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The influence of the application of biopreparations on the biological activity of the soil and the yield of cotton on irrigated meadow-alluvial soils

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Abstract

This study investigated the effects of three biological preparations Baikal EM-1, Microgrowth stimulator, and Trichodermin on soil microbial activity, plant biochemical responses, and cotton (*Gossypium hirsutum L.*) cv. "Bukhara-10" productivity under irrigated meadow-alluvial conditions in Bukhara region. All tested preparations enhanced soil microbial populations in the top 0–15 cm layer, with ammonifying bacteria increasing by 23–30%, actinomycetes by 134–147%, and cellulose-degrading microorganisms by 44–69% compared to the untreated control. Humus content improved by 11.5–12.7%, and the availability of phosphorus and potassium also increased, reflecting enhanced nutrient cycling. Biochemical analyses of 12-day-old seedlings showed that antioxidant enzyme activities were significantly stimulated: superoxide dismutase (SOD) increased by 5–13%, catalase (CAT) by 17–37%, and peroxidase (POD) by 17–35%, while proline accumulation rose by 10–31%, indicating strengthened osmoprotection and stress tolerance. Among the preparations, Microgrowth stimulator exhibited the most pronounced effects across soil, biochemical, and growth parameters, leading to improved early seedling development, fiber elongation, and quality. Consequently, field experiments revealed yield increases ranging from 8.4% to 10.1% compared to the control. These findings highlight the potential of microbial consortia-based biopreparations as an eco-friendly strategy to improve soil fertility, enhance plant physiological resilience, and increase cotton productivity under saline irrigated conditions. Integration of such treatments into sustainable cotton production systems could contribute to reducing dependency on chemical fertilizers while maintaining high yield and fiber quality.

1. Introduction

Soil is an integral component of natural ecosystems and plays a crucial role in maintaining the stability and productivity of plant communities. Soil fertility and nutrient cycling are strongly influenced by soil biological activity, including the activity of microorganisms and enzymes, which regulate organic matter transformation and nutrient availability (Wei et al., 2024). Soil biological activity, driven by microorganisms, fungi, and enzymes, is a key indicator of soil fertility and is influenced by microbial diversity, enzyme activity, humus content, and soil physicochemical properties (Chen et al., 2024; Daunoras et al., 2024; Qu et al., 2023; Semenov et al., 2025). In recent years, the application of environmentally friendly biopreparations in agriculture has expanded considerably, particularly within sustainable farming systems (Rowińska et al., 2024). Globally, the use of biopreparations is increasingly regulated to ensure environmental safety and product efficacy. Countries in Europe, North America, and Asia have established guidelines for the registration, quality control, and application of microbial and bio-based fertilizers (FAO, 2023; EU Regulation 2019/1009). These regulations aim to promote sustainable agricultural practices while safeguarding soil health and ecosystem functions. The targeted use of biopreparations contributes to restoring soil fertility, enhancing biological activity, and increasing plant resistance to abiotic and biotic stressors, ultimately improving crop yield and quality (Akchaya et al., 2025; González Guzmán et al., 2022). In agriculture, biopreparations are commonly applied to improve the availability and uptake of essential nutrients such as nitrogen, phosphorus, and potassium through microbial solubilization and biological fixation (Kumar et al., 2022), to stimulate plant growth via microbial production of phytohormones, to suppress pathogenic microorganisms (De Andrade et al., 2023), and to improve soil structure and organic matter content (Kanarek et al., 2022). Complex biopreparations based on microbial consortia are often more effective than single-strain formulations due to synergistic interactions within the soil environment (Cao et al., 2022). Irrigated meadow-alluvial soils are widely distributed in river valleys and lowland areas and are intensively used for agricultural production. These soils consist of alluvial deposits with varying proportions of sand, silt, and clay and are generally characterized by light to medium mechanical texture (Ortikov et al., 2024). Cotton, wheat, and vegetable crops are commonly cultivated on irrigated meadow-alluvial soils; however, prolonged irrigation and improper management may lead to soil salinization and deterioration of biological activity (Axmedov et al., 2023). In recent years, intensive agricultural practices, increasing salinization, and excessive agrochemical use have resulted in a decline in soil fertility and productive potential (Futa et al., 2024), accompanied by reduced soil biological activity and disruption of soil ecosystem functioning (Schlüter et al., 2025).

The cotton varieties of the "Bukhara" series were developed specifically for the agro-ecological conditions of the Bukhara region, Uzbekistan. Among them, "Bukhara-10" is distinguished by stable yield potential, medium maturity, favorable fiber quality, and relatively high resistance to soil-borne fungal diseases such as *Fusarium oxysporum* and *Verticillium dahliae*. Under appropriate agro-technical management, these varieties demonstrate stable productivity on irrigated meadow-alluvial soils and are widely used in agricultural practice. The integration of such cultivars with environmentally friendly technologies, including the application of biopreparations, further enhances their agrotechnical efficiency. In recent years, the incidence of diseases caused by soil-borne fungi, particularly *Fusarium oxysporum*, has increased in cotton fields cultivated on irrigated meadow-alluvial soils in the Bukhara region (Aripov et al., 2023; Axmedov et al., 2023). Soil microbial communities play a central role in biogeochemical cycles, and their composition is strongly influenced by climatic conditions as well as soil temperature and moisture regimes (Hao et al., 2025; Naylor et al., 2022). Under the combined influence of climate change and anthropogenic factors, soil biological activity has shown a declining trend (Oishy et al., 2025), making its restoration a priority for sustainable land management (Gamage et al., 2023; Sher et al., 2024). The use of biopreparations based on beneficial microorganisms is widely recognized as an environmentally friendly and economically efficient approach to restoring soil fertility (Pylak et al., 2025). Microbial consortia enhance soil microbiota diversity, accelerate nutrient cycling, suppress soil-borne pathogens, and stimulate plant growth, thereby increasing the biological potential of soils (Wei et al., 2024). Consequently, biopreparations are regarded as a promising tool for maintaining soil fertility and supporting sustainable crop production under changing environmental conditions (Nepal et al., 2023; Samantaray et al., 2024).

