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BIOLOGICAL PRODUCTS EFFECT ON GROWTH, PRODUCTIVITY, AND QUALITY OF POTATO (*SOLANUM TUBEROSUM* L.) IN SOUTHEASTERN KAZAKHSTAN

T.YE. AITBAYEV[1], ZH.ZH. MAMYRBEKOV[2], E.P. PETROV[2], and A.T. AITBAYEVA[2]*

[1]LLP Kazakh Research Institute of Fruit and Vegetable Growing, Almaty, Kazakhstan
[2]Regional Branch Kainar, LLP Kazakh Research Institute of Fruit and Vegetable Growing, Almaty, Kazakhstan
*Corresponding author's email: aitbaevaa86@gmail.com
Email addresses of co-authors: aitbayev.te@mail.ru, mamyrbekov.zh70@mail.ru, yevgeniy.petrov1958@mail.ru

SUMMARY

Potato (*Solanum tuberosum* L.) is a key food crop in Kazakhstan, though its productivity is low due to inefficient utilization of nutrients in Southeastern Kazakhstan. This study aimed to evaluate the effects of biological products and biostimulants on potato growth and development, tuber yield and quality, and economic efficiency. A potato field experiment with seven treatments (T1–T7), including an untreated control (T1), completed its conduct in 2024–2025. The results revealed foliar application of biostimulants accelerated phenological development and improved plant biometric traits. The most pronounced improvement was visible in the growth and yield of treatments T2 (Oboki), T3 (Celobacirin AS-24K + Phosphobacirin-S), T4 (BioSok Energy^{+}), and T6 (Fitolaza + Nano-sulfur). The highest tuber yield resulted in T2 (27.4 t/ha) and excelled control by 46.08% (8.65 t/ha). Biochemical analysis displayed increased dry matter, sugar, and starch contents (up to 17.2%); however, nitrate level was below permissible limits. Economic analysis showed the highest profitability with T4 (257%), with a net return of USD 1590.84/ha, followed by T3, T6, and T2 with high economic efficiency (203%, 188%, and 176%, respectively). The results suggested that integrated application of biological products in potato cultivation under semi-arid conditions could effectively improve plant growth, tuber yield and quality, and profitability.

Keywords: Potato (*S. tuberosum* L.), biostimulants, biological products, productivity, tuber quality, profitability, the foothill zone of Southeast Kazakhstan

Key findings: The foliar and root-applied biological products significantly improved potato (*S. tuberosum* L.) growth, yield, and tuber quality. The results confirmed biostimulants and biological fertilizers enhance resource-use efficiency, productivity, and economic returns while reducing dependency on chemical inputs.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the key crops playing a crucial role in ensuring food security globally. In terms of production and consumption, it ranks third among food crops after wheat and rice, highlighting its strategic importance in the global agricultural sector (Yalovik *et al.,* 2023). According to the Food and Agriculture Organization (FAO) data, the global area under potato cultivation exceeds 17.6 million ha, and total tuber production reaches 365 million tons, with approximately 80% of global output concentrated in Europe and Asia (Golin *et al.,* 2024).

The highest energy level of potato tubers shows a primary association with their starch content, with their biological value determined by biochemical contents. Among these are vitamins, mineral elements, and antioxidants, which have contributed to the perception of potatoes as the 'second bread' (Tamburino *et al.,* 2023).

Studies by Cortiello *et al.* (2024) have shown that effective potato cultivation in mountainous areas with adverse conditions can be successful through the combined use of protein hydrolysates and seaweed extracts. This stimulation significantly improves plant growth and tuber quality; however, to optimize productivity, it is necessary to consider varietal characteristics and seasonal climatic variability in mountainous regions.

The varietal potential of potatoes determines the plant's adaptability to specific soil and existing climatic conditions. Although, its full realization is possible only under scientifically grounded agrotechnologies, including rational plant nutrition, effective plant protection system, and proper water-regime management (Naumann *et al*., 2020).

