CROP PRODUCTION

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THE INFLUENCE OF EXOMETABOLITES *NOCARDIA VACCINII* IMV B-7405, *ACINETOBACTER CALCOACETICUS* IMV B-7241 AND *RHODOCOCCUS ERYTHROPOLIS* IMV AC-5017 ON YIELDS OF TOMATOES AND BARLEY

Research article

Abstract

In this study it was determined that under treatment of tomatoes root system with 3 times diluted supernatant of cultural liquid *Rhodococcus erythropolis* IMV Ac-5017, the number of fruits and their weight were 1.1–1.7 times higher than those for plants treated with water (control). In the case of treatment of barley seeds with 30 times diluted supernatants of culture liquid *Nocardia vaccinii* IMV B-7405, *Acinetobacter calcoaceticus* IMV B-7241 and *Rhodococcus erythropolis* IMV Ac-5017 yield increased by 58.55, 69.23 and 83.3%, respectively, compared with water seed treatment. The positive influence of extracellular exometabolites of surfactants producers on the yields of barley and tomatoes is the basis for the development of the technology of obtaining microbial preparations for application in crop production using cheap industrial wastes.

Keywords: phytohormones, surfactants, complex microbial preparations, greenhouse experiments.

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ВЛИЯНИЕ ЭКЗОМЕТАБОЛИТОВ *NOCARDIA VACCINII* ИМВ B-7405, *ACINETOBACTER CALCOACETICUS* ИМВ B-7241 AND *RHODOCOCCUS ERYTHROPOLIS* ИМВ AC-5017 НА УРОЖАЙНОСТЬ ПОМИДОРОВ И ЯЧМЕНЯ

Научная статья

Аннотация

В данном исследовании было установлено, что при обработке корневой системы помидоров в 3 раза разведенным супернатантом культуральной жидкости *Rhodococcus erythropolis* ИМВ Ac-5017 количество плодов и их масса были в 1,1–1,7 раза выше, чем у растений, обработанных водой (контроль). В случае обработки семян ячменя в 30 раз разведенными супернатантами культуральной жидкости *Nocardia vaccinii* ИМВ B-7405, *Acinetobacter calcoaceticus* ИМВ B-7241 и *Rhodococcus erythropolis* ИМВ Ac-5017 урожайность увеличилась на 58,55, 69,23 и 83,3% соответственно, по сравнению с обработкой семян водой. Положительное влияние внеклеточных экзометаболитов продуцентов ПАВ на урожайность ячменя и помидоров является основой для разработки технологии получения микробных препаратов для применения в растениеводстве с использованием дешевых промышленных отходов.

Ключевые слова: фитогормоны, поверхностно-активные вещества, комплексные микробные препараты, тепличные эксперименты.

1. Introduction

In the last decade, a majority of agriculturally oriented research has been aimed at studying rhizosphere microorganisms. The association of plants with microorganisms that do not suppress or even stimulate their development attracts the attention of scientists, not only as the object of study with respect to the fundamentals of the coexistence and interaction of different organisms but also because of their possible use in the practice of an environmentally oriented production of agricultural products [1].

Plant growth promotion and development can be facilitated both directly and indirectly. Indirect plant growth promotion includes the prevention of the deleterious effects of phytopathogenic organisms. This can be achieved by the production of compounds with antibiotic activity. Direct plant growth promotion includes symbiotic and non-symbiotic PGPR (plant growth promoting rhizobacteria), which function through phosphate solubilization, production of plant hormones (such as auxins, cytokinins, gibberellins, ethylene and abscisic acid), siderophores and others compounds useful for plants [2].

In previous studies [3], we have shown that surfactants synthesized by *Nocardia vaccinii* IMV B-7405, *Acinetobacter calcoaceticus* IMV B-7241 and *Rhodococcus erythropolis* IMV Ac-5017, have antibacterial properties against some phytopathogenic bacteria, in particular the genera *Pseudomonas* and *Xanthomonas*. Later [4], [5] the ability to simultaneously synthesize surfactants and exometabolites with phytohormonal activity (auxins, cytokinins and gibberellins) was established. It should be noted that the synthesis of metabolites of phytohormonal nature depended on the nature of the carbon source in the culture medium.

