OCL 2024, 31, 3
© G. Kabylbekova *et al.*, Published by EDP Sciences, 2024
https://doi.org/10.1051/ocl/2024001

Available online at:
www.ocl-journal.org

Research article

Open Access

Effect of pre-sowing treatment of soybean seeds with inoculant and microelements for yield and quality in the conditions of south-east of Kazakhstan☆

Gaukhar Kabylbekova[1], Svetlana Didorenko[2,*], Rinat Kassenov[2], Almagul Dalibaeva[2] and Zerekbai Alikulov[3]

[1] Department of Biology, L. N. Gumilyov Eurasian National University, Astana, Kazakhstan
[2] Laboratory of Oilseeds, LLP Kazakh Research Institute of Agriculture and Plant Growing, Almaty, Kazakhstan
[3] Department of Biotechnology and Microbiology, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan

Received 28 June 2023 – Accepted 5 January 2024

Abstract – Soybean is a high-protein and at the same time an oilseed crop. Its cultivation brings profit from the sale of seeds and enriches the soil through the activity of nitrogen-fixing plants. The effectiveness of pre-sowing treatment of soybean seeds with a nitrogen-fixing preparation (HiStick© inoculant) in combination with molybdenum and cobalt salts was evaluated at field level from 2019 to 2021 in the conditions of south-east Kazakhstan. The profitability of the crop could be increased by the use of pre-sowing treatment with these micronutrients which are involved in the processes of photosynthesis and nitrogen fixation. The most indicative characteristics for assessing the impact of pre-sowing seed treatment are the accumulation of protein and oil per hectare, since grain yield increased with pre-sowing treatment without changing quality characteristics (expressed as concentrations). Our research showed an increase in protein yield per hectare with pre-sowing treatment. When seeds of the early ripening Ivushka variety were treated with molybdenum and cobalt without HiStick©, protein yield per hectare increased by 8%. When using the HiStick© preparation together with microelements, the protein yield increased by 4.8%, 8.7% and 12.8% for Zhansaya, Lastochka (late-maturing) and Birlik CV varieties respectively. The increase in oil yield after pre-sowing seed treatment for the early-ripening Ivushka variety was 8.8% (complete treatment) and 6.8% for the late-ripening Lastochka variety (with micronutrients only). Therefore the increase of grain protein and oil yields improves the profitability of this crop for a range of soybean varieties.

Keywords: soybean / seeds / micronutrients / inoculant / yield / protein / oil

Résumé – Effect of pre-sowing treatment of soybean seeds with inoculant and microelements for yield and quality in the conditions of south-east of Kazakhstan. Le soja est une culture à la fois riche en protéines et en huile. Sa culture est rentable et enrichit les sols en azote. L'efficacité d'un traitement des semences avant semis du soja avec une préparation fixatrice d'azote (inoculant HiStick©) en combinaison avec des sels de molybdène et de cobalt, a été évaluée sur le terrain de 2019 à 2021 dans les conditions du Sud-Est du Kazakhstan. Du fait de l'implication de ces micronutriments dans les processus de photosynthèse et de fixation de l'azote, la rentabilité de la culture pourrait en être augmentée. Les variables les plus pertinentes pour évaluer l'impact du traitement de semences sont l'accumulation de protéines et d'huile par hectare, puisque le rendement en graines a augmenté avec le traitement de semences sans changer les caractéristiques de qualité (exprimées en concentrations). Nos recherches ont montré une augmentation du rendement protéique du soja par un traitement avant semis. Lorsque les graines de la variété Ivushka à maturation précoce ont été traitées avec du molybdène et du cobalt sans HiStick©, le rendement en protéines par hectare a augmenté de 8 %. Lors de l'utilisation combinée de la préparation HiStick© et des deux microéléments, le rendement en protéines a augmenté respectivement de 4,8 %, 8,7

☆ Contribution to the Topical Issue: "Soybean / Soja".
*Corresponding author: svetlanadidorenko2@rambler.ru

% et 12,8 % pour les variétés Zhansaya, Lastochka (maturation tardive) et Birlik CV. L'augmentation du rendement en huile après traitement des semences pour la variété Ivushka à maturation précoce était de 8,8 % (traitement complet) et de 6,8 % pour la variété Lastochka à maturation tardive (avec micronutriments uniquement). Par conséquent, l'augmentation des rendements en protéines et en huile améliore la rentabilité du soja pour une palette de variétés cultivées.

Mots-clés : soja / traitement de semences / micronutriments / inoculant / rendement / protéine / huile

Highlights

- The world's population will grow over the coming years, and the need for sustainably produced food will also increase.
- Soybean is one of the key protein and oil crops due to its prime grain quality and vegetative weight.
- Soybean is a highly profitable crop, with a unique combination of quality composition in seeds.

