FORMATION OF NODULES ON COMMON BEAN ROOTS AND THE EFFECT OF BIOACTIVE SUBSTANCES ON THEIR MASS

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Abstract: This article presents data on the number and mass of nodules formed on the roots of the "Ravot" and "Mahsuldor" bean varieties under the influence of bioactive substances.

Keywords: Biological nitrogen, nodule bacteria, symbiosis, nitrogenase, Uzgumi.

Introduction. The use of biostimulants is a method for increasing the yield of grain legumes and obtaining high-quality produce; it helps accelerate the physiological and metabolic processes of the varieties. Plant growth regulators not only influence the efficient uptake of minerals by plants but also enhance their resistance to stress, diseases, and pests. Plant growth regulators serve as powerful tools for managing plant ontogenesis and are widely used in agricultural crop production [1, 2].

A symbiotic relationship with nodule bacteria occurs in the roots of bean plants. This process positively influences plant growth and development, increases yield, and improves soil fertility. Rhizobium bacteria form nodules on the roots of leguminous plants, through which they exchange nutrients with the plants. As a result of this symbiotic relationship, plants obtain nitrogenous compounds essential for growth, while the bacteria receive carbohydrates and other nutrients from the plants [3].

Biological nitrogen fixation helps reduce the use of chemical fertilizers and promotes the development of agriculture in an environmentally friendly manner. Members of the *Rhizobium* genus are Gram-negative, aerobic, motile bacteria that primarily inhabit the soil [4].

Like the majority of plants in this family, the common bean accumulates biological nitrogen with the help of nitrogen-fixing bacteria—rhizobia [5].

The use of biopreparations and growth regulators to enhance the efficiency of rhizobial symbiosis in leguminous crops can be considered a modern agricultural practice. Treatment with biopreparations and growth regulators influences the functioning of the plant's hormonal system, physiological processes, and the metabolism of both the macrosymbiont and the rhizobia; this, in turn, affects symbiotic nitrogen fixation activity and, consequently, the yield of leguminous crops [6, 7].

Nitrogen fixation continues throughout the plant's life—typically until seed formation, when the nodules disintegrate and nitrogen fixation ceases. Some bacteroids lose their ability to reproduce, while others remain viable and persist in the soil after the plant ages and dies, surviving until the start of the next growing season [8].

Biological nitrogen fixation is the process of reducing atmospheric nitrogen to ammonium (NH4), catalyzed by the enzyme nitrogenase. This process is carried out by a small group of bacteria that establish an intracellular symbiosis with leguminous plants. Once the plant assimilates the ammonia, it enters into reactions for amino acid synthesis; specifically, asparagine is synthesized from aspartic acid, and glutamine from glutamate. Nitrogen is transported to all cells of the organism in the form of glutamine, where it is utilized to synthesize nitrogen-containing organic compounds [9, 10, 11].

We found no existing data regarding the physiological properties, symbiotic activity, or biological nitrogen accumulation of the “Ravot” and “Mahsuldor” common bean varieties in response to bio-active substances such as Uzgumi, Edagum SM, and Gumel Lyuks. Therefore, our study focused on examining the number and mass of root nodules formed on Phaseolus vulgaris L. varieties under the influence of the aforementioned bio-active substances.

Methods. In field experiments, seeds of the “Ravot” and “Mahsuldor” varieties—which are zoned for cultivation in the republic—were sown as a follow-up crop on land previously harvested for grain, using a 60x10x1 planting scheme. The total area of each variant was 120 m², with a recorded area of 60 m²; the variants were arranged in a randomized block design with four replications. The following treatments were tested in the field experiments: N35P60K30 (Background) + no bioactive substances (distilled water); Background + Uzgumi; Background + Edagum SM; and Background + Gumel Lyuks. Seeds were soaked in solutions of the bioactive substances (or distilled water for the control) at the concentrations specified in the experimental design. Additionally, the plants were sprayed with the solutions during the branching stage. Field experiments, phenological observations, and biometric measurements were conducted using standard, generally accepted methods [12]. Furthermore, to assess symbiotic activity, the formation of nodules, the appearance of leghemoglobin, and its conversion to choleglobin were monitored; based on these data, the total and active symbiotic potential were determined [13].

All statistical analyses were performed according to the methods of V.A. Ushkarenko et al. [14].

Results and Discussion. Research results indicated a sharp increase in the number of root nodules in common bean varieties across all developmental stages where bioactive substances were applied. This phenomenon is attributed to heightened biochemical activity in the rhizosphere, intensified activity of symbiotic bacteria (Rhizobium spp.), and the stimulation of nodule formation. For the “Ravot” variety treated with distilled water (control/background), the number of root nodules was 25.2 during the branching stage, 38.1 during flowering, 44.5 during pod formation, and 38.5 during the ripening stage. An increase in nodule count across all stages was observed when bioactive substances were applied to this variety. In the Background + Uzgumi variant, the number of nodules increased by 10.3% during branching, 13.1% during flowering, and 8.3% during pod formation. These figures were even higher in the Background+ Edagum SM' variant; specifically, 50.1 nodules formed during the pod formation stage—an increase of 5.6 nodules (or 12.6%) compared to the

control variant treated with distilled water. The Background + Gumel Lyuks variant proved the most effective, with 51.0 pods recorded at the pod-formation stage and 47.9 pods at maturity. This represents an increase of 6.5 pods (14.6%) and 9.4 pods (24.4%), respectively, compared to the variant treated with distilled water (background) without these bioactive substances.