For several decades, the increase in potato productivity reached massive achievements through the intensive use of synthetic mineral fertilizers and chemical plant-protection measures. According to Volpato *et al*. (2020), this strategy significantly increased productivity; however, it paralleled with negative environmental pollution. In the present era, a growing need to transition toward more environmentally oriented and sustainable agrotechnologies is crucial. In this context, the use of plant biostimulants has gained significant interest to improve growth, nutrient uptake, yield, and potato tolerance to abiotic stresses (Kundu *et al.,* 2023).

Unlike traditional mineral fertilizers, biostimulants act on potato metabolism by activating natural physiological mechanisms and improving the resource-use efficiency (Gitau *et al.,* 2022). The integrated application of biostimulants and mineral fertilizers considerably improved the nutrient-use efficiency, particularly under limited soil fertility and water stress conditions (Ride *et al.,* 2024).

Abiotic stresses, such as drought, salinity, and extreme temperatures, represent one of the major causes of global yield losses, affecting and reducing the productivity of most crops by more than 50%. In this regard, the application of biostimulants tended to be one of the most promising approaches to maintaining crop productivity and resilience (Caradonia *et al.,* 2022).

Modern strategies for increasing potato productivity involve the biologization of agrotechnologies through applying biostimulants based on living microorganisms, nitrogen-fixing and phosphate-solubilizing bacteria, beneficial fungi, as well as seaweed extracts, amino acids, phytohormones, and proteins (Yalovik *et al.,* 2025).

Field studies recognized that the integrated application of biological products in combination with rational agrotechnological practices leads to increased yield and improved quality parameters of potatoes (Caradonia *et al.,* 2022; Matychenkov *et al.,* 2022). Ukolova (2025) reported biological products could considerably contribute to regulating crop maturation timing, enhancing plant resistance to adverse environmental factors, and reducing pathogen incidence, ultimately allowing a reduction in pesticide load.

High efficiency of biological products has succeeded in demonstrating when their application be in combination with organic and mineral fertilizers. A synthesis of experimental data from multiple countries indicates a pronounced effect of mineral and organomineral backgrounds when using biological products (Ettlili *et al.,* 2022; Abitova *et al.,* 2025).

The market in the Republic of Kazakhstan offers a wide range of biological products; however, their use requires scientifically based recommendations that consider the biological characteristics of the crop and the agroclimatic conditions of the cultivation area. In this context, the development and optimization of application protocols for various forms of biostimulants, especially for new potato varieties under sharply continental climatic conditions, represent a pressing scientific challenge with significant practical importance. The use of biological fertilizers and biostimulants enables increased productivity and more efficient resource utilization while reducing chemical load. Still, their combined application remains insufficiently studied in the foothill zone of Southeastern Kazakhstan, which served as the rationale for this study. The uniqueness and scientific novelty of the research lie in the combination of a regional approach, the analysis of previously unstudied bioproducts with diverse compositions, and the development of optimal application protocols aimed at enhancing crop yield and ecological sustainability.

MATERIALS AND METHODS

Experimental site and procedure

Field experiments on potatoes proceeded during 2024–2025 at the regional branch of Kainar, LLP Kazakh Research Institute of Horticulture and Vegetable Growing, Zailiysky Alatau, Southeastern Kazakhstan (with an altitude of 1000–1050 masl). In the experiments, the potato cultivar Narly, a mid-late maturing variety, was the specimen used, as an officially recommended variety for cultivation in the Almaty Region. Seed tubers commenced planting on May 14 and 16 during cropping seasons of 2024 and 2025, respectively. The experiment arrangement was in a systematic design with four replications, and each subplot covered 50 m². Planting continued at the spacing of 75 cm × 30 cm, resulting in a plant density of 57000 plants per hectare. The seed tuber rate was 3.5–4.0 t/ha. The preceding crop was alfalfa. Mineral fertilizers applied comprised $N_{90}P_{90}K_{90}$, with five irrigations supplying 550–600 m³ ha⁻¹ of water. Agronomic practices with local recommendations included autumn plowing (27–29 cm), spring tillage, double harrowing, inter-row loosening, hilling, and irrigation and pests, weeds, and disease control.