Introduction

Soybean is one of the key oil-protein crops due to its prime grain quality and vegetative weight. It is applied for feeding, food, technical purposes and in the medicine. It is also a valuable plant for agronomy because as a nitrogen fixer it enriches soil with nitrogen and improves its structure (Shabalkin and Dubinkina, 2022). It is now one of the most essential food crops and the most important oil-protein in the world (Shekhovtsova and Perepelitsa, 2021). It has an average seed content of 37–42% of protein, 19–22% oil and up to 30% of carbohydrates. Its vegetative weight harvested in the bean-filling phase is abundant in proteins (16–18%), carbohydrates and vitamins. It is a staple food component of the traditional Asian cuisine and was used for thousands of years (Brodin, 2021; Khairullina, 2018). Soybean grains and derived products are a common dietary solution for vegetarians due to high protein content. They are versatile to produce the meat analogues and milk substitutes (Rizzo and Baroni, 2018).

The world's population will grow over the coming years and so will the need for sustainably produced food and dietary protein. Soybean production plays a strategic role in the economics of many countries around the world. It takes a special place in the agricultural sector of countries of the American continent (USA, Brazil and Argentina). These countries are the key producers and exporters of soybean grain and its conversion products (Levkina and Vassiliev, 2017). Statistics demonstrates that the leading soybean producing country in the world was the USA in 2018–2019 with about 120 million tons of soybeans produced. In 2020, Brazil overtook the USA as a leading soybean producing country, and about 138 million tons of soybeans were produced in 2020–2021 (Statista, 2022).

Among oil crops, the soybean is the most popular and accounts for 60% of the global production. However, the harvested area increased to 128 million ha (+5.3 million tons or 4%) in 2020–2021. Based on the USDA report, the top five soybean cultivated areas were Brazil (38.6 million ha), USA (33.3 million ha), Argentina (16.7 million ha), India (12.7 million ha) and China (9.9 million ha) (Latifundist.com, 2021). Soybean area was occupying 113 300 ha in Kazakhstan in 2021, with an average yield of 2.09 t/ha. Up to 93% of the cultivated area was concentrated in the irrigated lands of south-eastern Kazakhstan (GOV.KZ, 2022).

Soybeans, which contain more proteins than other legumes, may be in a great position to help meet this need. However, other plant sources are also used for this purpose, but the high quality of soy protein and the affordability of soybeans make it an ideal choice (Messina, 2022). Soybean reduces human risk to various health problems. It increases production of milk, meat and wool in animals. Its antioxidant action plays a significant role for the human health (Ali *et al.*, 2020; Rizzo, 2020).

A genetic potential of the soybean crop yield can be achieved by optimizing the nutritional conditions. Besides the basic nutrients (nitrogen, phosphorus and potassium), soybean strongly absorbs micronutrients that play a key role in the physiological and biochemical processes of plants (boron, cobalt, molybdenum and copper). Cobalt magnifies the photosynthetic activity of plants, nitrogen fixation, and protecting functions against plant disease damage. Molybdenum enhances nitrogen fixation, nitrogen metabolism, plant uptake of other nutrients (P, K, Mn) and promotes plant resistance to climatic stresses (Chernysheva *et al.*, 2018). Doses of molybdenum and cobalt have a beneficial influence on the physiological quality of soybean seeds through foliar nutrition (Dalmolin *et al.*, 2021).

The modern agriculture includes the extensive use of the mineral fertilizers. Yields cannot be increased without supplying mineral fertilizers. Therefore, the cost of the agricultural products will not be reduced. The organic fertilizers are also used. Thus, they acidify the soil less and positively affect the humus accumulation (Lukin *et al.*, 2021; Sychev, 2021). They enrich the soil with elements for plant nutrition and improve its physical and chemical properties. The organic fertilizers improve the phytosanitary state of the soil and enhance its biological activity. They improve the moisture regime and nutrient supply. They also improve the buffering capacity of the soil solution (Tkachenko *et al.*, 2021).

In addition, the use of the mineral fertilizers is one of the main methods for the intensive farming. The yield can be controlled and increased by several times with a high level of agricultural engineering and the using of fertilizers (Karayev and Aksenov, 2017). In the growing season of plants, the normal growth of crops is impossible without micronutrients which are involved in the complex processes of synthesis and breakdown of proteins, fats, carbohydrates, enzymes, vitamins, etc. Thus, based on these processes, the optimal content of micronutrients in the soil positively influences seed yield

Table 1. Soybean varieties created in LLP "Kazakh Research Institute of Agriculture and Plant Growing" and used in this study (Didorenko, 2019)

Variety	Plant height cm	Attachment height of lower beans cm	Growth type	Weight of 1000 seeds g	Maturity group (MG)	Protein %	Oil %	Yield t/ha
Lastochka	90–100	13–15	Determinate	160–165	III	39	19	3.5–4.0
Zhansaya	85–95	7–10	Determinate	160–165	II	40	19	3.9–4.5
Birlik KV	65–80	8–10	Determinate	170–175	0	41	22	2.0–2.5
Ivushka	60–70	8–10	Determinate	175–185	00	43	22	1.7–2.2

and quality. The application of microfertilizers became widespread in the world agricultural practices over the last quarter century.

Foliar spraying with nutrient solution can overcome the negative soil factors such as the leaching of nutrition elements, formation of the insoluble residue, ion antagonism, heterogeneity in soil which prohibits using the low doses of fertilizers and avoid forms of phosphorus and potassium unavailable for plants (Khasanov *et al.*, 2020a, 2020b, 2020c). Thus, the benefit of using foliar fertilizers in a single application is due to the fact that nutrients can be applied into plants to quickly eliminate their nutritional deficiencies and to significantly reduce fertilizer consumption. As a result, it is consistent with the economic and environmental requirements (Ossipov, 2020).