The objective of this study was to evaluate the effects of selected biological preparations on soil microbiological activity, humus content, antioxidant enzyme activities (SOD, CAT, POD), fiber quality, and yield of the cotton variety "Bukhara-10" grown on long-irrigated, moderately saline meadow-alluvial soils of the Bukhara oasis. The research hypothesis was that the application of microbial and bio-based preparations would enhance soil microbiological activity, increase humus content, stimulate antioxidant defense mechanisms in cotton plants, and improve fiber quality and overall yield under local soil and climatic conditions.

2. Materials and methods

2.1. Experimental site and soil characteristics

Field experiments were carried out during the 2022–2024 growing seasons at the "Bafo Mardon Sharif" farm (39°46' N, 64°25' E), located in the Bukhara district of the Bukhara region, Uzbekistan. The experimental soil was classified as irrigated meadow-alluvial, typical of the Bukhara oasis. According to its mechanical composition, the soil was mainly of light to medium loamy texture, while heavy loam and sandy loam layers were observed in some areas. Based on particle-size distribution, fine sand (0.1–0.05 mm) and coarse silt (0.05–0.01 mm) fractions predominated, accounting for 18.1–32.6% and 39.0–48.7%, respectively. The proportion of physical clay (<0.001 mm) ranged from 20.2–31.5%, while fine clay particles constituted 3.1–4.8%. The soil reaction was slightly alkaline (pH 7.7), and electrical conductivity (EC) averaged 4.2 dS m^{-1}, indicating moderate salinity. The organic matter content was 1.1%, while humus content averaged 1.3%. The soil contained 0.08% total nitrogen, 21.6 mg kg^{-1} available phosphorus, and 320 mg kg^{-1} exchangeable potassium. Bulk density ranged from 1.35–1.38 g cm^{-3} in the upper soil layers and 1.43–1.49 g cm^{-3} in the subsoil, while the field moisture capacity averaged approximately 24%. Overall, the soil can be characterized as a moderately saline, light- to medium-loamy meadow-alluvial soil with satisfactory fertility and structure, suitable for cotton cultivation under irrigated conditions.

2.2. Experimental design and crop management

The field experiment was conducted using three biological preparations, including Baikal EM-1 (BEM-1), Microgrowth stimulator (MGS), and Trichodermin (TRD). For brevity, these abbreviations are used throughout the manuscript, including figures and tables. The field trial was arranged in a randomized block design with four treatment variants and three replications per treatment. Each experimental plot measured 12 × 0.6 × 80 m (576 m^2), and the total experimental area covered 5.2 ha. The cotton variety "Bukhara-10" (Type IV fiber quality) was used in the experiment. Sowing was performed on April 15 using delinted (sulfuric acid-delinted) seeds at a rate of 35 kg ha^{-1}. Row spacing was 60 cm, intra-row spacing ranged from 4 to 5 cm, and sowing depth was 4–6 cm. Prior to sowing, the field was deep-plowed to a depth of 25–30 cm in November following the removal of cotton residues. Thinning was carried out on May 10–12 to ensure uniform plant density. Inter-row cultivation was performed five times during the growing season, and deep soil loosening

Table 1
Application rates of preparations and mineral fertilizers

Options	Mineral fertilizers, kg/ha	Consumption rate		
		Pre-sowing seed treatment	appearance of 2–4 true leaves	budding and flowering
Control	N_{200}, P_{140}, K_{100}	–	–	–
BEM-1, (0.001 l/ha)	N_{200}, P_{140}, K_{100}	0.001 l t^{-1}	0.001 l t^{-1}	0.001 l t^{-1}
MGS, (0.002%)	N_{200}, P_{140}, K_{100}	100 ml t^{-1}	100 ml t^{-1}	100 ml t^{-1}
TRD, (0.02%)	N_{200}, P_{140}, K_{100}	100 ml t^{-1}	100 ml t^{-1}	100 ml t^{-1}

(25–30 cm) was conducted on May 26 and July 5. Mineral fertilizers and biological preparations were applied according to the experimental treatments (Table 1). All agronomic practices, including seed treatment, fertilization, foliar application, and cultivation, were carried out in accordance with standard recommendations for irrigated cotton production.

2.3. Soil sampling procedure

Soil samples were collected between June and October from two depths, 0–15 cm and 15–30 cm. Sampling was conducted using sterile equipment, including polyethylene bags, spatulas, knives, alcohol, and a marking pen. Each sample was sealed and labeled immediately after collection. To prevent contamination, hands and tools were sterilized with 95% alcohol at each sampling time, and special care was taken throughout the process to maintain sterility.

2.4. Determination of soil chemical properties

Available phosphorus (P_2O_5) and exchangeable potassium (K_2O) were determined using the Machigin method based on extraction with a 1% ammonium carbonate ($(NH_4)_2CO_3$) solution, followed by colorimetric and flame photometric measurements, respectively (Machigin and Protasov, 1950), as modified by CINAO (GOST 26205–91). Soil humus content was determined using the Tyurin (1931) wet oxidation method with potassium dichromate in a sulfuric acid medium. All analyses were performed in triplicate, and the results were expressed on an oven-dry soil basis.

2.5. Microbiological analysis

The effects of soil treatments on the abundance of microorganisms were evaluated in the top 0–15 cm soil layer. Three microbial groups, ammonifying bacteria, actinomycetes, and cellulose-degrading microorganisms, were studied. Microbial abundance was expressed as colony-forming units (CFU × 10^3 g^{-1} of oven-dry soil).