Soil and climatic conditions

The conduct of research occurred in a region characterized by a sharply continental climate, where the average air temperature in July ranges from 24 °C to 26 °C, while in January, it varies from -8 °C to -12 °C. The annual precipitation ranges between 350 and 600 mm, of which approximately 120–300 mm occurs during the growing season. The sum of active temperatures during the vegetation period is 3100 °C–3400 °C.

The soil of the experimental site has a dark chestnut classification, characterized by a medium loamy texture and a weakly developed aggregate structure. In the topsoil layer (0–20 cm), the humus content is 2.27%, available nitrogen is 61.6 mg/kg, available phosphorus is 38 mg/kg, and exchangeable potassium is 240 mg/kg. The soil reaction is slightly alkaline, with pH values ranging from 8.36 to 8.37. The calcium carbonate ($CaCO_3$) content in the upper layer is 1.23% and decreases to 1.14% at a depth of 20–40 cm. The bulk density of the soil ranges from 1.1 to 1.2 g/cm³, and the minimum field moisture capacity is 26.6%. According to the particle size distribution, 41.41% of particles in the surface horizon fall within the 0.05–0.01 mm fraction, while the proportion of particles smaller than 0.001 mm is 18.68%.

Research objects

Potatoes, biological products with different compositions, phenological traits, biometric parameters, tuber biochemical composition, productivity, economic performance, and profitability made up the research.

The field experiments comprised seven treatments (T1–T7) designed to evaluate the effectiveness of various biological products, including control or untreated as T1. The following are descriptions of the other six treatments. T2 contained Obogi, based on silicon and seaweed extracts, applied at 5.0 L/ha, four times at 10-day intervals, starting from the budding phase, via foliar application. T3 included Celobacirin AS-24K, based on cellulolytic bacteria and micro- and meso-elements in chelated form, applied at 1.5 L/ha, three times at 14-day intervals, starting from the row closure phase, via foliar application. It also included seed inoculant Phosphobacirin-C at 2.0 L/t, applied once before sowing. T4 consisted of BioSok Energy, based on vermicompost enriched with macro- and microelements, applied at 6.0 L/ha, five times at 7–10-day intervals, starting from the row closure phase, via foliar application. T5 comprised Makfert Platinum, based on organic compounds and water-soluble potassium oxide, applied at 1.2 L/ha, four times at 14-day intervals, starting from the budding phase, via foliar application. T6 includes Phytolase, based on enzymes, elicitors, amino acids, and organic substances, applied at 300 mL/ha, five times at 10–14-day intervals. It also had Nano Sulfur, containing 40% sulfur particles, applied at 6.0 L/ha, two times at 30-day intervals, starting from the row closure phase, via foliar application. T7 contained Scudo, water-soluble copper compounds, amino acids, and peptides enriched with organic substances, applied at 0.8 L/ha once for seed treatment before sowing and at 3.0 L/ha, three times at 20-day intervals, via foliar application starting from the budding phase.

Determining the timing and methods of bioproduct application followed the BBCH scale for potatoes. It included pre-plant tuber treatment (BBCH 00), vegetative growth and row-closure stages (BBCH 31–39), as well as budding and flowering stages (BBCH 51–69) (Dospekhov, 1980; Litvinov, 2011; Meier, 2018).

Plant growth and development monitoring continued at three key stages of the growing season: Phase I—from row closure to the onset of budding (BBCH 35–55); Phase II—mass flowering (BBCH 65–69); and Phase III—intensive tuber formation (BBCH 71–75). For these measurements, random selection of 10 plants occurred per plot. At each stage, recording the following parameters included main stem height, stem diameter, the number of stems and leaves, leaf length and width, and leaf area. Additionally, during the tuber formation stage, total plant canopy area, tuber number, and tuber weight reached detection. Harvesting and tuber assessment ensued by complete plot harvesting.