During the last couple of decades, the use of PGPR for sustainable agriculture has increased tremendously in various parts of the world. Significant increases in growth and yield of agronomically important crops in response to inoculation with growth promoting bacteria have been reported [6], [7], [8].

The challenge of making microbial preparations is increasing for both yield and quality of fresh fruits and vegetables and to satisfy consumers avoiding deleterious effects on the environment. The use of such preparations can be limited by the high costs of biosynthesis, in particular, for raw materials. One way to reduce the cost of production is to use cheaper growth substrates for cultivation of bacteria, for example, waste from other industries. Moreover, this is one of the ways to dispose toxic waste.

Previous studies [9] determined the ability of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 to synthesize surfactants and phytohormones not only on traditional substrates, but also on industrial waste (fried oil and technical glycerol).

The ability to simultaneously synthesize of surfactants and plant hormones under conditions of growth on different substrates [4], [5], [9] provides the basis for developing a waste-free technology for the complex microbial preparations with various biological properties. Also we can conduct researches for integrating such technology into the practice of agricultural production.

In connection with the above, the aim of this work is to investigate the influence of exometabolites of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on the yield of tomatoes and barley under vegetative conditions.

2. Materials and methods

2.1. Object of research

Nocardia vaccinii K-8 strain, *Acinetobacter calcoaceticus* K-4 strain and *Rhodococcus erythropolis* EK-1 strain, registered in Microorganisms Depositary of Institute of Microbiology and Virology, the National Academy of Sciences of Ukraine under the numbers IMV B-7405, IMV B-7241 and IMV Ac-5017 respectively.

2.2. Medium composition and conditions of cultivation

N. vaccinii IMV B-7405 were grown in the liquid mineral medium (g/L distilled water): $NaNO_3$ – 0.5, $MgSO_4 \cdot 7H_2O$ – 0.1, $CaCl_2 \cdot 2H_2O$ – 0.1, KH_2PO_4 – 0.1, $FeSO_4 \cdot 7H_2O$ – 0.01, yeast autolysate – 0.5 % v/v, pH 6.8–7.0.

Strain *A. calcoaceticus* IMV B-7241 was cultivated in the liquid medium (g/L distilled water): $(NH_2)_2CO$ – 0.35, $MgSO_4 \cdot 7H_2O$ – 0.1, NaCl – 1.0, Na_2HPO_4 – 0.6, KH_2PO_4 – 0.14, pH 6.8–7.0. Yeast autolysate – 0.5 % v/v and solution of trace elements – 0.1 % v/v were also added to the medium. Trace elements solution contained (g/100 mL): $ZnSO_4 \cdot 7H_2O$ – 1.1, $MnSO_4 \cdot H_2O$ – 0.6, $FeSO_4 \cdot 7H_2O$ – 0.1, $CuSO_4 \cdot 5H_2O$ – 0.004, $CoSO_4 \cdot 7H_2O$ – 0.03, H_3BO_3 – 0.006, KI – 0.0001, EDTA – 0.5.

Strain *R. erythropolis* IMV Ac-5017 was grown in the liquid mineral medium (g/L distilled water): $NaNO_3$ – 1.3, NaCl – 1.0, $Na_2HPO_4 \cdot 12H_2O$ – 0.6, KH_2PO_4 – 0.14, $MgSO_4 \cdot 7H_2O$ – 0.1, $FeSO_4 \cdot 7H_2O$ – 0.001, pH 6.8–7.0.

The refined sunflower oil and oil after frying meat (McDonald's Restaurant Network, Kiev, Ukraine) were used as the carbon and energy sources in concentration of 2.0 % v/v.

The culture in the exponential phase was used as the inoculum and added in concentration of 5–10 % of nutritive medium volume. The concentration of the corresponding carbon source in the medium for the inoculum obtainment was 0.5 % v/v.

The cultivation was carried out in 750 mL flasks, containing 100 mL of medium, on the shaker (320 rpm) at 28–30 ºC during 7 days.

2.3. Obtaining of extracts with phytohormonal activity (phytohormonal extracts)

After cultivation of the strains *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017, the biomass was separated by centrifugation (5000 g) for 25 min. Residuals of sunflower oil were extracted from the cultural liquid using petroleum ether (ratio 1:1).