2.5.1. Culture media and incubation

Selective media were used for each microbial group. Ammonifying bacteria were cultured on meat-peptone agar, actinomycetes on Czapek medium, and cellulose-degrading microorganisms on Hutchinson–Clayton medium. Plates were incubated at 28 ± 2°C for 5–7 days, depending on the microbial group. Colonies were counted using a digital colony counter, and microbial densities were calculated according to standard procedures described by (Girard and Rougieux, 1967; Zvyagintsev, 1991).

2.6. Biochemical analyses of plants

Cotton seedlings treated with the experimental preparations were sampled 12 days after emergence. Plant tissues were immediately frozen in liquid nitrogen and homogenized for enzymatic assays. Superoxide dismutase (SOD) activity was determined based on the inhibition of nitroblue tetrazolium photoreduction according to Giannopolitis and Ries (1977). Catalase (CAT) activity was measured by monitoring H_2O_2 decomposition at 240 nm following the method of Aebi (1984), while peroxidase (POD) activity was assayed via tetraguaiacol formation at 470 nm as described by Chance and Maehly (1955). Free proline content was determined using the ninhydrin reagent as described by Bates et al. (1973), and total protein content was measured using the Lowry method (Lowry et al., 1951). All measurements were carried out using a UV-1800 spectrophotometer (Shimadzu, Japan) and were performed in triplicate.

2.7. Fiber quality analysis (HVI method)

Fiber quality parameters were analyzed using the High Volume Instrument (HVI) system (Uster Technologies, Switzerland) at the Bukhara Cotton Fiber Testing Laboratory. The analysis included the determination of fiber length (mm), uniformity index (%), micronaire value (fineness and maturity), fiber strength (g tex^{-1}), and elongation (%). Before testing, all fiber samples were conditioned for 24 hours at 21 ± 1°C and 65 ± 2% relative humidity, following ASTM D5867–12 (2020) standards. Each measurement was performed in three replications, and the mean values were used for statistical evaluation.

2.8. Statistical analysis

All measurements were performed in triplicate. Experimental data were analyzed using GraphPad Prism software (version 8.0.1, GraphPad Software, USA). One-way analysis of variance (ANOVA) was used to evaluate differences among treatment groups. Significant differences between treatment means were assessed using the least significant difference (LSD) post hoc test at $P < 0.05$. Results are presented as the arithmetic mean ± standard error (M ± SE).

2.9. Composition and characteristics of the preparations

Microgrowth stimulator (MGS) is a microbial growth stimulator containing *Trichoderma harzianum* UzCF–55, *Penicillium canescens* UzCF–54, and *Fusarium moniliforme* GC–12. The microorganisms enhance plant growth by synthesizing phytohormones (auxins, gibberellins, and indole-3-acetic acid) in the rhizosphere. The preparation is registered under Certificate No. 1A760 (2013–2017, Uzbekistan) and approved as a plant growth promoter for tomato, cucumber, and cotton.

Trichodermin (TRD). UzCF-55 is a strain capable of synthesizing cellulolytic complex enzymes, proteins, gibberellic acid, heteroauxin, and B-group vitamins. The strain is patented under Invention Patent No. IAP 04900 (May 20, 2014, Uzbekistan).

Baikal EM–1 (BEM–1) is a multi-component microbiological fertilizer developed in 2007 by EM-Corporation (Russia). The preparation contains about 60 strains of beneficial microorganisms, including photosynthetic bacteria, lactic acid bacteria, actinomycetes, yeasts, and fermentative fungi. These microorganisms improve soil microflora, enhance nutrient uptake, and synthesize biologically active compounds such as amino acids, nucleic acids, and vitamins, thereby promoting plant growth, yield, and overall soil health.

3. Results and Discussion

The effects of soil treatments on microbial abundance were evaluated in the top 0–15 cm soil layer. Three microbial groups, ammonifying bacteria, actinomycetes, and cellulose-degrading microorganisms were studied. All tested biological preparations enhanced microbial abundance compared to the untreated control. Specifically, MGS showed the highest stimulatory effect, as ammonifying bacteria increased by 29.5%, actinomycetes by 146.8%, and cellulose-degrading microorganisms by 68.7%. Both BEM-1 and TRD also improved microbial populations, although to a lesser extent (Fig. 1). In the untreated control variant, the abundance of ammonifying bacteria was 2,490 CFU g^{-1} soil, actinomycetes 412 CFU g^{-1} soil, and cellulose-degrading microorganisms 32 CFU g^{-1} soil. Application of BEM–1 resulted in an increase in all microbial groups, with ammonifying bacteria reaching 3,079 CFU g^{-1} soil, actinomycetes 966 CFU g^{-1} soil, and cellulose degraders 46 CFU g^{-1} soil. The most pronounced stimulation was observed under the MGS treatment, where ammonifying bacteria increased to 3,227 CFU g^{-1} soil, actinomycetes to 1,017 CFU g^{-1} soil, and cellulose-degrading microorganisms to 54 CFU g^{-1} soil. Compared to the control, these values corresponded to increases of 29.5%, 146.8%, and 68.7%, respectively. The TRD treatment also led to an increase in microbial abundance, although its effect was less pronounced than that of MGS. The observed increase in soil microbial abundance in the present study is consistent with previous reports demonstrating that the application of biostimulants enhances soil microbial activity by improving substrate availability and alleviating environmental stress (Adedayo and Babalola, 2023). Previous studies indicate that biostimulant application increases both the abundance and activity of beneficial soil microorganisms, which in turn enhances organic matter mineralization, enzymatic activity, and the availability of nutrients essential for plant growth. In the present study, all tested preparations enhanced soil microbiological activity, with MGS exhibiting the strongest effect. This stronger response may be associated with the complex composition of MGS, which includes phytohormones, amino acids, trace elements, and beneficial microorganisms that collectively enhance metabolic processes,

