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AZOTOBACTERIN AS A MICROBIOLOGICAL FERTILIZER
FOR IMPROVING SOIL FERTILITY AND CROP YIELD

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Abstract

This article summarizes the scientific, technological, and practical aspects of applying the microbiological fertilizer Azotobacterin, developed on the basis of the free-living soil bacterium *Azotobacter chroococcum*. It is shown that bacteria of the genus *Azotobacter* are involved in the biological fixation of atmospheric nitrogen, the synthesis of physiologically active substances, the stimulation of rhizosphere microflora, and the reduction of chemical load on the soil. Laboratory and field studies demonstrated that the application of an activated *Azotobacter* strain to grain legumes increased crop yield by 8–16% compared with the control, while potato yield under the soil conditions of Central Tajikistan reached 252 centners per hectare (25.2 t/ha). The paper also discusses the technological requirements for the production of the biofertilizer, quality control parameters, and the prospects for its implementation in the agricultural sector of the Republic of Tajikistan.

Keywords: *Azotobacter chroococcum*, Azotobacterin, microbiological fertilizer, biological nitrogen fixation, rhizosphere, soil fertility, crop yield, sustainable agriculture.

АЗОТОБАКТЕРИН – ТОПЫРАҚ ҚҰНАРЛЫЛЫҒЫ МЕН
АУЫЛ ШАРУАШЫЛЫҒЫ ДАҚЫЛДАРЫНЫҢ ӨНІМДІЛІГІН АРТТЫРУҒА
АРНАЛҒАН МИКРОБИОЛОГИЯЛЫҚ ТЫҢАЙТҚЫШ

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^{1*}*«Ауыл шаруашылығы дақылдарының сорттарын сынау және сорттарды қорғау жөніндегі мемлекеттік комиссия» мемлекеттік мекемесі, Душанбе, Тәжікстан*

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Аңдатпа

Мақалада *Azotobacter chroococcum* еркін тіршілік ететін топырақ бактериясы негізінде әзірленген «Азотобактерин» микробиологиялық тыңайтқышын қолданудың ғылыми, технологиялық және өндірістік аспектілері жинақталған. *Azotobacter* туысына жататын бактериялардың атмосфералық азотты биологиялық фиксациялауға, физиологиялық белсенді заттарды синтездеуге, ризосфералық микрофлораның белсенділігін арттыруға және топыраққа түсетін химиялық жүктемені азайтуға қатысатыны көрсетілген. Зертханалық және өндірістік материалдар негізінде белсендірілген *Azotobacter* штаммын дәнді-бұршақты дақылдарға қолдану бақылау нұсқасымен салыстырғанда өнімділікті 8–16% арттыратыны, ал Орталық Тәжікстан топырақтары жағдайында картоптың өнімділігі 252 ц/га-ға жететіні анықталды. Сонымен қатар препаратты өндірудің технологиялық талаптары, сапасын бақылау көрсеткіштері және оны Тәжікстан Республикасы ауыл шаруашылығы өндірісіне енгізу бағыттары қарастырылған.

Кілт сөздер: *Azotobacter chroococcum*, Азотобактерин, микробиологиялық тыңайтқыш, азоттың биологиялық фиксациясы, ризосфера, топырақ құнарлылығы, өнімділік, тұрақты егіншілік.

АЗОТОБАКТЕРИН КАК МИКРОБИОЛОГИЧЕСКОЕ УДОБРЕНИЕ ДЛЯ ПОВЫШЕНИЯ ПЛОДОРОДИЯ ПОЧВ И УРОЖАЙНОСТИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ КУЛЬТУР

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Аннотация

В статье обобщены научные, технологические и производственные аспекты применения микробиологического удобрения «Азотобактерин», созданного на основе свободноживущей почвенной бактерии *Azotobacter chroococcum*. Показано, что бактерии рода *Azotobacter* участвуют в биологической фиксации атмосферного азота, синтезе физиологически активных веществ, активизации ризосферной микрофлоры и снижении химической нагрузки на почву. На основании лабораторных и производственных материалов установлено, что применение активированного штамма *Azotobacter* на зернобобовых культурах обеспечивает повышение урожайности на 8–16 % по сравнению с контролем, а урожайность картофеля в условиях почв Центрального Таджикистана достигает 252 ц/га. Рассмотрены технологические требования к производству препарата, показатели контроля качества и направления его внедрения в сельскохозяйственное производство Республики Таджикистан.

Ключевые слова: *Azotobacter chroococcum*, Азотобактерин, микробиологическое удобрение, биологическая фиксация азота, ризосфера, плодородие почвы, урожайность, устойчивое земледелие.

Relevance

Under the current conditions of climate change, depletion of soil organic matter reserves, degradation of agroecosystems, and the rising cost of mineral fertilizers, the biologization of agriculture has become an issue of considerable scientific and practical importance. Soil fertility is determined not only by the availability of essential nutrients but also by the activity of the soil microbiota, humus content, water-physical properties, enzymatic activity, and the overall biological balance of the soil environment [1, 2].