Phytohormonal extracts were obtained from the supernatant of cultural liquid (CL). Gibberellin and auxin extracts were obtained from the supernatant of the cultural liquid by three times extraction with ethyl acetate (ratio 1:1) at pH 2.5, and cytokinin extracts were obtained by three times extraction with butanol (ratio 1:1) at pH 8.0. The extracts were evaporated to dryness under vacuum and redissolved in 80% ethanol. The obtained extracts were stored at –24 °C.

2.4. Determination of the influence of exometabolites on the test cultures of plants

Greenhouse experiments were carried out at the greenhouses of the D.K. Zabolotny Institute of Microbiology and Virology of National Academy of Sciences of Ukraine.

Greenhouse experiments. The experiments were conducted in greenhouses during 6 months from April to September. As a test culture, tomatoes of the Chicago variety were used. The yield was harvested during 3 months from July to September. Before planting in the soil, the root system of tomato seedlings was kept for an hour in culture supernatants, diluted in 2 and 3 times, obtained after cultivation of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 in a medium with refined sunflower oil. As a positive control, seedlings, which were kept for an hour in solutions of phytohormonal extracts (dilution 1:1000), obtained in similar conditions of cultivation, were used. As a negative control, seedlings, which were kept for an hour in distilled water, were used. There were three plants in each variant. During the experiment, the number of tomatoes and their weight was analyzed.

Experiments in the field. The experiments were conducted on the field in the summer period (3 months) using the seeds of brewer's barley. The yield was harvested in September. Before sowing, the seeds were kept for two hours in culture supernatants, diluted in 10 and 20 times, obtained after cultivation of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on waste oil after frying meat. As a positive control, seeds, which were kept for 2 hours in solutions of phytohormonal extracts (dilution 1:1000), obtained in similar conditions of cultivation, were used. As a negative control, seeds, which were kept for 2 hours in distilled water, were used. During the experiment, the weight of grain yield and the yield increase (comparing to the control) were analyzed.

2.5. Statistical analysis

All the experiments were repeated three times, and the number of parallel measurements in each experiment made up 3–5. The statistical processing of the experimental data was carried out in accordance with the algorithm described in [10]. Differences of mean indicators were deemed as reliable at the significance level $p < 0.05$.

3. Results and discussion

Selection of substrates (refined and waste oil after frying meat) for the cultivation of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 with the aim to study exometabolites of these bacteria on agricultural crops was predetermined for the following reasons. First, under conditions of growth on refined oil, the strain *N. vaccinii* IMV B-7405 synthesized the highest amount of phytohormones (1124.36 µg/L) [5]. Second, during cultivation on waste oils, the concentration of phytohormones synthesized by all strains was practically the same and was within the range of 124–135 µg/L [5]. Third, the waste oil is a toxic waste, the emissions of which are not regulated in Ukraine, and its use as a substrate will enable simultaneously to dispose of hazardous waste and reduce the cost of a complex microbial preparation for plant growing.

3.1. Yields of tomatoes of the Chicago variety under treatment of exometabolites of strains IMV B-7405, IMV B-7241 and IMV Ac-5017

Experiments have shown that the treatment of tomato seedlings of Chicago variety with exometabolites of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 before planting in the soil stimulated the growth of the seedlings, increased the number of formed flowers and accelerated the formation and maturation of the fruit (Table 1).

Table 1 – Effect of extracellular metabolites of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on yield of tomatoes of Chicago variety

Strain	Treatment	No. of fruit	Total fruit weight (g)	Average fruit weight (g)
Control	Treatment with water	15	1167.0	74.2±25.3
N. vaccinii IMV B-7405	Supernatant (1:1)	10	673.0	67.3±24.8
	Supernatant (1:2)	14	834.0	59.6±20.4
	Phytohormone extract (1:1000)	12	647.0	53.9±15.1
A. calcoaceticus IMV B-7241	Supernatant (1:1)	21	971.0	46.2±14.3
	Supernatant (1:2)	18	858.0	47.7±16.8
	Phytohormone extract (1:1000)	15	611.0	40.7±13.5
R. erythropolis IMV Ac-5017	Supernatant (1:1)	18	987.0	54.8±16.4
	Supernatant (1:2)	25	1226.0	49.0±22.0
	Phytohormone extract (1:1000)	33	2069.0	62.7±28.1

The data of Table 1 show that the highest yield increase was observed for tomato seedlings, treated with exometabolites of strain *R. erythropolis* IMV Ac-5017. So, when treating plants with supernatant of this strain, diluted in 2 and 3 times, as well as the extract of phytohormones, the number of mature fruits in comparison with the control was higher by 12, 56 and 106%, respectively. It should be noted that at the same time there was a slight decrease in the mass of fruits, but the total yield of tomatoes at the end of the vegetation when treated with an extract of phytohormones, exceeded control by almost 1.8 times.