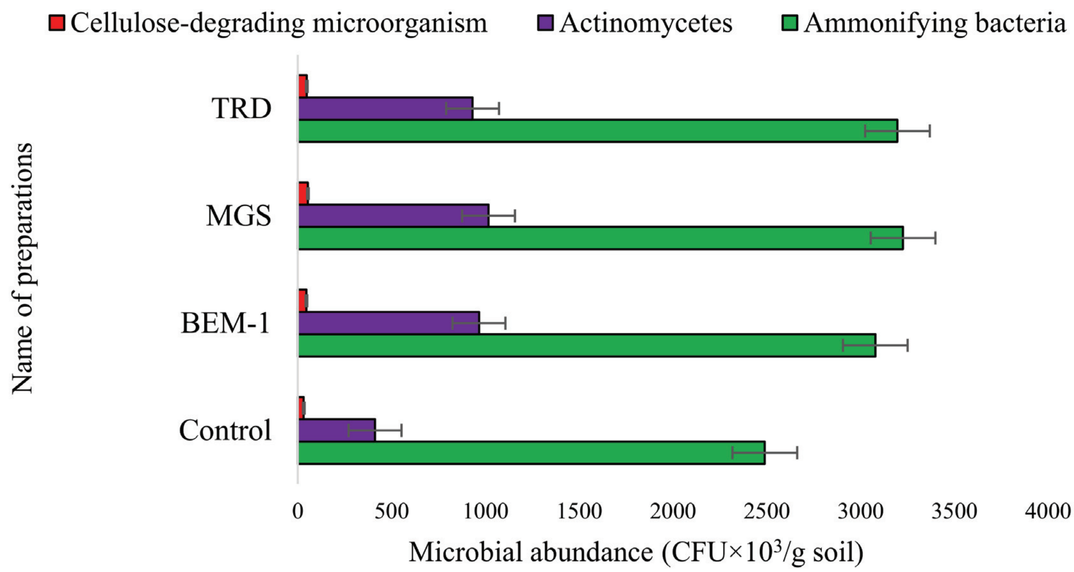

Fig. 1. Effect of biological on soil microbial activity. Error bars represent standard deviations. Data are expressed as mean ± SE (n = 4), with statistical significance set at $P < 0.05$

enzymatic activity, and nutrient cycling, particularly of nitrogen and carbon. Intensified microbial activity accelerates organic matter decomposition, improves soil aeration and aggregation, and increases nutrient availability, ultimately contributing to improved root growth and soil fertility. Therefore, MGS demonstrated the greatest potential for the sustainable enhancement of soil microbial populations and fertility under field conditions. The application of all tested biological preparations positively influenced soil fertility indicators, including humus content as well as available phosphorus and potassium. Humus accumulation increased by 12.7% under MGS, by 11.5% with BEM–1, and by 11.7% with TRD compared to the untreated control (Fig. 2), suggesting that intensified microbial decomposition and improved nutrient cycling contributed to organic matter buildup. The content of available phosphorus in the 0–20 cm soil layer was highest under BEM–1 (18.1 mg kg^{-1}), followed by MGS (17.9 mg kg^{-1}) and TRD (17.6 mg kg^{-1}), while potassium concentrations were maximized under MGS (186.4 mg kg^{-1}), followed by TRD (173.1 mg kg^{-1}) and BEM–1 (169.1 mg kg^{-1}) (Fig. 3). These results indicate that differences among the tested preparations are related to their specific composition. In particular, the complex mixture of phytohormones, amino acids, trace elements, and beneficial microorganisms in MGS likely enhanced microbial activity, thereby accelerating organic matter mineralization and nutrient solubilization. Similar improvements in soil organic carbon and nutrient availability following the application of biological and silicon-based preparations have been reported in previous studies (Juknevicius et al., 2018; Mamasolieva et al., 2023). Overall, the results indicate that all tested bioproducts positively influenced soil fertility, with MGS exhibiting the most pronounced effect under field conditions. During the study, the effect of biological preparations on the germination of the cotton variety "Buxoro-10" was evaluated based on monitoring conducted from April 20 to May 10 (2022–2024). The analysis revealed that, compared to the control, seed germination increased by 8.9% under BEM–1 treatment, 13.3% under MGS, and 9.2% under TRD. These results indicate that the applied biological preparations positively influenced seed germination dynamics. Seed germination and early seedling establishment are governed by internal biochemical processes, including enzyme activation, osmoregulatory adjustments, hormonal signaling, and the induction of protective metabolic responses (Kurilova, 2020). Accordingly, parameters such as enzyme activity, phytohormone balance,

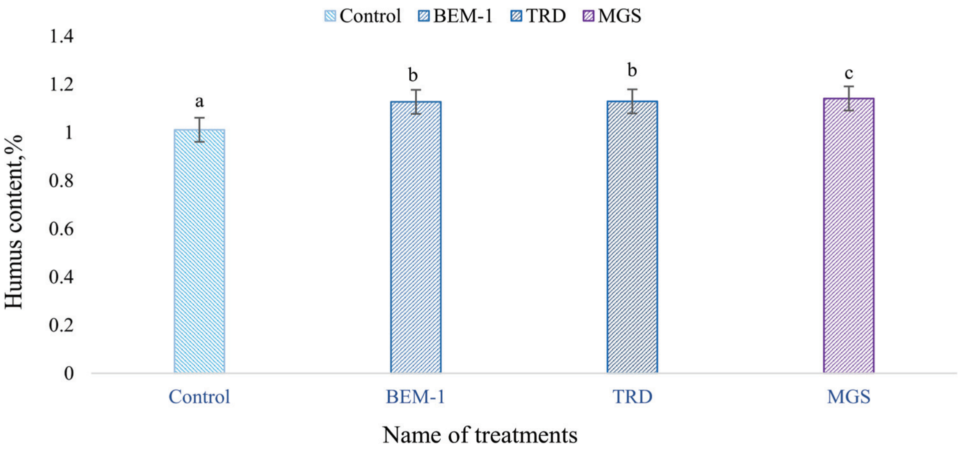

Fig. 2. Effect of biological preparations on soil humus content. Data are expressed as mean ± SE (n = 4), with statistical significance set at $P < 0.05$

