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BIOLOGICAL PRODUCTS SWAY THE YIELD AND QUALITY TRAITS OF CHICKPEA (*CICER ARIETINUM* L.) IN A CONTINENTAL CLIMATE

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SUMMARY

An increased intensity of agricultural mineral fertilizers' use to raise crop yields has disrupted the soil's natural balance. Researchers worldwide continually analyze biological factors in farming systems as a transitional stage to organic farming to increase soil fertility. The presented study pursued evaluating the effect of organic products on the yield and quality indicators of chickpeas in the continental climate of the Kostanay Region, Republic of Kazakhstan. In this study, the chickpea (*Cicer arietinum* L.) cultivar Yubileinyi, sown with four variants, used various biological preparations and a control (pure sowing). The plant samples' analysis ensued in the laboratory of the State Institution Republican Scientific and Methodological Center of Agrochemical Service, with the field experiments established in the Zarechnoye Agricultural Experimental Station Limited Liability Partnership. The object of the study was the cultivar. During the probe period, the experimental site climate had a continental characteristic, meteorological conditions were arid, and the hydrothermal coefficient was 1.0. Based on various experiment variants and the biological preparations, chickpea grain yield ranged from 8,740 to 13,699 kg ha^{-1} compared with the control treatment (7,980 kg ha^{-1}). The chickpea's quality indicators also showed improvements, and the grains harvested from one hectare contained 245.6 kg of protein and 62.4 kg of carbohydrates. The significant yield improvement in chickpeas was due to increased organic active substances in the different preparations used during the study.

Keywords: Chickpea (*Cicer arietinum* L.), biological nitrogen, nodule bacteria, biological preparations, grain yield, biochemical traits, quality traits

Key findings: The biological preparations, viz., Baikal EM-1 and Rizovit AKS, compared with the mineral fertilizer (double superphosphate), significantly enhanced the growth and yield traits of the chickpea crop.

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INTRODUCTION

The provision of the bulging population with nutritious food depends on the production of vegetable and animal proteins, and both protein sources depend upon the best crop and livestock manufacturers, which need soil management with high-quality feed (Cary *et al*., 2021; Kuldybayev *et al*., 2021). Therefore, it is obligatory to incorporate the set of leguminous crops in crop rotations (Lohani *et al*., 2020; Kuldybayev *et al*., 2023). Chickpea (*Cicer arietinum* L.) is one of those leguminous plants that mostly adapted to arid areas with a continental climate. Chickpeas can easily tolerate drought, suspend their growth even if there is an acute lack of moisture, and resume it when favorable conditions occur to ensure good grain yield (Hussain *et al*., 2022). Chickpeas tolerate soil and air drought well, with their beans not cracking when ripe, making them the most suitable crop for mechanized harvesting (Polienko *et al*., 2020; Goyal *et al*., 2021; Ansabayeva, 2023).

The chickpea has a wide cultivated area, and its intensive use is because of its high nutritional value. Chickpeas are mainly grown in arid zones to produce mature seeds containing protein (31%), fats (4% to 7%), carbohydrates (55% to 60%), and vitamins A, B_1, B_2, B_6, C, and PP, as well as essential macro- and microelements. Like other legumes, chickpeas also contain sufficient oil in the seeds (some cultivars contain up to 8%), making them rich in unsaturated fatty acids (Daubech *et al*., 2017). Given the balanced amino acid composition and high content of methionine and tryptophan, chickpeas exceed all other leguminous crops in nutritional values.

Nodule bacteria adapted to chickpeas form large nodules on the main root of the plants, while small nodules dispersed throughout the root system. However, in most cases, they do not fix nitrogen (Choudri *et al*., 2018; Rathjen *et al.,* 2020). As a rule, the nodules formed on the plant roots have the most aerated layer of soil (0–10 cm). Often, symbiosis activities take place in the nodules with a red color, indicating the presence of leghemoglobin in them (Zhu *et al.,* 2019; Deng *et al*., 2022; Herridge *et al*., 2022). The most active fixation of atmospheric nitrogen occurs at 20 °C. The 10 °C is the acceptable lower threshold of nitrogen fixation, although nodules' formation occurs at lower temperatures. The low temperature primarily affects the legume plant development (Liu *et al.,* 2022), leading to a decrease in carbohydrates' provision by the nodules. The nodule bacteria react to temperature fluctuations to a lesser extent (Arpaia *et al.,* 2020).