Our research aim is to determine the most optimal scheme of the pre-sowing seed treatment for a significant increase in the soybean yield. In this study, pre-sowing seed treatment consisted of spraying the seeds with a solution of molybdenum and cobalt salts with or without a nitrogen-fixing preparation. The following objectives were defined to achieve this aim:

1. To conduct experiments with various pre-treatment methods on commercial soybean varieties;
2. To identify correlations between pre-sowing treatments and crop yields;
3. To determine the most appropriate system of pre-sowing seed treatment to reliably increase crop yields without reducing the grain quality (protein and oil content).

2 Materials and methods

2.1 Materials

The research was conducted in 2019–2021 in the experimental fields of LLP "Kazakh Research Institute of Agriculture and Plant Growing" located 25 km from Almaty city. The region is characterized by an extreme continental climate. The frost-free period lasts about 180 days. Soils are light-chestnut. Fall wheat was used as a preceding crop. Four commercial soybean varieties were chosen as the research object (Table 1).

2.2 Methods

Four types of pre-sowing treatments were applied to each variety. The day before sowing, the soybean seeds were treated with ammonium molybdate 4% w/v aqueous solution (at the rate of 40 g per 100 kg of seeds) and cobalt (II) sulfate heptahydrate (at the rate of 4 g per 100 kg of seeds). On the sowing day, seeds were inoculated with HiStick© containing nitrogen-fixing bacteria (on the basis of 400 g per 100 kg of seeds).

The scheme of the experiment is presented below:

No. 1–control, no treatment;

No. 2–seed treatment with HiStick©;

No. 3–seed treatment with Mo (molybdenum) and Co (cobalt);

No. 4–complete seed treatment with HiStick© + Mo + Co.

Sowing was done in the third decade of April. Registration plot was 25 m^2. The seeding amount was 50 seeds/m^2. The spacing was 30 cm. The depth of seed sowing was 4 cm. The randomized seeding was replicated four times. The agrotechnological actions were made with the standard methods and recommendations for the research area (Kudaibergenov and Didorenko, 2014). Ploughing to a depth of 25 cm was made in autumn and cultivation to a depth of 8 cm was conducted in spring. Before sowing, 150 kg/ha of ammophos fertilizer were applied.. After sowing, the fields were treated with soil herbicide Lazurit (Metribuzin) – 700 g/ha with a working solution consumption of 200 l/ha. The contact herbicides of Bazagran (bentazone – 480 g/l) – 2.5 l/ha and Zellek super (haloxyfop-*p*-methyl – 108 g/l) – 1 l/ha were used for applications during vegetation. Establishment of experiments, harvesting and crop accounting was performed according to Dospekhov (2012). During the three growing seasons, furrow irrigation was applied three times in the development phases (flowering, full pod, full seed) on June 15–20, July 10–15 and August 10–15 with an irrigation rate of 1200 (m^3/ha) each time.

The monitored crop phenological stages were seedlings (VE), emergence of the trifoliolate leaf (V1), beginning of the bloom (R1), full pod (R4), full seed (R6) and full maturity (R8) (Fehr and Caviness, 1977). The structural analysis was performed under the All-Russian Scientific Research Institute of Plant Growing procedure as described in Vishnyakova *et al.* (2010).

Crude protein content was determined according to GOST 13496.4.84. Nitrogen content was determined by the Kjeldahl method with conversion of total nitrogen content in crude protein using a coefficient of 6.25. Seed oil concentration was determined by the Rushkovsky method, using Soxhlet apparatus according to GOST 13496.15.85. The statistical processing was performed in the open-source R (https://cran.r-project.org/) software and in the Windows Excel program.