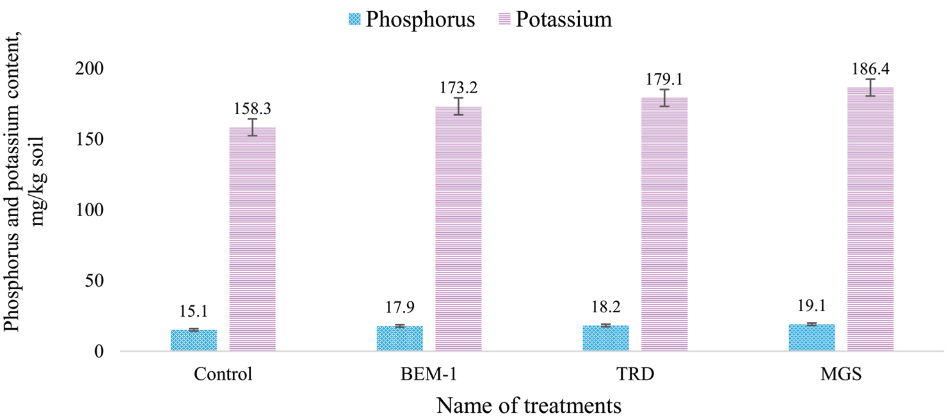

Fig. 3. Effect of biological preparations on soil potassium and phosphorus content. Data are expressed as mean ± SE (n = 4), with statistical significance set at $P < 0.05$

and proline accumulation are commonly used indicators to assess the physiological status of seedlings during the emergence stage. These processes are critical determinants of the effectiveness of applied preparations under stress conditions (Moghaddam et al., 2020). To better elucidate the physiological and metabolic responses of plants to the applied treatments, the activities of key antioxidant enzymes superoxide dismutase SOD, POD, and CAT as well as proline content were evaluated in 12-day-old cotton seedlings grown under local soil and climatic conditions (Table 2). Biochemical analyses showed that the application of the preparations at the early growth stages of cotton seedlings positively affected antioxidant enzyme activity and stimulated proline synthesis. Further analysis demonstrated that the application of biological preparations during early seedling growth led to a notable increase in antioxidant enzyme activities and proline accumulation compared to untreated control plants. The application of BEM–1 resulted in a moderate stimulation of the antioxidant defense system, with SOD activity increasing by approximately 5%, CAT activity by 17%, and POD activity by 17% relative to the control. In addition, proline accumulation increased by nearly 10%, indicating enhanced osmoprotective mechanisms in seedlings treated with this preparation. A stronger physiological response was observed following treatment with MGS. Compared to the control, SOD activity increased by approximately 13%, CAT activity by nearly 37%, and POD activity by 35%. Proline accumulation increased by more than 30% relative to the control, demonstrating that MGS had the most pronounced stimulatory effect on both antioxidant enzyme activity and proline synthesis among the tested treatments. The application of TRD also resulted in significant improvements in the analyzed biochemical parameters, although its effects were less pronounced than those observed under MGS treatment. Under TRD, SOD activity increased by approximately 6%, CAT activity by 27%, and POD activity by 31%, while proline accumulation increased by around 14% compared to the control. The superior effect of MGS is likely associated with its complex biochemical composition, which includes amino acids, vitamins, enzymes, organic acids, and microbial metabolites. Bioactive substances in the preparation activate redox signaling pathways, thereby promoting the synthesis and activity of antioxidant enzymes such as SOD, CAT, and POD. Amino acids and organic acids further support these processes by acting as precursors and signaling molecules involved in plant stress-response regulation (Kohler et al., 2008; Omoarelojie et al., 2021). Proline accumulation, which was most pronounced under MGS treatment, plays a key protective role in plant stress tolerance. Proline acts not only as an osmolyte that stabilizes cellular water potential but also as a molecular chaperone that preserves membrane integrity and scavenges reactive oxygen species (ROS), thereby maintaining cellular redox homeostasis under stress conditions (Szabados and Savouré, 2010; Verbruggen and Hermans, 2008). Microbial metabolites present in MGS may further induce the expression of genes involved in ROS detoxification, thereby enhancing redox homeostasis and limiting oxidative damage to cellular components (Kurilova, 2020). Consequently, the coordinated activation of both enzymatic and non-enzymatic antioxidant systems strengthens overall plant stress tolerance and promotes physiological stability during early growth stages (Moghaddam et al., 2020). Although BEM–1 and TRD also contain beneficial microorganisms that improve nutrient cycling and soil microbial activity, their influence on plant internal biochemical pathways is more indirect than that of MGS, which provides both microbial and biochemical stimulation. Therefore, the synergistic interaction of microbial metabolites, amino acids, and antioxidant components in MGS likely accounts for its superior stimulatory effect on enzyme activity and proline synthesis. During fiber formation and maturation in cotton, substantial amounts of cellulose are required for secondary cell wall synthesis. At this stage, cell elongation gradually slows, and an increase in hydrogen peroxide (H_2O_2) concentration in the cell wall initiates oxidative processes essential for wall strengthening. The maintenance of appropriate cell wall softness during fiber elongation is critical for determining fiber length and mechanical strength. Superoxide dismutase plays a central role in this process by catalyzing the dismutation of superoxide radicals into H_2O_2. The accumulated H_2O_2 regulates lignification processes, thereby modifying the mechanical properties of the cell wall while maintaining sufficient flexibility for fiber elongation. In the present study, the effects of different preparations, particularly MGS, on SOD activity were evaluated in cotton seed integuments at 20, 30, and 40 days during early fiber development (Table 3). Enzyme activity was measured to assess oxidative stress responses and the protective effects of treatments during the initial stages of fiber formation. These results were integrated with HVI analyses of