Inoculation of seed material with highly active nodule bacteria strains improved the symbiotic activity in chickpeas (Kou *et al.,* 2022). Despite the numerous biological properties of the culture, the effect of organic preparations on the quality indicators of chickpeas in Northern Kazakhstan has few studies. For active symbiosis, the main conditions are specific virulent strains of *Mesorhizobium cicero* contained in the soil (Li *et al.,* 2021; Zhong *et al.,* 2022). The practical study pursued to evaluate the effect of biological products on the yield and quality indicators of chickpeas in the continental climate of the Kostanay Region, Republic of Kazakhstan.

MATERIALS AND METHODS

Research area

The study began from 2020 to 2022 in the Kostanay Region, Kazakhstan Republic. The plant samples' analysis occurred in the laboratory of the State Institution (GU) Republican Scientific and Methodological Center of Agrochemical Service, with the field experiments established in the Zarechnoye Agricultural Experimental Station (SKhOS) Limited Liability Partnership (LLP).

The Kostanay Region is part of North Kazakhstan. Its area exceeds 19.6 million ha, with a 10-million ha area used for agriculture. The variations in geomorphological, climatic, and soil and plant conditions in the region determine the diversity of landscapes belonging to well-defined natural zones in the latitudinal direction, such as forest-steppe, steppe, and semidesert (desertified steppes

Figure 1. The experimental plot area and location.

and steppificated deserts). The experimental site comprised an arid steppe, mainly with southern low-humus chernozems (Figure 1). The trial site's total area was 1000 m^2, and each experimental variant's area was 12 m^2.

Climatic conditions

The experimental area has a continental climate. The summers are dry, and the winters are snowy and cold. The annual amplitude of the air temperature is 35 °C–40 °C and, in rare cases, it reaches 45 °C–50 °C. In summer, the absolute temperature is +41 °C–43 °C. The warm period with an average daily temperature above 0 °C lasts 195–200 days, mainly from the first 10-day period of April to the third 10-day period of October.

Meteorological conditions

According to long-term data (Department of Statistics, https://stat.gov.kz/region/258742 ?lang=ru), the annual norm in the research area is 340 mm. Precipitation, where most fall in the second half of the warm period of summer (April to October), amounts to 71.2% of the total rainfall.

The analysis of the relationship between the harvest of leguminous crops and the amount and time of precipitation showed that in the northern region of Kazakhstan, its height has rainfall determining it in June and grain quality by precipitation in August and September. In the first case, the more rainfall in June, the higher the yield; in the second, the less rain and the higher the temperature observed at the end of ripening and harvesting, the better the technological quality of grain was.

During the study years (2020 to 2022), the amount of precipitation for the period (October to September) was 210.2 to 442.2 mm (60.8% to 128.1%) of the annual norm. The average daily air temperature (2020–2022) was 42% higher than the mean yearly standard. The hydrothermal coefficient (HTC) for the study's growing season averaged 1.0. The conditions have arid characteristics, according to the Selyaninov method, which is the ratio of the amount of precipitation for at least a month to the sum of temperatures above 10 °C for the same period, reduced by 10 times. According to the HTC, the classification of humidification zones was humid (1.6–1.3), slightly arid (1.3–1.0), tepid (1.0–0.7), very warm (0.7–0.4), and dry (<0.4).

Soil conditions

The experiments transpired on southern medium loamy chernozem with a pH of 7.3. Layer A_{max} (0–25 cm) was dark gray, loose, lumpy, permeated with roots, and slightly loamy, with a clear transition in density and structure; B (25–42 cm) was grayish and yellow loam, with narrow humus patches, dense, with rare plant roots, and the transition was clear; BC (42–51 cm) was yellow, sandy loam with occasional carbonate spots, and the shift was sharp, and C_1 (51–100 cm) was yellowish and brown clay with abundant carbonates of a prismatic structure. The chemical properties of southern chernozem (layer 0–40 cm) were humus content (3.45) and hydrolyzable nitrogen (34.28 mg kg^{-1}).