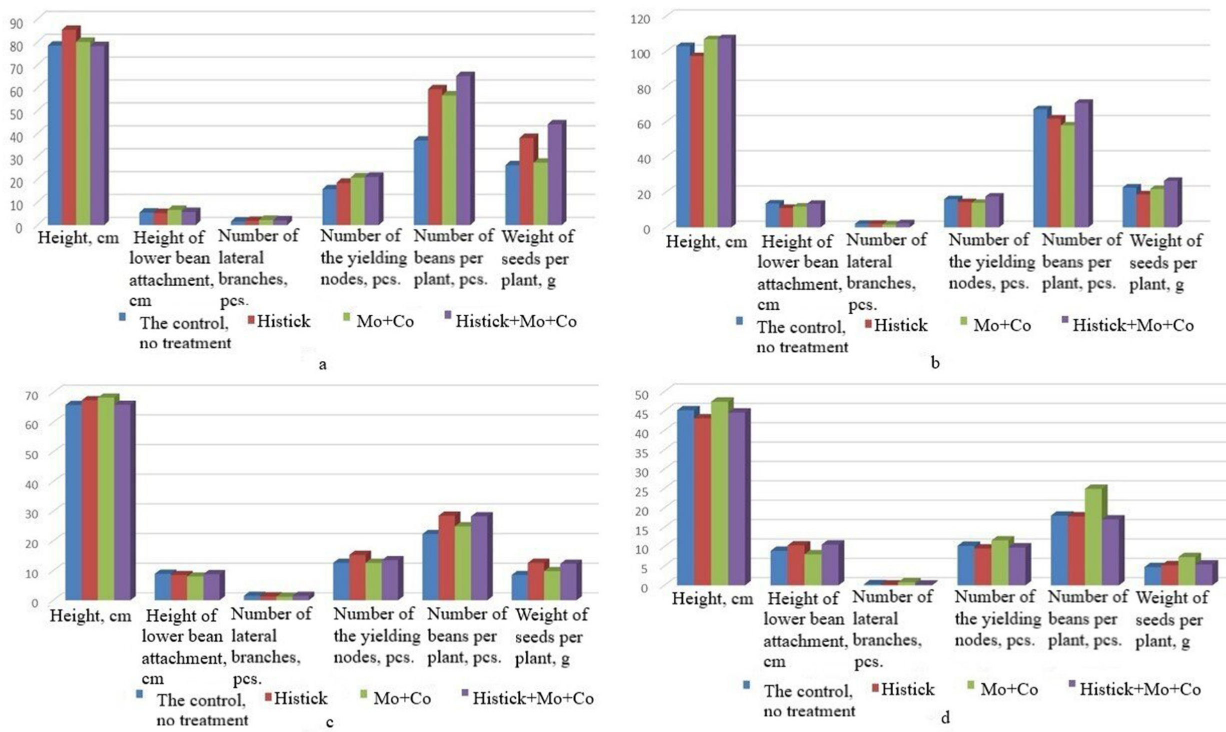

Fig. 1. Main components of crop yield for 4 soybean varieties: (a) Zhansaya, (b) Lastochka, (c) Birlik KV, (d) Ivushka as a function of pre-sowing seed treatment.

3 Results

Weather conditions were not uniform during the research years. The most favorable year was 2019. A wet and warm April in 2019 allowed the plants to undergo the first stage of growth under the favorable conditions. Rainfall in June, August and September (183 mm, 73 mm and 68 mm) had a significant positive effect on yield components and crop yield. Precipitation during the vegetation was 443 mm, 359 mm and 210 mm in 2019, 2020 and 2021 respectively. Insufficient precipitation in all months of soybean vegetation was accompanied by high temperature. Temperatures were 3.0 °C, 2.8 °C and 4.5 °C above the mean annual data, in May, July and September, respectively. Thus the average temperature was 20.3 °C during 2019 and 2020 seasons, and 21.1 °C in 2021.

The monitoring of the crop phenological stages showed low variations by study years within one variety. However, the types of treatments had no significant effect on the individual stages of development. All varieties in the control and after treatments ripened according to their maturity group. The growing season of varieties of Ivushka was 97–101 days, Birlik KV – 108–117 days, Zhansaya – 130–139 days and Lastochka – 140–150 days.

The length of the growing season was measured by the number of days from sprouting to maturity. Changes of its duration were affected by the number of days from sowing to sprouting. A cool spring was observed in 2019 and the germination process was slowed down. Thus, full sprouts were noted on the 15th day after sowing. As a result, the growing season in that year for all varieties was the shortest.

The basic components of soybean crop yield are height, amount of lateral branches and the yielding nodes, number of beans per plant, seed weight per plant, and weight of 1000 seeds. Yield was positively correlated to each of these components.

It was found that pre-sowing seed treatment with micro-elements had an effect on the components of crop yield.

Overall, the architectonics of the plant was maintained under different treatments. The plant height, height of lower pod attachment and branching were independent of treatment. They were ranging within the varietal characteristics, conditions of the year and the applied agronomic techniques.

The pre-sowing seed treatments had a great effect on the flowering phase, enhancing the amount of seeds and pods per plant. As a result, they influenced the increase of crop yield.

For the middle-late soybean varieties of Zhansaya and Lastochka, the greatest increase in the amount of beans per plant and weight of seed per plant was observed after the combined seed treatment with HiStick© + Mo + Co (Fig. 1a and 1b). For a middle-early Birlik KV variety, the greatest effect on yield components was observed during the treatment with HiStick© and combined with micronutrients of HiStick© + Mo + Co (Fig. 1c). For the early-ripening soybean variety of Ivushka, the best result was obtained after seed treatment with only micronutrients (Fig. 1d).

Yields of soybean varieties were positively correlated with the maturity group ($r = 0.87$). It is interesting to point out that weather conditions had contrasting effects on the crop yield of varieties from various maturity groups. The pre-sowing seed treatment showed varietal specificity for the types of treatments.