This phenomenon is attributed to the fact that the Gumel Lyuks preparation contains humic and fulvic acids, as well as microelements, which enhance the activity of microorganisms in the rhizosphere and stimulate the symbiotic activity of Rhizobium bacteria. The Mahsuldor variety exhibited a similar trend, although a slightly higher number of nodules was recorded compared to the Ravot variety. In the control variant (Background treatment with distilled water and no bioactive substances), the number of nodules formed was 26.2 at the branching stage, 45.7 at the pod-formation stage, and 39.7 at the ripening stage. In the Background + Uzgumi variant, the number of nodules reached 48.0 at the pod-formation stage—an increase of 2.3 nodules (5.0%) compared to the control—and 44.7 at the ripening stage (an increase of 5.0 nodules or 12.6%). In the Background+ Edagum SM variant, this figure reached 50.7 nodules (an increase of 5.0 nodules or 11.0%), while the Background+ Gumel Lyuks variant demonstrated the highest results: 53.5 nodules (at the pod-formation stage) and 48.9 nodules (at the ripening stage). These figures represent increases of 7.8 nodules (17.1%) and 9.2 nodules (23.2%), respectively, compared to the control variant. The proliferation of root nodules is primarily linked to heightened symbiotic bacterial activity and the activation of carbon and nitrogen cycling in the rhizosphere. Bioactive substances—particularly those of a humic nature—create a favorable environment for microorganisms, thereby enhancing the ability of Rhizobium bacteria to form root nodules. These processes increase the activity of the nitrogenase enzyme in the roots, facilitating the plant's assimilation of atmospheric nitrogen. In the conducted field experiments, both the number and the mass of nodule bacteria on the roots of bean varieties were measured. The study examined the growth dynamics of nodule bacterial mass in the Ravot and Mahsuldor bean varieties treated with bioactive substances across various developmental stages (branching, flowering, pod formation, and ripening), analyzing their responses at each stage from a scientific perspective. The results clearly demonstrate that the intensity of symbiotic nitrogen fixation in bean roots depends directly on the type of bioactive substance used and the biological characteristics of the variety. According to the findings, the mass of the nodules increased consistently throughout the growing season across all varieties and experimental treatments. It was determined that the nodule mass was highest (5426–6388 mg), particularly during the pod-formation phase.

This process is attributed to a sharp increase in the bean plant's nitrogen requirements and the peak of rhizobial activity. In the control variant (using distilled water without bioactive substances), the nodule mass for the Ravot variety was 312 mg during the branching phase and reached 603 mg by the ripening stage; this indicates a moderate level of natural symbiotic capability in the absence of bioactive substances. It was found that the use of bioactive substances significantly increased nodule bacterial mass: specifically, the nodule mass in the Background+Uzgumi variant was 5.4–8.3% higher than in the control across all stages, while the Background+Edagum SM variant showed an increase of 8.6–10.2%. The highest result was recorded in the Background+Gumel Lyuks variant, where the mass reached

6,300 mg during the pod-formation stage—an increase of 874 mg (or 16.1%) compared to the control. The primary reason for this is that humic-based biostimulants enhance microbiological activity in the rhizosphere, stimulate root exudation, accelerate rhizobial processes, and thereby increase nodule mass. In the Mahsuldor variety, the tuber mass in the control variant (distilled water without bioactive substances) was on average 3–8% higher (334–622 mg) than in the Ravot variety, indicating a higher biological potential for tuber formation in this variety. Under the influence of bioactive substances—specifically in the Background + Uzgumi variant—growth across all phases ranged from 4.8% to 15.1% higher than in the control variant; meanwhile, in the Background + Edagum SM variant, the tuber mass reached 6,267 mg during the pod-formation stage, exceeding the control variant by 663 mg. The Background + Gumel Lyuks variant yielded the best results, showing a mass of 786 mg during the ripening stage (an increase of 164 mg, or 26.3%, compared to the control variant). The effect of bioactive substances was more pronounced in the Mahsuldor variety than in the Ravot variety, with maximum tuber mass values for both varieties recorded in the Background + Gumel Lyuks variant. The Mahsuldor variety consistently demonstrated higher tuber mass across all growth phases compared to the Ravot variety; this difference is attributed to varietal characteristics, root system development, and the degree of propensity for rhizobial symbiosis.

In conclusion, research conducted between 2023 and 2025 on the irrigated typical grey-brown soils of the Samarkand region demonstrates that the number and mass of root nodules in bean varieties consistently increase throughout the growing season, with peak values observed during the pod-formation stage. The application of bioactive substances resulted in an increase in both the number and mass of nodules across all growth stages—a trend consistently observed in both varieties. The highest values were recorded in the Background + Gumel Lyuks variant; this preparation increased the number of root nodules by 14–17% compared to the control variant (background treatment with distilled water). The Mahsuldor variety outperformed the Ravot variety in terms of nodule-forming capacity, producing an average of 2–3 additional nodules. The use of bioactive substances significantly enhanced the increase in nodule mass (by 8–26%). Among the tested preparations, Gumel Lyuks demonstrated the highest efficacy, promoting both nodule formation and increased nodule mass. The Mahsuldor variety surpassed the Ravot variety in nodule mass, indicating a high level of adaptation to rhizobial symbiosis. The use of bioactive substances sharply intensifies the nitrogen fixation process, thereby contributing to increased crop yields, improved fertilizer utilization efficiency, and the restoration of soil fertility.

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