The determination of mobile phosphorus and potassium compounds followed the method by Chirikov. This method determines the mobile forms of phosphorus. The technique relied on the extraction of mobile phosphorus and potassium compounds from the soil with a solution of acetic acid concentration of mol/dm with a ratio of soil to the solution equaling 1:25 and subsequent determination of phosphorus in the form of a blue phosphorus-molybdenum complex on a photoelectric colorimeter and determination of potassium on a flame photometer. The mobile phosphorus and potassium contents were 89 mg/kg and 198 mg/kg, respectively. The various contents were humus (3.0% to 3.2%), gross nitrogen content in the upper soil layer of 0–20 cm (0.15% to 0.15%), and phosphorus (0.10% to 0.13%).

Biological preparations used in the experiment

The biological preparation Baikal EM-1 is a microbiological fertilizer. It contains anabiotic (useful) effective microorganisms (EMs), photosynthetic bacteria, lactic acid, yeast, and cellular bacteria living in the soil. By interacting with the soil, they produce enzymes and physiologically active substances like amino acids and nucleic acids, which have direct and indirect positive effects on the growth and development of crop plants. Its application during the chickpea branching and budding (July) used a knapsack sprayer, in an amount of 0.9 l/ha. The preparation's manufacturer is Biotechsoyuz, Russian Federation.

Double superphosphate is a phosphoric, concentrated, water-soluble mineral fertilizer. It contains 46% P_2O_5, enhances productivity, and improves the quality of agricultural products. This preparation's manufacturer is BioMaster, Russian Federation. Rizovit AKS contains nodule bacteria in powder form as an active substance. It is a preparation of highly effective nodule bacteria used to treat the seeds before sowing for five hours. The Promyshlennaya Mikrobiologiya LLP, Republic of Kazakhstan, produced the product.

Crop husbandry and experimental design

Deep tillering commenced with a FINIST PLN 5-35 plow (PLN stands for a mounted plow) to a depth of 25 cm, followed by disking with heavy BDT Zvezda-10 harrows (BDt stands for a heavy disk harrow) to a depth of 6 cm. Sowing continued with a seeding rate of 0.8 million and the germinating grains to a depth of 6 cm. The introduction of mineral fertilizer (double superphosphate) proceeded into the rows by the SZS 2.1 seeder (SZS stands for stubble grain seeder) made by Omsilmash before sowing in an amount of 2.3 kg (calculated by the active substance).

The experiments emerged with different variants in three-fold repetitions to determine the impact of various biological products and obtain some tangible results (Table 1). In the research, a control (pure sowing) and four variants with organic preparations incur application: double superphosphate, double superphosphate + Rizovit AKS, Baikal EM-1, and Baikal EM-1 + Rizovit AKS. The chickpea's sowing continued from May 11 to 20, and during planting, the following scheme comprised a 35–45 cm distance between rows and 50 cm space between the bands (with band sowing).

The object of the study was the chickpea cultivar Yubileinyi, with an economic suitability of 95%. A total of 132 samples examined had the cultivar Yubileinyi zoned in

Table 1. Experimental variants and treatments.

No.	Experiment variants
1	Control (clean sowing)
2	Double superphosphate
3	Double superphosphate + Rizovit AKS
4	Baikal EM-1
5	Baikal EM-1 + Rizovit AKS

Table 2. Elements of the chickpea crop structure based on various preparations used (Averaged for 2020–2022).

Experiment variants	Number of plants harvested (pcs/m^2)	Number of beans in a plant (pcs)	Number of grains in a bean (pcs plant^{-1})	1000-seed weight (g)
Control (clean sowing)	30.0	24.0	48.0	241.0*
Double superphosphate	33.0	27.0	54.0	260.1**
Double superphosphate + Rizovit AKS	36.6	32.0	64.0	280.0*
Baikal EM-1	39.2	36.0	68.0	285.1*
Baikal EM-1 + Rizovit AKS	40.1	37.2	71.2	285.9**
Least significant difference (LSD)$_{0.5}$	0.23	0.27	0.32	0.45

**, *: Significant at the 1% and 5% levels of probability.

the Kostanay Region. The plants were low in height (up to 45 cm) and erect, with white blooms. The flowers appeared on shortened peduncles. Like the previous cultivar, seeds were yellow and pink, had a wrinkled surface structure, and occurred in thick, short beans with two kernels in each. From planting to ripening, the vegetation time took 90–100 days. The 1000-seed weight was 250–300 g, while grain yield from 10 m^2 was equal to 1.5 to 3 kg. The specimen in question showed resistance to diseases and pests and tolerates drought well, with the seeds not prone to cracking.