Table 2
Effects of biological preparations on biochemical processes in cotton seedlings

Treatment	Enzyme activity (U mg^{-1} protein)			Proline ($\mu g\ g^{-1}$ fresh mass)
	Superoxide dismutase	Catalase	Peroxidase	
Control	132.12 ± 3.2	71.78 ± 2.7	112.96 ± 3.1	102.3 ± 4.2
BEM-1	139.11 ± 3.2	84.08 ± 1.8	131.65 ± 2.2	112.3 ± 4.2
MGS	148.69 ± 1.9	98.21 ± 1.7	152.01 ± 2.2	134.7 ± 3.8
TRD	140.12 ± 2.5	91.01 ± 2.3	147.87 ± 1.8	116.5 ± 4.2

The values presented are the mean ± SE of three independent experiments (n=4). $p < 0.05$

Table 3
Effect of preparations on SOD activity in cotton integuments at different developmental stages (20, 30, 40 days)

Treatment	Time dynamics of SOD activity (U min^{-1} mg^{-1} protein)		
	Day-20	Day-30	Day-40
Control	37.21 ± 2.4	61.31 ± 3.7	13.75 ± 0.7
BEM-1	44.18 ± 1.8	75.13 ± 1.6	3.43 ± 0.09
MGS	52.13 ± 0.10	82.11 ± 0.09	2.09 ± 1.01
TRD	48.12 ± 1.03	79.02 ± 1.3	3.17 ± 1.2

The values presented are the mean ± SE of three independent experiments (n=4). $p < 0.05$

Table 4
Effect of preparations on cotton fiber quality parameters and productivity (Bukhara-10 c ha^{-1})

Options	Fleece yield/%	Micro-naire	Fiber length/ mm	Oil content of seeds/ %	Yield/ c ha^{-1}	Compared to control addition/	
						c ha^{-1}	%
Control	34.53	4.1	35.0	20.0	36.6	–	–
BEM-1	37.85	4.4	35.7	20.4	39.7	+3.1	8.4
MGS	38.68	4.6	36	20.8	40.3	+3.7	10.1
TRD	38.00	4.3	35.8	20.3	40.1	+3.5	9.5

The values presented are the mean ± SE of three independent experiments (n=4). $p < 0.05$

fiber quality parameters and yield performance (Table 4). In the untreated control, fiber yield was 34.53%, micronaire value 4.1, fiber length 35.0 mm, seed oil content 20.0%, and productivity 36.6 c ha^{-1}. Application of BEM-1 increased fiber yield to 37.85%, micronaire value to 4.4, fiber length to 35.7 mm, and seed oil content to 20.4%, resulting in a productivity increase of 3.1 c ha^{-1} (8.4%) compared to the control. The MGS treatment resulted in the highest improvements across most parameters, with fiber yield reaching 38.68%, micronaire value 4.6, fiber length 36.0 mm, and seed oil content 20.8%. Productivity under MGS increased by 3.7 c ha^{-1} (10.1%) relative to the control. Similarly, TRD treatment enhanced fiber yield to 38.0%, micronaire value to 4.3, fiber length to 35.8 mm, and seed oil content to 20.3%, with a corresponding productivity increase of 3.5 c ha^{-1} (9.5%). The observed differences in efficacy among the tested preparations are likely attributable to their distinct compositions. MGS contains a complex mixture of phytohormones, amino acids, trace elements, and beneficial microorganisms, whereas BEM–1 primarily supplies microbial inoculants and TRD functions mainly as a biocontrol agent with moderate biostimulatory effects. The positive responses observed are associated with improved nutrient assimilation, enhanced metabolic and enzymatic activity, and increased physiological resilience, which collectively support root development, boll formation, and fiber quality. These findings are consistent with previous studies demonstrating that the application of biostimulants and plant-based preparations enhances cotton growth, reproductive development, and yield by improving early seedling performance, nutrient availability, and physiological stability under field conditions (Davronov and Ibragimova, 2025; Rashidova et al., 2023; Zhangjin et al., 2025). Overall, the results of this study indicate that biologically active preparations can improve cotton productivity and fiber quality by enhancing nutrient cycling, enzyme activity, and key physiological processes, highlighting their potential for sustainable yield improvement and soil fertility management under field conditions.

4. Conclusions

The results of this study confirm that the application of biological preparations, particularly Microgrowth stimulator, significantly enhances soil biological activity, improves nutrient availability, and promotes cotton growth and yield on irrigated meadow-alluvial soils. All applied treatments BEM-1, MGS, and TRD contributed to an increase in soil microbial populations, humus accumulation, and available phosphorus and potassium content, leading to improved soil fertility. Biochemical analyses revealed that these preparations stimulated antioxidant enzyme activities (SOD, CAT, and POD) and proline synthesis in cotton seedlings, suggesting enhanced stress tolerance and early growth development. Notably, MGS showed the strongest effect in boosting antioxidant defense mechanisms and modulating oxidative metabolism during fiber development, contributing to improved fiber elongation and structural quality. High Volume Instrumentation (HVI) analysis demonstrated that biological treatments positively affected fiber quality parameters fiber yield, length, micronaire value, and seed oil content. Yield performance increased by 8.4% to 10.1%, with the highest productivity observed under Microgrowth stimulator treatment.