Table 2. The crop yield of soybean of four maturity groups with various types of the pre-sowing seed treatment, t/ha – MSD : minimal significant difference

Types of treatments	2019	2020	2021	Average	Deviations from control
Ivushka (00)					
Control	2.29±0.19	1.65±0.25	1.45±0.29	1.80±0.42	0.00
HiStick	2.34±0.18	1.46±0.17	1.50±0.10	1.77±0.44	-0.03
Mo + Co	2.45±0.24	1.63±0.44	1.74±0.59	1.94±.041	0.14
HiStick+ Mo+Co	2.41±0.28	1.67±0.31	1.67±0.04	1.92±0.37	0.12
MSD	*0.181*	*0.177*	*0.125*		
Birlik KV (0)					
Control	2.71±0.12	3.41±0.33	2.46±0.77	2.86±0.48	0.00
HiStick	2.81±0.23	3.25±0.35	2.50±0.71	2.85±0.38	-0.01
Mo+Co	3.02±0.31	3.00±0.48	2.77±0.17	2.93±0.13	0.07
HiStik+ Mo+Co	3.31±0.24	3.51±0.42	2.83±0.61	3.22±0.34	0.36
MSD	*0.211*	*0.212*	*0.188*		
Zhansaya (II)					
Control	4.16±0.43	5.92±0.92	4.07±0.44	4.72±0.93	0.00
HiStick	4.11±0.38	6.14±0.96	4.06±0.29	4.77±0.10	0.05
Mo+Co	4.04±0.41	5.89±0.52	3.53±0.85	4.49±0.11	-0.23
HiStik+ Mo+Co	4.33±0.39	6.46±0.71	3.90±0.40	4.90±0.12	0.18
MSD	*0.211*	*0.155*	*0.214*		
Lastochka (III)					
Control	5.44±0.32	4.69±0.42	5.00±0.42	5.04±0.38	0.00
HiStick	5.51±0.27	4.64±0.27	5.69±0.63	5.28±0.53	0.24
Mo+Co	5.72±0.41	4.97±0.69	5.69±0.63	5.46±0.38	0.42
HiStick+ Mo+Co	5.64±0.21	4.99±0.19	5.69±0.21	5.44±0.35	0.42
MSD	*0.221*	*0.199*	*0.185*		

Table 3. The quality indicators of soybean seeds with various types of treatments

Variant of the experience	Protein content, %				Oil content, %			
	2019	2020	2021	Average	2019	2020	2021	Average
Ivushka								
Control	43.4	47.4	47.0	45.9	20.7	19.0	19.4	19.7
HiStick	44.2	47.0	47.6	46.3	20.5	19.1	19.2	19.6
Mo + Co	43.8	47.2	47.2	46.1	20.1	19.1	19.4	19.5
HiStick + Mo + Co	43.5	44.7	47.5	45.2	20.7	20.2	19.5	20.1
Birlik KV								
Control	40.1	43.3	43.4	42.3	22.7	21.2	20.8	21.6
HiStick	40.2	43.4	43.2	42.3	22.5	21.1	20.5	21.4
Mo + Co	40.5	43.0	43.7	42.4	22.7	21.1	20.9	21.6
HiStick + Mo + Co	40.1	43.1	43.9	42.4	22.8	21.2	20.8	21.6
Zhansaya								
Control	39.1	40.7	41.5	40.4	22.7	22.0	23.0	22.6
HiStick	39.7	40.1	40.6	40.1	22.0	22.0	22.6	22.2
Mo + Co	38.7	40.8	39.8	39.8	22.6	21.9	22.8	22.4
HiStick + Mo + Co	39.8	40.5	42.0	40.8	22.2	21.9	22.6	22.2
Lastochka								
Control	37.0	39.9	39.5	38.8	21.3	21.1	21.7	21.4
HiStick	38.1	40.4	39.5	39.3	21.1	21.2	21.9	21.4
Mo + Co	37.8	40.1	39.2	39.0	21.5	21.0	21.7	21.4
HiStick + Mo + Co	38.3	39.8	39.3	39.1	21.4	20.9	21.3	21.2

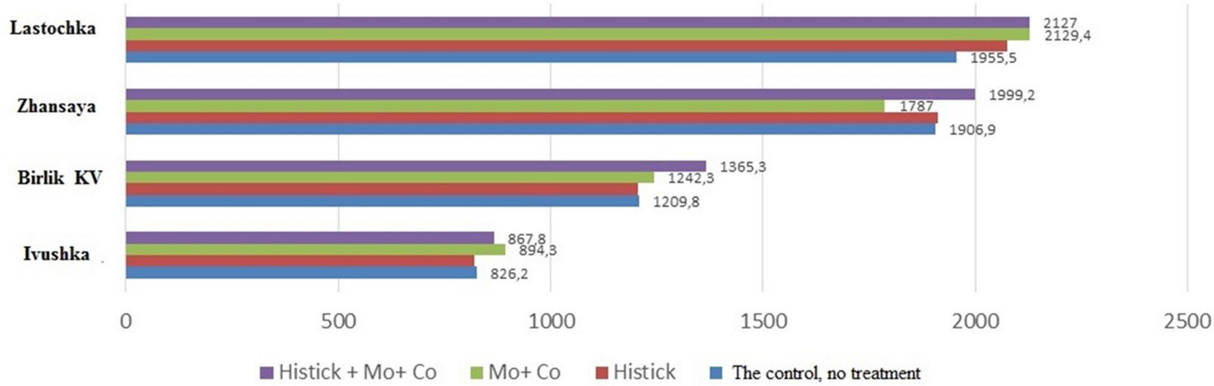

Fig. 2. Protein yield per hectare of various soybean varieties depending on the type of pre-sowing seed treatment (kg/ha).