As for the exometabolites of the strain *A. calcoaceticus* IMV B-7241, the most effective was the use of the 2 times diluted supernatant for the treatment of tomatoes seedlings, in which the number of fruits was greater than control by 40%. Treatment with the exometabolites of the strain *N. vaccinii* IMV B-7405 allowed us to obtain the highest average fruit weight among all the studied variants, although the amount of tomatoes was less than control.

Such different results of the influence of exometabolites of the three studied strains on the yield of tomatoes may be due to different concentrations of phytohormones synthesized by *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on refined oil (Table 2) [4], [5].

Table 2 – Synthesis of phytohormones under cultivation of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on refined oil

Strain	Auxins, μg/L	Gibberellins, μg/L	Cytokinins, μg/L	Total concentration, μg/L
N. vaccinii IMV B-7405	770.4	5.96	348.0	1124.36
A. calcoaceticus IMV B-7241	39.6	8.0	75.1	122.7
R. erythropolis IMV Ac-5017	19.4	7.8	17.1	44.3

From the data given in Table 2, it can be seen that *N. vaccinii* IMV B-7405 synthesizes almost 10 times more phytohormones than *A. calcoaceticus* IMV B-7241 and 25 times more than *R. erythropolis* IMV Ac-5017. It is known that high concentrations of phytohormones cause the inhibitory effect on plants rather than stimulating [11]. Since the dilutions of the supernatants in the treatment of tomatoes were the same, the concentrations of phytohormones and other metabolites in the variants of treatment differed in order. For tomatoes, the seedlings of which were treated with exometabolites of *R. erythropolis* IMV Ac-5017, the number of phytohormones was optimal for stimulation of growth and increase in yield.

It is known that all three classes of phytohormones take part in the process of growth and development of plants, and each of them plays a role at a particular stage of the plant development. That is why the best stimulating effect is observed for the total influence of all phytohormones. In the literature data there are studies about impact of phytohormones complex [12] and individual groups on the development of the plants [13], [14]. For example, it was determined [12], that bacterial endophyte *Sphingomonas* sp. LK11 due to the ability to synthesize indole-3-acetic acid (IAA) and gibberellins (in particular, GA_4), stimulated the growth of tomatoes (*Tephrosia apollinea*). In plants treated with a culture liquid of the strain, the shoot length was 68.6% higher than control (treatment with distilled water), and the dry weight of the plant was 48.9% higher.

Due to the ability to synthesize biologically active gibberellins (5.4–15.8 ng/L), the strain *Leifsonia soli* sp. SE134 stimulated the growth of cucumbers, tomatoes and young radishes in the experimental conditions. After pre-sowing seed treatment the length of the shoot increased on 14.1–16.4% and total plant weight increased on 14.8–91.9% compared with control [13]. Isolate from rhizosphere of pepper, *Serratia nematodiphila* PEJ1011, produce GA_4 in the amount of 8650 ng/L [14]. The inoculation of

pepper plants with *S. nematodiphila* PEJ1011 significantly increased plant growth rates compared to control. In the experimental conditions the length of the root and shoot increased by 55.8% and 12.9% respectively.

It should be noted that in the works [12], [13], [14] the authors did not analyze the number and fruit weight, as in our studies. However, there are data in the literature on the influence of plant growth-promoting rhizobacteria (PGPR) on the fruit weight. So, in the work [4] pre-sowing inoculation of tomato seeds with different strains of *Pseudomonas* bacteria, capable of phosphate solubilization and auxin formation, positively influenced the weight of the fruits, collected during the experiment for 11 weeks. The total fruit weight of the plants treated with bacteria exceeded control (treatment with distilled water) by 9–14%. However, it should be noted that the treatment with one of the strains, *P. fluorescens* Migula G, resulted in a 1% decrease in fruit weight compared to control.

