C. michiganensis*, *P. caratovorum* and *E. carotovora*. They are considerable plant pathogens which cause significant crop losses and negative economic effect (Peeters *et al.*, 2013). *C. michiganensis* is a vascular pathogen that typically enters through natural openings or wounds and breeds in the xylem, causing wilting symptoms and cankers. Asymptomatic latent infections and tomato seeds invasion are widespread (Nandi *et al*., 2018). *P. siringae* causes spots in the form of burns, necrosis, suppresses the normal development of plants and reduces the assimilation surface of leaves (Zelentsov *et al*., 2021). *E. carotovora* (also known as *P. carotovorum*) produces pectolytic enzymes that degrades plant tissue, causing soft root diseases. It is one of the pectolytic bacteria that causes massive bacterial rot in tomatoes and potatoes. Due to the growth of bacteria in the pith, the stem appears moist and slimy. The vascular tissue retains its normal color above or below the hollow section of the stem (Cheon and Jeon, 2014; Vieira *et al*., 2020).

It was demonstrated that the *Pseudomonas* sp. GEOT11 is pronounced ability to inhibit the growth of phytopathogenic bacteria. The studied strain effectively inhibited the growth of *P. siringae* and *C. michiganensis* upon contact and by releasing volatile compounds, while the growth of *E. carotovora*

was inhibited only by the synthesis of volatile compounds. It was shown that *Pseudomonas* proved to be antagonistic activity against *P. carotovorum*, which contain the synthesis genes of secondary metabolites, including volatile compounds. At the same time, the presence of genes involved in the synthesis of hydrogen cyanide positively correlated with the overall inhibitory ability of strains (Zboralski *et al.*, 2022). There is also evidence that biocontrol strains of *Pseudomonas* that inhibit the growth of *C. michiganensis* are moderate producers of hydrogen cyanide and volatile antibiotics, as well as nonvolatile antibacterial substances (Takishita *et al.*, 2018). Moreover, *Pseudomonas segetis* P6 strain is reported to be able to suppress the growth of *P. carotovorum* due to the synthesis of Quorum Quenching lactonase enzymes (Rodr ́guez *et al.*, 2020).

In planta study showed that inoculation of plants infected with *P. siringae* and *C. michiganensis* with the studied strain of *Pseudomonas* sp. GEOT11 increased wet and dry weight of shoots and length of shoots and roots. The obtained results are consistent with published data on the effect of soil bacteria of *Pseudomonas* on the growth and development of tomato cultures infected with *C. michiganensis* and *P. siringae* (Takishita *et al.*, 2018; Durairaj *et al*., 2018; Rodr ́guez *et al*., 2020; Zboralski *et al*. 2022).

In plants infected with pathogenic *E. carotovora* in corporated with *Pseudomonas* sp. strain GEOT11 increased in shoot and root wet weight and shoot height. *Pseudomonas* is reported to suppress the development of *E. carotovora in vitro* (Zboralski *et al*., 2022) and *in vivo* on potato tubers and carrots (Rodr ́guez *et al*., 2020).

Furthermore, *in planta* experiment, it was shown that pre-inoculation of plants with *Pseudomonas* sp. GEOT11 increased in wet weight and root length. It is due to the fact that the strain has a number of growth-promotion activities, in particular, phosphate-mobilizing, nitrogen-fixing activity, and the ability to secrete siderophores. The use of bacteria with these properties in agriculture can help to reduce the amount of mineral fertilizers applied and reduce the chemical load on the soil (Grobelak *et al*., 2018). The studied strain proved to be capable to synthesize the phytohormone IAA at a concentration of 5 μg/mL, which compared to the parameters of some biocontrol bacteria of the *Pseudomonas* genus (Oh *et al*., 2013). This hormone stimulates the elongation of shoots and roots, and probably promotes more efficient bacterial colonization of plant roots (Etesami *et al*., 2015). *Pseudomonas* acts as inoculants with positive results to increase the grain yield of various crops, such as wheat (*Triticum aestivum*), sunflower (*Helianthus annuus*), corn (*Zea mays*), lettuce (*Lactuca sativa*), tomato (*Solanum lycopersicum*) (Magnucka and Pietr, 2015; Abbaszadeh-Dahaji *et al*., 2021; Zboralski *et al*., 2022).

Thus, the data obtained in this work gave an evidence of the perspective use *Pseudomonas* sp. GEOT11 in agriculture to increase plant productivity, biocontrol of plant diseases and reduce the chemical load on the soil.

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