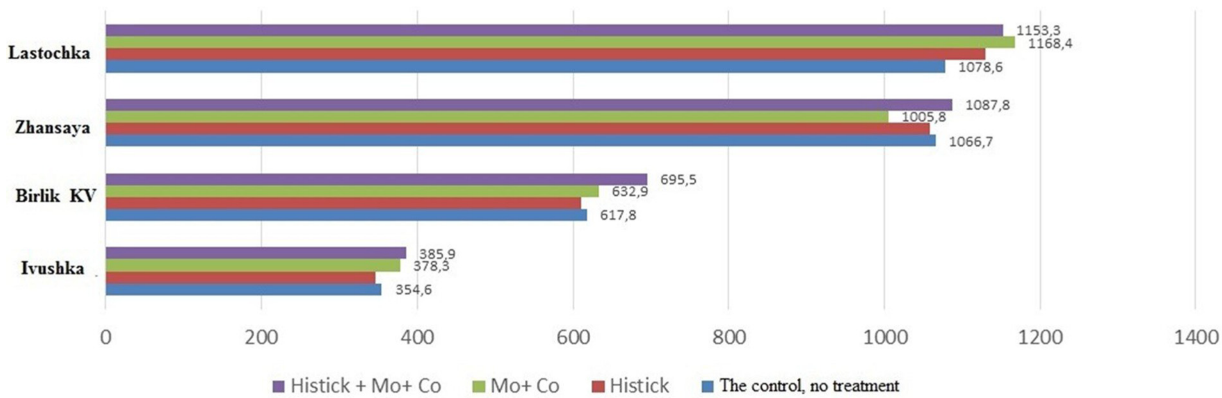

Fig. 3. Oil yield per hectare of various soybean varieties depending on the type of pre-sowing seed treatment (kg/ha).

Thus, the average crop yield for the three years of the study was the lowest for the early ripening Ivushka variety. The crop yield was in the range from 1.77±0.44 t/ha to 1.94±0.41 t/ha depending on the treatment. The highest yield for this variety was observed with seed treatment with micronutrients only. It is noteworthy that it aligns with the data on components of crop yield.

The second highest crop yield was middle-early Birlik KV variety with values from 2.86±0.48 t/ha to 3.22±0.34 t/ha. Soybean varieties of maturity groups of II and III were the highest yield. Crop yield of Zhansaya variety during the study years ranged from 4.49±1.18 t/ha to 4.90±1.28 t/ha. Crop yield of the most late-ripening Lastochka variety ranged from 5.04 ±0.38–5.46±0.38 t/ha.

The crop yields of ultra-ripening Ivushka variety and late-ripening Lastochka variety were most influenced by the pre-sowing treatment with micronutrients of Mo, Co without nitrogen-fixing inoculant. Yield increase compared to the control for these varieties was 0.14 and 0.42 t/ha, respectively.

Crop yield of early-ripening Birlik KV variety and mid-season Zhansaya variety significantly enhanced by 0.36 t/ha and 0.18 t/ha with a combined seed treatment with the nitrogen-fixing inoculant HiStick© and micronutrients of Mo, Co (Table 2).

The oil and protein accumulation in seeds of soybean had a strong negative correlation irrespective of the growing conditions. This negative correlation ranged from $r = -0.25$ to $r = -0.93$ (Yussova *et al.*, 2018) with a high coefficient of hereditability of 0.89–0.93 (Stobaugh *et al.*, 2017). Overall crop yield was usually negatively correlated with protein content but the correlation was weaker than between protein and oil contents.

The studies revealed that the various types of pre-sowing seed treatment had no effect on seed protein and oil concentrations. More visible variations in the qualitative composition were observed with year of study, in relation with weather conditions.

Therefore, in 2019, the obvious decrease of protein content and an increase of oil level in the seeds of all studied varieties were observed (Table 3).

Protein and oil yield per hectare are significant characteristics to assess the impact of the pre-sowing treatment because the yields increased without any change in quality (expressed as %).

In the soybean varieties of the new generation from LLP "Kazakh Research Institute of Agriculture and Plant Growing", the protein yield was within 945–1705 kg/ha and oil yield −416–975 kg/ha. Crop yield of varieties ranged from 2.09 to 4.39 t/ha depending on the group of maturity (Didorenko *et al.*, 2021).

Our experiments showed an increase in protein yield per hectare. The early-season variety of soybean Ivushka reached 826 kg/ha in the control and up to 894 kg/ha after treatment with pure micronutrients (+8.2%). The variety Birlik KV had

1210 kg/ha in the control and up to 1365 kg/ha after the using of HiStick© + Mo + Co (+12.8%). The variety Zhansaya had 1907 kg/ha without treatment and up to 1999 kg/ha after the using of HiStick© + Mo + Co (+4.8%). The full-season variety Lastochka had 1955 kg/ha without treatment and up to 2127 kg/ha after the using of HiStick© + Mo + Co (+8.8%) (Fig. 2).

The results on oil yields were analogous to the ones on protein yields (Fig. 3). The lowest oil yield was observed for the early-season Ivushka variety, *i.e.* 355 kg/ha without seed treatment and up to 386 kg/ha with the complete treatment (+8.7%). The highest oil yield was observed for full-season Lastochka variety, *i.e.* 1079 kg/ha without the pre-sowing treatment and 1153 kg/ha after treatment with salts of molybdenum and cobalt (+6.8%).