Assessing the quality attributes of potato tubers used the following methods: soluble solids content—refractometric method (GOST 28562-90); total sugars (GOST 8756.13-87); starch content (GOST 7194-81); pH; vitamin C (GOST 24556-89); and the nitrate content determined by the potentiometric method (GOST 29270-95).

Statistical analysis

All the recorded data based on morphological and yield-related traits underwent analysis by using computer software. The data received statistical processing using one-way analysis of variance (ANOVA) and Tukey's significance criterion ($p \leq 0.05$). Data processing ensued using R 4.2.1 and STATISTICA 10.

Economic analysis

The economic analysis comprised accounting for costs of mineral fertilizers, biological fertilizers, labor involved (in the application of chemical and biological fertilizers and harvesting), fuels and lubricants, and product transport. Calculations on these depended on actual use and market prices for 2024–2025. Revenue computation relied on yield and the average market price (USD 258.97/ton). Net income and profitability calculations used the following formula:

$$\text{Profitability (\%)} = \text{Net income} / \text{Costs} \times 100$$

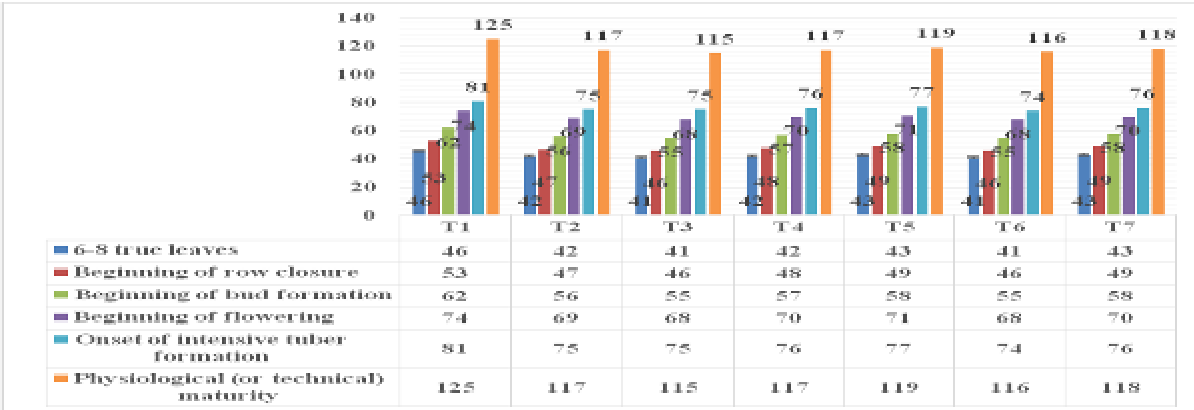


Figure 1. Dynamics of potato phenological development under the influence of biological products.

RESULTS AND DISCUSSION

Phenological observations are an important tool for evaluating the potato (*Solanum tuberosum* L.) plants' response to biological products. The results showed the combined use of bioproducts accelerated the onset of specific phenological stages by 3–9 days compared with the control (T1). The most pronounced effect resulted in treatments T3 and T6, with plants treated with a combination of two products, which contributed to the stimulation and acceleration of physiological and biochemical processes. This included cell division, metabolic activation, and earlier formation of generative organs. The duration from planting to physiological maturity ranged from 115 days (T3) to 125 days (control). These results confirmed the positive effect of bioproducts on potato growth and development. Gazdanova *et al.* (2020) and Sievidov and Alferov (2025) also reported a reduction of 2–9 days in phenological phases of various crops with the influence of biostimulants (Figure 1).