In summary, integrating biopreparations, particularly MGS, into cotton cultivation systems offers an effective, eco-friendly strategy to enhance soil health, improve plant biochemical responses, and increase both yield and fiber quality. These findings highlight the potential of microbial consortia-based treatments for sustainable cotton production under saline, irrigated conditions.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Odiljon Sharipov Bafoyevich – Conceptualization, Methodology development, Experimental design, Data collection and analysis, Supervision. **Muxamad Ahmedov Ismatovich** – Field investigation, Laboratory experiments, Validation of results, Resource provision, Contribution to manuscript preparation. **Nigora Khalilova Ikhtiyorovna** – Assistance in research activities, Preliminary data collection, Technical support, Contribution to manuscript drafting. **Malika Mamasolieva Adxamovna** – Scientific editing, writing – review and editing. All authors read and approved the final manuscript.

References

Adedayo, A.A., Babalola, O.O., 2023. The potential of biostimulants on soil microbial community: A review. Frontiers in Industrial Microbiology 1, 1308641. https://doi.org/10.3389/finmi.2023.1308641

Aebi, H., 1984. Catalase in vitro. Methods in Enzymology 105, 121–126. Elsevier. https://doi.org/10.1016/S0076-6879(84)05016-3

Akchaya, K., Parasuraman, P., Pandian, K., et al., 2025. Boosting resource use efficiency, soil fertility, food security, ecosystem services, and climate resilience with legume intercropping: A review. Frontiers in Sustainable Food Systems 9, 1527256. https://doi.org/10.3389/fsufs.2025.1527256

Aripov, B.F., Akhmedova, Z.R., Farmonov, B.B., 2023. Characteristics of irrigated soils of Bukhara region intended for cotton sowing. E3S Web of Conferences 389, 03115. https://doi.org/10.1051/e3sconf/202338903115

Axmedov, M., Sharipov, O., Karimova, X., 2023. The effectiveness of the biological preparation "Ivan Ovsinsky-fulvohumate" on the cotton variety "Bukhara-6" under irrigated meadow-alluvial soils of the Bukhara region. E3S Web of Conferences 460, 11004. https://doi.org/10.1051/e3sconf/202346011004

Bates, L.S., Waldren, R.P., Teare, I.D., 1973. Rapid determination of free proline for water-stress studies. Plant and Soil 39(1), 205–207. https://doi.org/10.1007/BF00018060

Chance, B., Maehly, A.C., 1955. Assay of catalases and peroxidases. Methods in Enzymology 2, 764–775. Elsevier. https://doi.org/10.1016/S0076-6879(55)02300-8

Chen, Q., Song, Y., An, Y., Lu, Y., Zhong, G., 2024. Soil microorganisms: Their role in enhancing crop nutrition and health. Diversity 16(12), 734. https://doi.org/10.3390/d16120734

Daunoras, J., Kačergius, A., Gudiukaitë, R., 2024. Role of soil microbiota enzymes in soil health and activity changes depending on climate change and the type of soil ecosystem. Biology 13(2), 85. https://doi.org/10.3390/biology13020085

Davronov, Q., Ibragimova, Q., 2025. Effect of new preparations on cotton yield components. Web of Agriculture: Journal of Agriculture and Biological Sciences 3(3), 140–143. https://webofjournals.com/index.php/8/article/view/1141

European Union, 2019. Regulation (EU) 2019/1009 of the European Parliament and of the Council of 5 June 2019 laying down rules on the making available on the market of EU fertilising products. Official Journal of the European Union, L 170, 1–114. http://data.europa.eu/eli/reg/2019/1009/oj

Futa, B., Gmitrowicz-Iwan, J., Skersienë, A., Đlepetienë, A., Parađotas, I., 2024. Innovative soil management strategies for sustainable agriculture. Sustainability 16(21), 9481. https://doi.org/10.3390/su16219481

Food and Agriculture Organization (FAO), 2023. The State of Food and Agriculture 2023: Revealing the true cost of food to transform agrifood systems. Rome. https://doi.org/10.4060/cc7724en

Gamage, A., Gangahagedara, R., Gamage, J., et al., 2023. Role of organic farming for achieving sustainability in agriculture. Farming System 1(1), 100005. https://doi.org/10.1016/j.farsys.2023.100005

Giannopolitis, C.N., Ries, S.K., 1977. Superoxide dismutases: I. Occurrence in higher plants. Plant Physiology 59(2), 309–314. https://doi.org/10.1104/pp.59.2.309

Girard, H., Rougieux, R., 1967. Technique de microbiologie agricole. Dunod, Paris, 216 pp.

González Guzmán, M., Cellini, F., Fotopoulos, V., et al., 2022. New approaches to improve crop tolerance to biotic and abiotic stresses. Physiologia Plantarum 174(1), e13547. https://doi.org/10.1111/ppl.13547

GOST 26205–91, 1993. Soils. Determination of mobile compounds of phosphorus and potassium by the Machigin method modified by CINAO. Gosstandart of the Russian Federation, Moscow.

Hao, Y., Mao, J., Bachmann, C.M., et al., 2025. Soil moisture controls over carbon sequestration and greenhouse gas emissions: A review. Npj Climate and Atmospheric Science 8(1), 88. https://doi.org/10.1038/s41612-024-00888-8

Juknevicius, D., Sarauskis, E., Rimkuviene, D., Rukaite, J., Karayel, D., 2018. Effect of biological preparation on changes in soil organic carbon and its environmental impact applying precision farming. Engineering for Rural Development, Proceedings of the 17th International Scientific Conference, 398–403. https://doi.org/10.22616/ERDev2018.17.N398