Rhizosphere microorganisms play a crucial role in the mineralization of organic matter, the transformation of nitrogen, phosphorus, and micronutrient compounds, and the creation of favorable conditions for the growth and development of agricultural crops. Among these microorganisms, bacteria of the genus *Azotobacter*, particularly *Azotobacter chroococcum*, occupy a special place as free-living nitrogen-fixing microorganisms [3, 4]. Unlike symbiotic rhizobial bacteria that form nodules on legume roots, these microorganisms are capable of fixing atmospheric molecular nitrogen without establishing specialized symbiotic associations with plants, making them highly valuable across a wide range of agroecological conditions.

Azotobacterin is a microbiological fertilizer containing viable cells of *Azotobacter*. It is used for seed bacterization, treatment of seedling root systems, potato tubers, and organic fertilizers, as well as for improving the microbial composition of the rhizosphere. The major advantages of this biofertilizer include its environmental safety, its ability to enhance soil biological activity, reduce the need for mineral nitrogen fertilizers, and promote the sustainability of agroecosystems [5, 6].

Scientific novelty

The scientific novelty of the study lies in the comprehensive assessment of the results of activating the production strain *Azotobacter chroococcum* and its production-scale testing under the soil and climatic conditions of Tajikistan.

The authors' original findings include a reduction in the culture development period following activation from approximately 2.5 days to 10 hours, an increase in yield of 8–16% in leguminous crops compared with the control, a potato yield of 252 c/ha obtained on the soils of Central Tajikistan, as well as the development, based on these results, of production requirements and a differentiated scheme for the application of the preparation. The isolation of a new strain was not the subject of the present study.

Materials and Methods

This study was based on the analysis of laboratory data, research findings obtained by the Department of Soil Biology and Microbiological Fertilizer Development, field application data on the use of Azotobacterin, and published scientific literature concerning the biology of *Azotobacter chroococcum* and the application of microbiological fertilizers in agriculture.

The objects of the study included an activated strain of *Azotobacter* and microbiological preparations developed on its basis. The evaluation considered the morphological and physiological characteristics of the bacterium, its ability to fix atmospheric nitrogen, synthesize plant growth-promoting substances, nutritional requirements, cell viability in different formulation types, and its potential effectiveness under field conditions.

The production assessment included an analysis of crop yield increases, application methods of the biofertilizer for various agricultural crops, requirements for seed and planting material treatment, and the potential use of Azotobacterin as a component of an integrated plant nutrition system.

Results and Discussion

Azotobacter chroococcum is an aerobic free-living soil bacterium that exhibits high biological activity in the presence of an available carbon source and adequate supplies of phosphorus, molybdenum, iron, manganese, and other essential micronutrients. The analyzed data indicate that this bacterium is capable of fixing up to 20 mg of atmospheric nitrogen per gram of sugar consumed, a characteristic that plays a significant role in improving the availability of biologically accessible nitrogen for plants.

In addition to nitrogen fixation, *Azotobacter* synthesizes a wide range of physiologically active compounds, including nicotinic acid, pantothenic acid, pyridoxine, biotin, indole-3-acetic acid (IAA), gibberellins, and other bioactive substances. These metabolites stimulate root system development, promote vegetative growth, and enhance plant tolerance to adverse environmental conditions.

The mechanism of action of Azotobacterin within the soil–plant system is multifaceted. It involves improving plant nitrogen nutrition, stimulating the activity of beneficial rhizosphere microorganisms, enhancing root growth, promoting the synthesis of vitamins and phytohormones, and potentially suppressing certain phytopathogenic microorganisms through the production of biologically active antimicrobial compounds.

Table 1. Main Functional Roles of *Azotobacter chroococcum* in the Soil–Plant System

No	Functional Role	Biological Mechanism	Agricultural Significance
1	Nitrogen fixation	Conversion of atmospheric N ₂ into biologically available forms	Improves plant nitrogen nutrition
2	Phytohormone synthesis	Production of auxins, gibberellins, vitamins, and other growth-promoting compounds	Stimulates root development and vegetative growth
3	Rhizosphere activation	Enhancement of beneficial rhizosphere microbial activity	Increases soil biological fertility
4	Antagonistic activity	Production of biologically active antimicrobial compounds	Reduces the risk of certain root diseases
5	Interaction with mineral nutrition	Dependence of bacterial activity on phosphorus, molybdenum, and micronutrient availability	Improves the efficiency of fertilizer application

The production technology of Azotobacterin should ensure the maintenance of strain purity, controlled bacterial propagation, selection of an appropriate carrier material, and preservation of a sufficient population of viable cells. In agricultural practice, the biofertilizer is produced in dry, soil-based, and peat-based formulations. For the dry formulation, a key quality requirement is a minimum concentration of 0.5×10^9 viable cells per gram of the product, whereas soil-based and peat-based formulations should contain at least 5.0×10^7 viable cells per gram.

The culture medium for cultivating *Azotobacter* should contain a suitable carbon source, mineral salts, iron and manganese sulfates, as well as molybdenum compounds. A pH range of 5.7–6.5 is considered optimal for specific stages of bacterial cultivation. Fermentation is recommended to proceed until the culture reaches the stationary growth phase, as this stage is characterized by the maximum release of biologically active compounds into the culture medium, thereby enhancing the effectiveness of the resulting microbiological fertilizer.