In evaluating the effect of biostimulants on potato (*S. tuberosum* L.) growth parameters, the seven experimental treatments (T1–T7) revealed significant differences using one-way analysis of variance (ANOVA), followed by a post-hoc test at the significance level of $p < 0.05$. These results were consistent with the findings of Mbuyisa *et al.* (2023), who also reported positive effects of biological fertilizers and phytohormones based on auxins, gibberellins, and cytokinins. It refers to their ability to induce active cell division and elongation, thereby enhancing biomass development in potato plants.

Measurements of model potato plants during the early vegetative stage (Phase I) exhibited improved biometric parameters compared with the control. Main stem height ranged from 54.71 to 56.87 cm (Table 1); however, it did not significantly differ from the control. Meanwhile, the stem diameter at the plant base displayed a significant increase in T6 (13.08 ± 0.64 mm), reflecting enhanced mechanical strength and conducting capacity. The seven treatments revealed substantial differences for leaf number, and the treatments T3, T6, and T7 reached 45.30 to 45.85 leaves per plant, remarkably exceeding the control (39.13 ± 4.42).

This effect is likely ascribable to the combined stimulatory action of bioproducts (T3, T6, and T7), including both foliar applications and pre-planting treatments of seed tubers. The obtained results are consistent with the findings of Cardarelli *et al.* (2022), who reported that the combined use of such approaches creates a synergistic effect. This ensured a more intensive initial growth through the stimulation of the root system development, which appears in increased overall plant biomass.

At the second developmental stage (Phase II), the effects of biostimulants further

Table 1. Effect of biostimulants on biometric parameters of potato plants (phenological phase - row closure to beginning of budding).

Experimental variants	Stem height (cm)	Stem base diameter (mm)	Number of stems	Number of leaves	Leaf width (cm)	Leaf length (cm)
T1	52.66±1.49	11.38±0.40	4.40±0.32	39.13±4.42	11.76±0.47	18.58±0.54
T2	56.55±2.00	12.50±0.53	4.70±0.17	40.70±2.95	11.69±0.62	19.07±1.00
T3	55.24±2.96	12.33±0.83	4.73±0.34	45.85±2.32	12.36±0.17	20.10±0.51
T4	55.19±2.38	12.08±0.66	4.63±0.34	44.65±2.02	12.60±0.56	19.87±1.03
T5	55.18±2.19	12.30±0.75	4.55±0.17	44.80±1.97	12.20±0.37	19.64±1.33
T6	56.87±2.97	13.08±0.64	4.70±0.32	45.53±2.54	12.26±0.87	20.03±0.70
T7	54.71±3.19	12.43±1.10	4.55±0.17	45.30±2.31	12.09±0.35	19.75±1.07

Table 2. Effect of biostimulants on biometric parameters of potato plants (phenological phase - full flowering).

Experimental variants	Stem height (cm)	Stem base diameter (mm)	Number of stems	Number of leaves	Leaf width (cm)	Leaf length (cm)
T1	58.56±1.65	13.22±0.43	4.78±0.28	47.52±2.53	13.45±0.40	21.15±0.26
T2	61.69±3.54	14.46±0.99	4.85±0.24	49.45±5.42	13.81±0.32	22.81±0.37
T3	60.42±3.82	13.57±1.01	5.38±0.25	51.35±2.76	14.07±0.18	22.42±0.92
T4	61.00±2.70	13.53±0.67	5.00±0.39	49.67±1.80	14.34±0.58	22.39±1.07
T5	60.84±2.56	13.84±0.75	4.90±0.14	50.00±1.07	13.97±0.31	22.93±0.44
T6	62.35±3.72	13.87±0.72	5.03±0.17	52.25±2.98	12.63±0.76	21.60±0.90
T7	60.16±3.52	13.77±0.95	5.55±0.13	50.74±2.24	13.79±0.46	22.32±1.03

improved. Maximum plant height was evident in T6 (62.35 ± 3.72 cm), and the highest stem diameter appeared in T2 (14.46 ± 0.99 mm) (Table 2). Stem number per plant increased in T3 and T7, exhibiting more branches and potentially higher productivity. Leaf number reached 49.45–52.25 in the treated variants compared with the control (47.52 ± 2.53), with significant enhancement in leaf length and width, particularly in T3 and T5. These results agreed with the findings of Wadas (2021) and Mohammad *et al.* (2024), where biostimulants enhanced aboveground biomass, leaf area, and overall plant mass.