Statistical analysis

The recorded data for various variables' analysis used the Statistica software. A factorial analysis of variance (ANOVA) to analyze the differences between treatments ensued. H_0 states that there is no effect, no changes, and the preparation does not work, and H_1 is an alternative hypothesis for accepting if rejecting H_0 proceeds. When ANOVA gave a significant difference, the Duncan Multiple Range Test (DMRT) helped compare the various means in each variable. All experiments materialized in triplicate, with no experimental error reported.

RESULTS

Overall, comparing all the variants, the biological preparation Baikal EM-1 showed positive effects at all stages of phenophases, with the highest grain yield (Table 2). At the experimental site for 2020–2022, the crop traits probed with various preparations were the number of plants to harvest (ranging from 30.0 to 40.1 plants per m^2), the number of beans in a plant (24.0 to 37.2 pcs), the number of grains in a bean (48.0 to 71.2 pcs per plant), and the 1000-seed weight (241.0 to 285.9 g) (Table 3).

The various variants (treatments) revealed significant differences in biological yield. The actual grain yield ranged from 7,980 to 13,699 kg/ha. However, the combination of Baikal EM-1 + Rizovit AKS showed a maximum increase in the actual harvest compared with the control variant (5,719 kg/ha). The studied treatment preparations also affected the biochemical composition of chickpea grains.

Table 3. Chickpea grain yield based on various preparations used.

Experiment variants	Biological yield (kg ha^{-1})	Actual yield (kg ha^{-1})
Control (clean sowing)	8,400**	7,980
Double superphosphate	9,200**	8,740$_{+760}$
Double superphosphate + Rizovit AKS	12,250**	11,638+$_{3,658}$
Baikal EM-1	12,920**	12,274$_{+4,294}$
Baikal EM-1 + Rizovit AKS	14,420**	13,699$_{+5,719}$
$LSD_{0.5}$	0.25	0.17

Table 4. Grain yield and biochemical composition of seeds based on various preparations used.

Experiment variants	Grain yield (kg ha^{-1})	Content in seeds (%) per dry substance		Collection (kg ha^{-1})	
		Protein	Carbohydrates	Protein	Carbohydrates
Control (clean sowing)	7,980	18.8	4.0	150.0*	32.0*
Double superphosphate	8,740	19.3	4.6	168.6*	40.2*
Double superphosphate + Rizovit AKS	11,638	19.9	5.0	231.5*	58.2*
Baikal EM-1	12,274	20.2	5.2	234.2*	58.4*
Baikal EM-1 + Rizovit AKS	13,699	20.8	5.4	245.6*	62.4*
$LSD_{0.5}$	0.45	0.16	0.23	0.29	0.48

The highest content of protein and carbohydrates in chickpea seeds was evident using Baikal EM-1 (Table 4). Yet, chickpea seeds' protein and carbohydrate contents gave nonsignificant differences between the variants because the protein content positively correlated with seed yield. However, using Baikal EM-1, the total collection of protein and carbohydrates from 1 ha significantly ($P < 0.01$) excelled all other variants.

The studied preparations influence the qualitative composition of chickpea grains (Figure 2). Correlation dependence gained representation only by treatments without Rizovit AKS because only complex applications had an effect. The highest content of protein and carbohydrates (20.8 g and 5.4 g, respectively) in chickpea seeds manifested using the combined preparation of Baikal EM-1 + Rizovit AKS. Still, the difference among the variants based on protein and carbohydrates in chickpea seeds was insignificant because the protein content positively links with the seed yield. Using Baikal EM-1 + Rizovit AKS, the total collection of protein and carbohydrates from one ha were 245.6 and 62.4 kg per ha, respectively.

As a result of the study, the effects of various preparations appeared on the grain yield and quality of chickpea grains. On studying the impacts of the biological treatment (Baikal EM-1) and the complex application of Baikal EM-1 + Rhizotorphin on the formation of the chickpea crop structure, the complex application (Baikal EM-1 + Rizovit AKS) significantly increased the chickpea yield (13,699 kg/ha) compared with the control treatment (7,980 kg/ha).