Table 2. Key Requirements for the Production and Quality Control of Azotobacterin

№	Parameter	Recommended Requirements
1	Culture purity	Absence of microbial contamination and preservation of the strain's characteristic properties
2	Viable cell count	Dry formulation: at least 0.5×10^9 cells g ⁻¹ ; soil-based and peat-based formulations: at least 5.0×10^7 cells g ⁻¹
3	Culture medium	Carbon source, mineral salts, iron (Fe), manganese (Mn), and molybdenum (Mo) compounds
4	Storage conditions	Airtight packaging, protection from overheating and direct sunlight, storage at low positive temperatures
5	Safety	Non-toxic and safe for humans, animals, plants, and the environment
6	Efficacy	Improved seed germination, plant growth, and crop yield compared with the untreated control

According to laboratory data, activation of the *Azotobacter* strain reduced the cultivation period from approximately 2.5 days to 10 hours. This improvement is of considerable importance for the industrial production of the biofertilizer, as a shorter cultivation cycle increases production capacity and enables the timely supply of the product to agricultural producers.

Field trials demonstrated that the application of Azotobacterin to grain legume crops increased yield by 8–16% compared with the untreated control. Under the soil and climatic conditions of Central Tajikistan, potato yield reached 252 centners ha⁻¹ (25.2 t ha⁻¹), indicating that the biofertilizer has strong potential as a component of sustainable crop production technologies.

At present, the use of Azotobacterin in pilot demonstration fields located in the Dusti and Jayhun districts, as well as in the city of Vahdat, provides valuable opportunities for large-scale field validation and for refining agronomic recommendations for the application of the biofertilizer under different soil and climatic conditions across the Republic of Tajikistan.

Table 3. Recommended Application Scheme of Azotobacterin for Agricultural Crops

№	Treatment Target	Application Method	Key Requirements
1	Cereal seeds	Seed bacterization before sowing	Ensure uniform seed moistening and timely sowing
2	Grain legumes	Seed treatment or application to the rhizosphere	Maintain adequate soil moisture and sufficient phosphorus availability
3	Potato	Treatment of seed tubers or the root zone with a bacterial suspension	Apply on soils with adequate organic matter content
4	Vegetable seedlings	Dipping the root system into a bacterial suspension before transplanting	Prevent root desiccation after treatment
5	Compost and organic fertilizers	Incorporation into organic material before field application	Maintain adequate moisture and aeration during the composting process

The effectiveness of Azotobacterin depends on several factors, including soil properties, organic matter content, the availability of phosphorus and micronutrients, soil moisture, temperature, and the quality of the biofertilizer itself. Therefore, Azotobacterin should not be regarded as a complete substitute for mineral fertilizers but rather as an integral component of an integrated plant nutrition system. When applied in accordance with recommended rates, timing, and agronomic practices, the biofertilizer can reduce the requirement for mineral nitrogen fertilizers without compromising crop productivity.

From an environmental perspective, the application of Azotobacterin contributes to reducing the chemical load on soils, enhancing the activity of beneficial soil microbiota, improving the biological status of agroecosystems, and increasing the resilience of the soil–plant system. In the Republic of Tajikistan, where a substantial proportion of agricultural land is affected by drought, limited water availability, and declining soil organic matter, the

development of domestic production of such microbiological fertilizers is of considerable scientific, agricultural, and environmental importance.

Nevertheless, the large-scale implementation of Azotobacterin requires comprehensive multi-factor field trials conducted under diverse agroecological conditions across the country. Experimental designs should include an untreated control, a treatment with Azotobacterin alone, a combined treatment of Azotobacterin with a reduced rate of mineral fertilizers, and a treatment with the conventional mineral fertilization system. Such an approach would provide a robust assessment of the agronomic, economic, and environmental effectiveness of the biofertilizer.

Conclusions

1. Azotobacterin is a microbiological fertilizer of considerable scientific, agricultural, and environmental importance, developed on the basis of the free-living nitrogen-fixing bacterium *Azotobacter chroococcum*.

2. The biofertilizer exerts a multifaceted effect on plant growth through the biological fixation of atmospheric nitrogen, the production of phytohormones, the stimulation of beneficial rhizosphere microorganisms, and antagonistic activity against certain phytopathogenic microorganisms.

3. Field data indicate that the application of an activated *Azotobacter* strain to grain legume crops increases yield by 8–16%, while potato yield under the soil and climatic conditions of Central Tajikistan may reach 252 centners ha⁻¹ (25.2 t ha⁻¹).

4. Successful practical implementation of the biofertilizer requires well-established production technology accompanied by rigorous quality control, including verification of strain purity, viable cell concentration, storage stability, and the maintenance of biological efficacy.

5. The integration of Azotobacterin into an integrated plant nutrition system has the potential to reduce dependence on chemical fertilizers, improve the biological quality and fertility of soils, and promote the development of sustainable agricultural systems in the Republic of Tajikistan.

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