In Phase III during the intensive tuber formation stage, the most pronounced effects were visible. All treated variants exhibited increased plant height (68.10 to 72.60 cm) and stem diameter compared with the control (Table 3). The recorded highest leaf number was in T6 (59.60 ± 4.95), resulting in the largest leaf area. In treated variants, the leaf area ranged from 2828.52 to 3462.60 cm², whereas the control recorded 2553.35 ± 263.22 cm². The assimilative surface expansion showed an accompaniment of enhanced reproductive traits, and in T2–T7 the tuber number and average tuber mass exceeded the control. The maximum tuber mass per plant was evident in T2 and T4 (1324.10 and 1315.83 g, respectively), indicating effective conversion of morpho-physiological variations in yield. Previous reports on similar correlations between assimilative apparatus development and tuber productivity under biostimulant treatment came from Wadas and Dziugiel (2020) and Dziugiel and Wadas (2020). Moreover, the harvested tubers had uniform shapes, no major defects, and consistent sizes across the fractions.

In addition to tuber shape and weight, biochemical traits of tubers were critical quality indicators. Biostimulants can positively affect the tuber composition by optimizing mineral nutrition, as observed in Solanaceae crops (Mishra and Kumar, 2021; Aitbayev *et al.*, 2025). The results detailed that dry matter content ranged from 20.54% (control) to 30.40% (T4), reflecting enhanced metabolic activity and carbohydrate accumulation. According to Ride *et al.* (2024), the

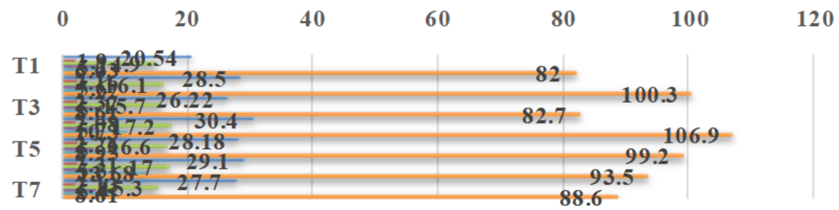
Table 3. Effect of biostimulants on biometric parameters of potato plants (phenological phase - intensive tuber formation).

Experimental variants	Stem height (cm)	Stem base diameter (mm)	Num-ber of stems	Number of leaves	Leaf width (cm)	Leaf length (cm)	Leaf area (cm²)	Num-ber of tubers	Tuber weight (g)
T1	63.52± 5.38	14.80± 0.36	4.82± 0.28	48.90± 5.51	14.93±0. 70	24.10± 0.51	2553.35± 263.22	8.82± 1.11	637.80± 29.32
T2	70.90± 5.55	17.40± 1.32	5.40± 0.22	57.00± 4.96	16.30±0. 94	25.52± 1.34	3097.93± 763.86	13.10±3. 22	1324.10± 269.34
T3	69.70± 3.46	15.22± 0.51	5.50± 0.39	56.60± 2.90	16.60±0. 55	26.10± 0.80	3273.75± 240.57	12.30±1. 43	1173.20± 246.77
T4	70.60± 4.88	15.70± 1.04	5.20± 0.56	55.20± 4.97	17.30±0. 98	26.40± 1.24 a	3462.60± 431.19	12.70±1. 25	1315.83± 271.27
T5	68.52± 3.90	16.30± 0.77	5.10± 0.22	56.10± 5.33	15.78±1. 12	25.42± 1.42	2828.52± 705.57	11.00±1. 54	909.20± 110.32
T6	72.60± 9.27	16.65± 1.57	5.30± 0.68	59.60± 4.95	15.68±1. 30	25.28± 1.51	2864.50± 321.04	12.40±2. 11	1234.95± 309.69
T7	68.10± 5.79	15.90± 1.06	5.50± 0.58	56.20± 2.99	16.05±0. 34	25.40± 1.31	3049.75± 882.76	11.40±2. 36	1022.20± 277.84