Concerning influences of the mineral fertilizer (double superphosphate) on the formation of chickpea grain yield and its biochemical and quality indicators, the harvested number of plants was 33 pcs/m^2, the number of beans per plant was 27 pcs, the number of grains in one bean was 54 pcs per plant, and the 1000-seed weight was 260.1 g. The biological yield was 9,200 kg/ha, incurring 5% losses during harvesting and humidity, and using mineral fertilizer (double superphosphate), the chickpea grain yield was 8,740 kg/ha. Comparing the mineral fertilizer with the control, the increase in chickpea grain yield was +760 kg.

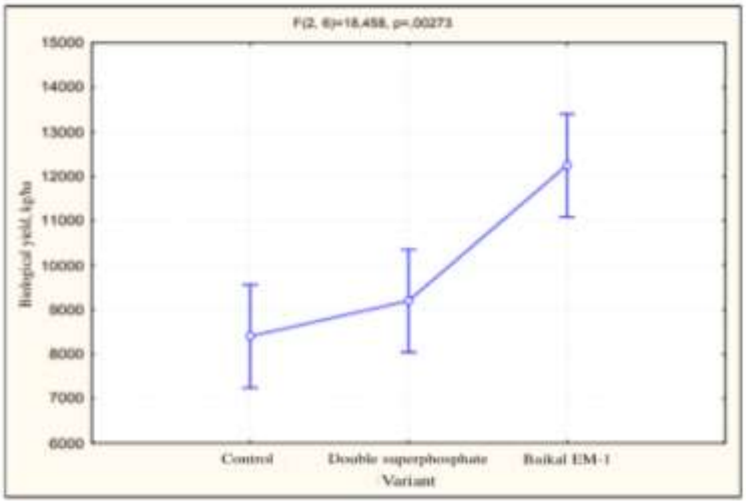

Figure 2. Correlation dependence of chickpea yield on experimental variants.

DISCUSSION

In the applicable study, the growth and development according to the various elements of the chickpea crop structure sustained influences from the biological preparation Baikal EM-1, contrary to the mineral fertilizer (double superphosphate). The qualitative indicators of chickpea seeds were also the most important in the entire chain of organization of chickpea sowing. Chickpea cultivation using microbiological preparations allows for an increase in the grain yield and the seed protein content by 3%–4% (Wang *et al.,* 2021; Qulmamatova, 2023). In the study, the biological preparation used also positively impacted the various biochemical parameters of chickpea seeds, especially the ratio of proteins and carbohydrates, making it possible to produce high-quality products with minimal environmental stress.

On the correlation dependence analysis, the use of Rhizotorphin AKS did not show a correlation dependence. However, the number of nodules on chickpea plant roots incurs influences from meteorological and soil conditions (Storck *et a*l., 2018). In a study conducted in an experiment of the Belgorod Agricultural Research Institute (NISKh) in 2013–2015, the chickpea cultivar Yubileinyi's yield significantly increased by 22%–34% using microbiological preparations. The authors also noted the association of meteorological conditions and treatments on the chickpea grain yield (Popova *et al.,* 2020; Van-Mansvelt *et al*., 2020; Wang *et al*., 2022).

The microbiological preparation, Rizovit AKS, did not affect the elements of the crop structure, which confirms H_0. During the crop growing season, the nodule formation was visible in a vast amount. In 2017, an experiment to study the effect of symbiotic nitrogen fixation by legumes and the pea and chickpea seeds sustained bacterial infection five hours before sowing in the steppe zone conditions of the Akmola region (Popov *et al.,* 2017). The legumes' seed inoculation positively influenced the various elements of the crop structure; however, it did not affect phenological conditions (Vasilchenko *et al*., 2018; Yan *et al.,* 2018).

CONCLUSIONS

The study results achieved the goal of the experiment. Hypothesis H1 attained proof with identified differences in the use of biological products. Comparing the Baikal EM-1 and Rizovit AKS organic preparations with the double superphosphate mineral fertilizer affected the growth and development and, accordingly, the elements of the structure of the chickpea crop. The limitations of the study included the following: 1) Only one variety of chickpeas in the study; 2) The analysis of the relationship between the harvest of leguminous crops and the amount and time of precipitation has shown that in the northern region of Kazakhstan, precipitation determines crop height in June, and grain quality by precipitation in August and September. In the first case, the more rainfall there was in June, the higher the yield, and in the second case, the less rain and the higher the temperature observed at the end of ripening and harvesting, the better the technological quality of the grain. In future studies, it is necessary to study the effects of biological preparations on other chickpea varieties.

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