4 Discussion

Soybeans and other legumes have a major requirement of boron and molybdenum from the soil (Anspok and Lieninsh, 1988). Thus, scientists are faced with the mission to improve and optimize the micro-fertilization in soybean cultivation. In our research we studied the technology of soybean varieties and ways to increase the crop yields through the use of the pre-sowing seed treatment with salts of cobalt and molybdenum in gray soils of the south-east Kazakhstan.

At the initial phase of the plant development, molybdenum can promote the growth of the root system, accelerate and stimulate the development and activity of nodule bacteria (Chumak and Dovgayuk-Semenyuk, 2017). Molybdenum is applied as a pre-sowing seed treatment at a rate of 30-50 g of ammonium-molybdenum acid (50% of Mo) per kg of soybean seeds. It is used for foliar fertilizing and application directly into the soil (Golov and Kazachkov, 1973).

Kazachkov (1987) observed that wetting the seeds with high molybdenum doses (50 g/ha and more) resulted in significantly higher absorption coefficient than after spraying plants. The application of molybdenum through seed wetting method is not ideal. The experiments of Kazachkov (1987) in meadow grey soil showed that in a dry year the using of molybdenum for wetting seeds at a dose of 100 g/ha reduced the crop yield of soybean grain by 0.2–0.6 t/ha. In our study, soybeans were grown under irrigation, *i.e.* it is difficult to assess the decrease in effectiveness of preparations during the drought.

Experiments demonstrated that the combined application of molybdenum and boron gave better results than when used separately (Novikova, 2018). Our study confirmed this finding.

In the Far East of Kazakhstan, the high efficiency of sulfur and molybdenum fertilizers in the soybean cultivation was observed in previous years. The treatment of soybean seeds with molybdenum was examined as the mandatory method for the existing zonal farming systems (Kazachkov, 1987). A minimum concentration of molybdenum in fertilizers must be applied to obtain seeds with a sufficient content of molybdenum for next reproduction (5 mg/kg and above), *i.e.* the dose of 50 g/ha is used for the wetting of the initial seeds and the dose of 200 g/ha for the spraying of plants. The pre-treatment of soybean seeds with molybdenum can avoid its antagonism with sulfur during the combined application of fertilizers containing these elements and achieve an additional increase in soybean crop yield (Golov, 2012).

Cobalt enhances the leg hemoglobin content in nodules. Its content determines the intensity of their respiration. The process of nitrogen fixation with cobalt is active. Cobalt is directly involved in the nitrogen assimilation processes from the air, being concentrated in the nodules themselves (AgroBio, 2023).

Soybean treatment at the beginning of flowering with a mixture of chelates of Zn, Cu, Co, Mn with boric acid and molybdenum significantly increased crop yield and protein content in seeds. Among microelements influencing crop yield, molybdenum was the most effective (Tishkov *et al.*, 2017). Our research confirmed the effectiveness of the molybdenum application to treat soybean seeds before sowing. Increase in crop yield with influence of molybdenum reached 0.75 t/ha, and increase in protein content in seeds was up to 2.5% in leached chernozem (Khadikov, 2012).

Efficiency of treatment with boron, molybdenum and cobalt in the budding phase was observed in the sod-podzolic soil. The crude protein content was increased significantly with the use of cobalt and molybdenum. Their synergistic effect was observed with the combined application of microelements (Tsyganov *et al.*, 2007). However, in our studies, the application of the pre-sowing seed treatment did not determine an increase in protein and oil concentration in the seeds.

Unconventional micronutrients (iodine, selenium, chromium and others) have been also used (Zherukov *et al.*, 2019). In Brazil, efficiency of a new organo-mineral fertilizer based on the mixing of minerals with the organic compost, conditioning and granulation of the mixture were studied. The efficiency of the conventional and organic mineral fertilizers was measured in commercial field crops of soybean. Results of this experiment showed that soybean crop yields were enhanced by higher rates of the organic mineral fertilizer. The soybean crop yields in treatments enriched with the organic mineral fertilizer were higher than with the mineral fertilizer in all tested dosages. The statistical analysis demonstrated an agronomic equivalence between 201 kg/ha of the organic mineral 03–15–15 and 400 kg/ha of the mineral 04–20–20. The nitrogen content was enhanced in soybean leaves after treatment with the organic mineral fertilizer in comparison with treatment with the mineral fertilizer. This experiment resulted in higher efficiency of organic mineral than mineral fertilizer on soybean. This higher efficiency was due to prevention of mineral losses and the gradual release of nutrients from this organic mineral fertilizer provided by protection of the hard-organic matrix of the pellets. The presence of the organic matter also had a positive impact on soybean crop yields (de Sousa *et al.*, 2020). In order to optimize the growth of soybean, the overdosage of the chemical fertilizers for this crop is usually practised. Thus, the constant application of the chemical fertilizers without the adding of the organic fertilizers can lead to the rapid nutrient depletion in the soil. The experiments were conducted to estimate the efficiency of the organic fertilizer treatments to reduce the amount of urea as a chemical fertilizer required in soybean cultivation. The results demonstrated the beneficial effects of the chemical and organic fertilizers to increase the yield of this crop. Thus, it mitigates the environmental impact caused by the overuse of the chemical fertilizers (Sandrakirana and Arifin, 2021). In addition, researches were conducted to determine the impact of a type and level of dosage of the organic fertilizers on soybean yields. Factors were the types and doses of the organic fertilizers. Parameters as number of grains per pod, weight of 100 grains and weight of grains per plot were estimated. The results of variance analysis demonstrated that various types of the used organic fertilizers resulted in different levels of the components of growth and yield. Fertilizer doses were much different in almost all yield parameters (Syaranamual *et al.*, 2022). Studies were also conducted to define the growth and crop yield of soybean varieties to various application methods of nitrogen, phosphorus and expanded clay-containing fertilizers. Single NPK fertilizer application provided better growth than split fertilizer application. Thus, the height of plants was indicative of this. However, split fertilizer application resulted in higher soybean yields due to higher total number of pods, number of filled pods, 100-grain weight and dry weight of seeds. Based on the results of soil analysis, the K content after harvest was higher than before sowing. The P content was higher after the split fertilizer application (Timotiwu *et al.*, 2020).