combination of humic and salicylic acids improved photosynthetic efficiency and carbohydrate translocation, exploring an increase in sugar and dry matter. Total sugar content ranged from 1.90% to 2.32%, and starch was from 14.9% to 17.2%, with maximum values in T4 and T6. Starch is a key technological quality parameter, and its increased content indicates improved consumer and processing properties of potato tubers. Cortiello *et al.* (2024) reported that starch content considerably depends on the potato cultivation area, while the biostimulant effects received influence from environmental conditions and varietal traits. Nevertheless, the results demonstrated an obvious association between biostimulant application and increased carbohydrate accumulation in tubers, leading to higher starch content.

Tuber pH remained within the optimal range (5.0–5.7), while vitamin C content enhanced from 6.03 mg % (control) to 13.68 mg % (T6), reflecting the stimulatory effect of biostimulants on ascorbic acid biosynthesis (Figure 2). These results were consistent with the findings of Mystkowska *et al.* (2021), who reported that treatment with the hormone-based biostimulant BrownBio Gold increased the vitamin C content in tubers (205.0 ± 1 mg/kg fresh weight). In all the experimental variants, the nitrate levels did not exceed the maximum permissible concentration (150 mg/kg), indicating the safety of applied biological products.

Comparative analysis revealed a significant increase in potato yield in biostimulant-treated variants compared with the control. Average tuber yield in the control treatment was 18.8 t/ha, with a range of 16.2 to 20.9 t/ha, reflecting the highest variability without stimulating effects (Table 4). In all treated variants (T2–T7), the tuber yield ranged from 24.0 to 27.4 t/ha, indicating consistently higher productivity under the biostimulant influence. The lowest variability resulted in the variants T2, T4, and T6, suggesting the highest reproducibility of positive effects, whereas the variants T3, T5, and T7 exhibited slightly wider ranges. The optimum average tuber yield appeared in treatment T2 (27.4 t/ha), which corresponds to an increase of 8.65 t/ha (+46.08%) versus the control. Following it was the treatment T4, where an additional 8.53 t/ha (+45.44%) of tuber yield occurred. Moreover, a higher productivity observed in treatments T2 and T4 could be because of the optimal composition of the applied formulations, the effectiveness of which has received confirmation in our other studies on tomatoes. Reports of similar trends using biological products came from Salvage *et al.* (2024), where tuber mass increased by 33% under production conditions with a stable gain in total yield of 5.2%. Likewise, Barbas *et*



	T7	T6	T5	T4	T3	T2	T1
Dry matter (%)	27.7	29.1	28.18	30.4	26.22	28.5	20.54
Total sugars (%)	2.13	2.21	2.26	2.08	2.32	2.16	1.9
Starch content (%)	15.3	17	16.6	17.2	15.7	16.1	14.9
pH level (%)	5.4	5.3	5	5.7	5	5.6	5.2
Vitamin C (mg%)	8.61	13.68	8.95	10.3	8.61	7.22	6.03
Nitrates (mg/kg) (MAC - 150 mg/kg)	88.6	93.5	99.2	106.9	82.7	100.3	82

Figure 2. Influence of biological fertilizers and biostimulants on biochemical quality parameters of potato tubers.

Table 4. Effect of biostimulants on potato productivity (tuber yield).