Other researchers have shown [15] that pre-sowing treatment with PGPR strains *P. putida, P. fluorescens, Serratia marcescens, Bacillus amyloliquefaciens, B. subtilis* and *B. cereus* increased the shoot weight, the height of the tomato plants and their yield. The treatment with *S. marcescens* strain gave the best effect on the yield, due to which the number of fruits exceeded control by 128.0% and weight by 129.4%. For other strains, these indicators were in the range of 57.0–85.8% and 85.2–103.1% respectively. Only the treatment with *B. amyloliquefaciens* had a negative effect – though the number of fruits exceeded control by 85.0%, the weight was lower by 37.8%.

Babu et al. [5] demonstrated the positive effect of treatment with all five unidentified studied PGPR strains, which are capable of synthesizing IAA. Due to the treatment the weight of tomatoes exceeded control by 51.3–116.0%. Moreover, the authors noted the earlier formation of flowers on plants treated with bacteria. The same effect was observed during the study of the influence of exometabolites *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on tomatoes.

Therefore, literature data confirm the possibility of using the bacteria that are capable of synthesizing growth-stimulating metabolites in crop production to increase yields. In most cases, researchers observed an increase in both the number of fruits and their weight. That is why our further researches will focus on the selection of optimal dilutions of the culture liquid of the studied strains and the search for ways to increase not only the yield but also the mass of the fruits.

3.2. Yield of brewer's barley under treatment with exometabolites of strains IMV B-7405, IMV B-7241 and IMV Ac-5017

Use of waste oil after frying meat for cultivation of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 in the future can become the basis for realization of technology of industrial waste utilization by bioconversion in microbial preparations for plant growing.

Experiments have shown that the treatment of barley seeds with exometabolites of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 strains stimulated the growth of barley and promoted the grain yield increase (Table 3).

Table 3 – Barley grain yield under treatment with exometabolites of *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017

Strain	Treatment	Grain weight, g	Yield increase, % compared with control
Control	Treatment with water	234.0	–
N. vaccinii IMV B-7405	Supernatant (1:10)	331.0	+41.50%
	Supernatant (1:20)	371.0	+58.55%
	Phytohormone extract (1:1000)	370.0	+58.12%
A. calcoaceticus IMV B-7241	Supernatant (1:10)	394.0	+68.38%
	Supernatant (1:20)	396.0	+69.23%
	Phytohormone extract (1:1000)	345.0	+47.43%
R. erythropolis IMV Ac-5017	Supernatant (1:10)	312.0	+33.30%
	Supernatant (1:20)	429.0	+83.30%
	Phytohormone extract (1:1000)	381.0	+62.80%

The data presented in Table 3 show that stimulation of barley growth and grain yield increase were observed in all treatment options. The highest increment of yield was observed for the treatment of barley seeds with exometabolites of strain *R. erythropolis* IMV Ac-5017. So, the use of IMV Ac-5017 supernatant in dilution of 1:20 increased the yield by 83.3%, at the same time in dilution 1:10 the increase was only on 33.3%. Independent of the supernatant dilution, for the strain *A. calcoaceticus* IMV B-7241 we observed almost the same growth stimulation: the increase in barley grain yield was within the range of 68.3-69.2%.

Since the concentration of phytohormones synthesized by *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on the waste oil is practically even (Table 4), the same increase in barley grain yield, regardless of the supernatant dilution of the strain IMV B-7241 (as opposed to the supernatant of strains IMV B-7405 and IMV Ac-5017, see Table 3) can be explained by the fact that this strain also forms other metabolites that have a positive effect on the growth of barley.

Unlike the greenhouse experiment with tomatoes, where the increase in yield was not observed for all strains, in an experiment with barley, each treatment had a positive effect on the grain yield. We attribute this to the fact that on the waste oil producers of surfactants synthesize almost the same amount of phytohormones (Table 4) [4], [5].

Table 4 – Phytohormones synthesized by *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 under cultivation on waste oil after frying meat

Strain	Auxins, μg/L	Gibberellins, μg/L	Cytokinins, μg/L	Total concentration, μg/L
N. vaccinii IMV B-7405	23.3	46.8	53.9	124.0
A. calcoaceticus IMV B-7241	83.2	9.5	43.6	136.3
R. erythropolis IMV Ac-5017	91.3	5.8	37.8	134.9

Literature data confirm the increase in yield of cereals under the influence of PGPR and phytohormones synthesized by them.