Kohler, J., Hernández, J.A., Caravaca, F., Roldán, A., 2008. Plant-growth-promoting rhizobacteria and arbuscular mycorrhizal fungi modify

alleviation biochemical mechanisms in water-stressed plants. Functional Plant Biology 35(2), 141–151. https://doi.org/10.1071/FP07218
Kurilova, D., 2020. The effect of biopreparations on soybean germination ability and contamination with seed infection. E3S Web of Conferences 222, 02037. https://doi.org/10.1051/e3sconf/202022202037
Lowry, O.H., Rosebrough, N.J., Farr, A.L., Randall, R.J., 1951. Protein measurement with the folin phenol reagent. Journal of Biological Chemistry 193(1), 265–275. https://doi.org/10.1016/S0021-9258(19)52451-6
Mamasolieva, M.A., Gafurova, L.A., Jabbarov, Z.A., Hudoynazarov, I.A., 2023. The effect of silicon-based preparation on the amount of humus and essential nutrients in the soil. Journal of Agriculture Sustainability and Environment 2(2), 86–96. https://doi.org/10.56556/jase.v2i2.959
Moghaddam, M., Farhadi, N., Panjtandoust, M., Ghanati, F., 2020. Seed germination, antioxidant enzymes activity and proline content in medicinal plant Tagetes minuta under salinity stress. Plant Biosystems – An International Journal Dealing with All Aspects of Plant Biology 154(6), 835–842. https://doi.org/10.1080/11263504.2019.1701122
Naylor, D., McClure, R., Jansson, J., 2022. Trends in microbial community composition and function by soil depth. Microorganisms 10(3), 540. https://doi.org/10.3390/microorganisms10030540
Nepal, J., Ahmad, W., Munsif, F., Khan, A., Zou, Z., 2023. Advances and prospects of biochar in improving soil fertility, biochemical quality, and environmental applications. Frontiers in Environmental Science 11, 1114752. https://doi.org/10.3389/fenvs.2023.1114752
Oishy, M.N., Shemonty, N.A., Fatema, S.I., et al., 2025. Unravelling the effects of climate change on the soil–plant–atmosphere interactions: A critical review. Soil & Environmental Health 3(1), 100130. https://doi.org/10.1016/j.seh.2025.100130
Omoarelojie, L.O., Kulkarni, M.G., Finnie, J.F., Van Staden, J., 2021. Biostimulants and the modulation of plant antioxidant systems and properties. Biostimulants for Crops from Seed Germination to Plant Development, 333–363. Elsevier. https://doi.org/10.1016/B978-0-12-823048-0.00008-3
Ortikov, T., Umarov, O., Bafayeva, Z., Ochilova, M., 2024. Microbiological activity of irrigated meadow-alluvial soil in Bukhara depending on salinity level. E3S Web of Conferences 587, 04015. https://doi.org/10.1051/e3sconf/202458704015
Pylak, M., Oszust, K., Panek, J., et al., 2025. Impact of microbial-based biopreparations on soil quality, plant health, and fruit chemistry in raspberry cultivation. Food Chemistry 462, 140943. https://doi.org/10.1016/j.foodchem.2024.140943
Qu, R., Liu, G., Yue, M., et al., 2023. Soil temperature, microbial biomass and enzyme activity are the critical factors affecting soil respiration in different soil layers in Ziwuling Mountains, China. Frontiers in Microbiology 14, 1105723. https://doi.org/10.3389/fmicb.2023.1105723
Rowińska, P., Gutarowska, B., Janas, R., Szulc, J., 2024. Biopreparations for the decomposition of crop residues. Microbial Biotechnology 17(8), e14534. https://doi.org/10.1111/1751-7915.14534
Samantaray, A., Chattaraj, S., Mitra, D., et al., 2024. Advances in microbial based bio-inoculum for amelioration of soil health and sustainable crop production. Current Research in Microbial Sciences 7, 100251. https://doi.org/10.1016/j.crmicr.2024.100251
Schlüter, S., Wu, M., Phalempin, M., et al., 2025. Divergence in physical, chemical, and biological soil properties caused by different long-term bare fallow management and natural succession. Geoderma 459, 117361. https://doi.org/10.1016/j.geoderma.2025.117361
Semenov, M.V., Zhelezova, A.D., Ksenofontova, N.A., Ivanova, E.A., Nikitin, D.A., Semenov, V.M., 2025. Microbiological indicators for assessing the effects of agricultural practices on soil health: A review. Agronomy 15(2), 335. https://doi.org/10.3390/agronomy15020335
Sher, A., Li, H., Ullah, A., Hamid, Y., Nasir, B., Zhang, J., 2024. Importance of regenerative agriculture: Climate, soil health, biodiversity and its socioecological impact. Discover Sustainability 5(1). https://doi.org/10.1007/s43621-024-00662-z
Szabados, L., Savouré, A., 2010. Proline: A multifunctional amino acid. Trends in Plant Science 15(2), 89–97. https://doi.org/10.1016/j.tplants.2009.11.009
Tyurin, I.V., 1931. New modification of the volumetric method for determining humus using chromic acid. Soil Science 1(6), 36–47.
Verbruggen, N., Hermans, C., 2008. Proline accumulation in plants: A review. Amino Acids 35(4), 753–759. https://doi.org/10.1007/s00726-008-0061-6
Wei, X., Xie, B., Wan, C., Song, R., et al., 2024. Enhancing soil health and plant growth through microbial fertilizers: Mechanisms, benefits, and sustainable agricultural practices. Agronomy 14(3), 609. https://doi.org/10.3390/agronomy14030609
Zhangjin, Soothar, R.K., Shar, S.U., Alharthi, B., et al., 2025. Responses of cotton yield and water productivity to irrigation management: Assessment of economic costs, interactive effects of deficit irrigation water and soil types. Discover Life 55(1), 1. https://doi.org/10.1007/s11084-024-09677-y
Zvyagintsev, A.I., 1991. Extremal problem of the norm of an intermediate derivative. Mathematical Notes of the Academy of Sciences of the USSR 49(2), 145–151. https://doi.org/10.1007/BF01137544