Experimental variants	Replicates (t/ha)				Mean yield (t/ha)	Additional tuber yield	
	I	II	III	IV		t/ha	%
T1	19.3	16.2	20.9	18.7	18.8±1.95	-	-
T2	27.7	29.3	25.6	27.1	*27.4±1.53	8.65	46.08
T3	24.9	26.2	24.6	25.5	*25.3±0.71	6.53	34.79
T4	28.1	25.8	27.4	27.9	*27.3±1.04	8.53	45.44
T5	24.0	25.2	23.8	23.1	*24.0±0.87	5.25	27.97
T6	26.9	25.7	26.2	29.0	*27.0±1.45	8.18	43.58
T7	26.2	23.9	24.6	24.8	*24.9±0.96	6.10	32.50
Experiment precision (m%):					2.69		
Least significant difference ($LSD_{0.05}$):					2.08		
Significance: * - $p < 0.05$; Nonsignificant - NS							

al. (2024) stated the application of the amino acid-based biostimulant Supporter resulted in a 13.3% increase in total tuber yield and a 21.1% increase in marketable yield.

According to the results of this study, some differences were evident in biometric parameters (T3 and T6) and productivity levels (T2 and T4). Similar results from a study by Liu *et al*. (2023) disclosed excessive shoot growth alters nitrogen distribution and reduces the proportion of assimilates directed to tubers, whereas balanced distribution promotes their formation and increases productivity. Other studies also indicated the distribution of assimilates in annual plants, including potatoes, succeeded their determination by competition among consumers and the balance between sources and consumers. Excessive development of leaf and stem biomass restricts the flow of photosynthetic products to tubers, while moderate shoot growth facilitates their effective accumulation. Thus, obtaining high tuber yield is successful with a balanced biomass distribution, and aboveground growth does not exceed the needs of underground organs. This could explain the higher productivity observed in treatments T2 and T4, despite relatively lower aboveground biomass (Tekalign and Hammes, 2005; Rozentsvet *et al*., 2022).

Table 5. Economic efficiency of the various biological products in potato production.

Experimental treatments	Additional yield (t/ha)	Total revenue (KZT/ha)	Total cost (KZT)	Total costs (USD/ha)	Net profit (KZT/ha)	Net profit (USD/ha)	Profitability (%)
T1	-	-	240.363	-	-	-	-
T2	8.65	1167.75	423.444	812.285	744.306	1427.79	176
T3	6.53	882.55	291.454	559.091	591.096	1133,89	203
T4	8.53	1151.55	322.247	618.160	829.303	1590.84	257
T5	5.25	708.75	284.507	545.764	424.243	813.82	149
T6	8.18	1104.3	383.355	735.383	720.945	1382.97	188
T7	6.10	823.5	401.785	770.737	421.715	808.97	105

Economic efficiency

The analysis of economic efficiency revealed that the highest net profit and substantial yield increase resulted in the variant T4 (BioSok Energy$^+$) (Table 5). Treatments T2 (Oboki), T3 (Celobacirin AS-24K + Phosphobacirin-S), and T6 (Fitolaza + Nano Sulfur) also showed the ultimate profitability and significant yield gains, proving them as suitable options when a higher budget is available. Treatment T5 demonstrated moderate profitability, providing an economically viable solution under limited costs, while T7 was less efficient due to the high cost of products. Overall, the variants T2, T3, T4, and T6 were distinctly the most economically efficient treatments.

CONCLUSIONS

The most pronounced effects of biological stimulation were evident in treatments T2 (Oboki), T3 (Celobacirin AS-24K + Phosphobacirin-S), T4 (BioSok Energy+), and T6 (Fitolaza + Nano-sulfur). These manifestations were in the acceleration of phenological stages by 3–9 days, promotion of leaf development, enhancement in vegetative growth, and improvement in reproductive performance of plants. The highest yield appeared in T2 (27.4 t/ha), accompanied by improved biochemical composition of tubers, including increased dry matter, starch, sugars, and vitamin C, while nitrate level remained low compared with the control (T1). Economic analysis showed the greatest profit for T4, whereas T2, T3, and T6 provided the maximum tuber yield and stable profitability. The results confirmed the potential of biostimulants to enhance potato productivity, tuber quality, and economic efficiency in the foothill zone of Southeastern Kazakhstan, highlighting the need for further studies under diverse agroclimatic conditions.

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