Rajput et al. [16] determined that inoculation of wheat seeds with 12 PGPR strains, which produce IAA (9.33–411.5 mg/L) and also capable of phosphate solubilization, improves plant growth, which in the future can positively affect the yield of plants. Thus, the root length increased by 181.0%, and weight of plants by 48.0%.

In the work [17] synthesis of IAA and siderophores at the level 17.0–31.7 mg/L by the strain *Serratia marcescens* B2 was shown. Due to this ability there was an improvement in wheat growth after inoculation with *S. marcescens* B2: the increase was observed in shoot length (+ 3.4–12.0%), shoot weight (+ 1.8–15.2%), root length (1.92–12.0%) and root weight (6.45–12.9%).

In the following articles, the authors analyzed the increase in grain yield after inoculation with PGPR strains, which allows us to compare them with the results of our work.

It was found in the work [18] that strains *Azospirillum brasilense* increase the yield of corn and wheat. Due to pre-sowing inoculation, the grain yield of corn and wheat increased compared to control by 27.0% and 31.0% respectively.

Several unidentified PGPR strains were isolated by Khalid et al. [6] and the ability to synthesize auxins in significant amounts (5.1–12.1 mg/L) was determined. Due to pre-sowing treatment of wheat seeds, grain yield increased by 15.0–27.5% compared to control.

Growth stimulation also was observed under treatment of rice seeds with PGPR cultures of *Gluconacetobacter diazotrophicus* LMG7603, *Herbaspirillum seropedicae* LMG6513, *Azospirillum lipoferum* 4B LMG4348 та *Burkholderia vietnamiensis* LMG10929 (all strains synthesize IAA) [19]. In the experiment, an increase in rice grain yield was noted at 9.5–23.6% relative to control.

The higher barley yields obtained in our studies (Table 3) can be explained not only by the effect of phytohormones, but also by surface-active substances that are present in the supernatant of the culture liquid. Thus, the researchers have shown [20] that pre-sowing seeds treatment of cereals, legumes, and oilseeds by microbial surfactant complexes (extracellular rhamnolipids and polysaccharides *Pseudomonas serum* PS-17, cell-bound tragalosolipids, fatty acids and carotenoids, and extracellular lipoaminopolysaccharide complex *Gordonia rubripertincta* UCM Ac-122) contributed to increase the energy of germination of seeds, increase of growth, biochemical parameters of plants and yields.

It has been determined that the rhamnolipid complex (0.01–0.05 g/L) is an effective regulator of the growth of cereal crops, in particular barley, rye, and wheat. Under pre-sowing treatment of wheat seeds with a solution of ramnolipid biocomplex, the vegetative mass of plants increased by 16.0–35.0% relative to control. The authors of work [20] note that the positive effect of surfactant on plants is probably due to the increased permeability of cell membranes, which contributes to the bioavailability of nutrients and other exogenous substances, as well as the activation of metabolic processes of soil microbiota. Another explanation of the impact of microbial surfactants on plants may be the effect on cell growth through stretching: in a biotest with the segments of wheat coleoptiles the growth was observed by 12.0–16.0% higher than without surfactant. Besides, the use of complex microbial surfactants in combination with indole-3-acetic acid (IAA) contributed to increased activity of this phytohormone. A similar effect of surfactants on the IAA is also determined by the biotest with the rhizogenesis of bean seedlings. The results indicate a possibility to reduce the working dose of IAA in 2–4 times in compositions with surfactants [20].

Thus, the literature data show that the seeds treatment of cereal crops by growth-stimulating bacteria contributes to the increase of yield. Moreover, among the analyzed works, the greatest increase in grain yield was 31.0%, while in our work the gain was 33.3–83.3%. This indicates a significant effect of exometabolites *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on the growth and development of barley.

4. Conclusion

The positive influence of extracellular exometabolites *N. vaccinii* IMV B-7405, *A. calcoaceticus* IMV B-7241 and *R. erythropolis* IMV Ac-5017 on the yields of barley and tomatoes is established in this work. It is the basis for the development of microbial preparations technology using cheap industrial wastes for application in crop production.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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