Currently, the fertilizers were used in the advanced crop technology to grow crops as the main component of the high and sustainable yields. The nutritional status of plants cannot be optimized with the macro and meso-elements such as nitrogen, phosphorus, potassium, calcium, magnesium, sulfur and others. They also need micronutrients that can increase the plant resistance to adverse growing conditions, diseases and pests.

In conclusion, we can state that our researches confirm the high efficiency of pre-sowing treatment of soybean seeds with molybdenum, cobalt and nitrogen-fixing inoculants in our pedoclimatic conditions.

5 Conclusions

Soybean is a highly profitable crop, with a unique combination of quality composition in seeds. It is possible to increase the productivity of this crop by pre-sowing seed treatment with nitrogen fixers and salts of trace elements of molybdenum and cobalt.

Studies revealed the varietal response to types of treatments. Ivushka and Lastochka were responsive to micronutrients without nitrogen fixer. Zhansaya and Birlik KV were responsive to the complete treatment of seeds.

The average crop yield for the three years of the study on the early ripening of variety Ivushka was the lowest. The highest yield for this variety was observed with seed treatment with micronutrients only (1.94±0.41 t/ha). The second highest crop yield was middle-early variety Birlik KV with values from 2.86±0.48 t/ha to 3.22±0.34 t/ha. Soybean varieties from maturity groups II and III were the most yielding ones.

The crop yields of very early-ripening Ivushka variety and late-ripening Lastochka variety were most influenced by the pre-sowing treatment with micronutrients of Mo, Co without nitrogen-fixing inoculant. Yield increase compared to the control for these varieties was 0.14 and 0.42 t/ha, respectively. The crop yield of early-ripening Birlik KV variety and mid-season Zhansaya variety significantly increased by 0.36 t/ha and 0.18 t/ha with a combined treatment of seeds with nitrogen-fixing inoculant HiStick© and micronutrients of Mo, Co.

Stabilizing oil and protein concentration in the seeds and increasing crop yield after various treatments enhance the protein and oil yield for each studied soybean variety.

For the first time, this research was conducted in Kazakhstan conditions. Many agricultural producers in Kazakhstan sow and grow soybeans without any pre-treatment. Our research aims to popularize the implementation of all agronomic practices to increase soybean yields.

Conflict of interest

The authors declare that there are no conflicts of interest related to this article.

Funding

This research was done within the program-targeted funding of the Ministry of Agriculture under the budget program 267, BR22885857 "Development and introduction of highly productive oilseeds and cereals varieties and hybrids to ensure food security of Kazakhstan".

Authors contributions

Conceptualization: Gaukhar Kabylbekova; Methodology: Rinat Kassenov; Formal analysis and investigation: Almagul Dalibaeva; Writing – original draft preparation: Gaukhar Kabylbekova, Svetlana Didorenko; Writing – review and editing: Almagul Dalibaeva, Zerekbai Alikulov; Funding acquisition: Zerekbai Alikulov; Resources: Rinat Kassenov; Supervision: Svetlana Didorenko.

Availability of data and material

Data will be available on request.

References

Cobalt, AgroBio. 2023. *Cobalt (Co) acts on the formation of nitrogen-fixing nodule bacteria*. https://agro.bio/ru/kobalt-co#

Ali W, Ahmad M, Iftakhar F, Qureshi M, Ceyhan A. 2020. Nutritive potentials of soybean and its significance for humans health and animal production: a review. *Euras J Food Sci Technol* 4: 41–53.

Anspok PI, Lieninsh YYA. 1988. The content of trace elements in soils and the need for their application. *Chem Agric* 2: 73–75.

Brodin NV. 2021. Value of soybean as a protein and oil crop. *Proc V Int Sci Pract Conf* 1: 45–51.

Chernysheva NV, Tossunov YK, Barchukova AY. 2018. Biological efficiency of application of organomineral fertilizer Quantum boron-molybdenum on soybean. *Rice Breed* 4: 46–50.

Chumak A, Dovgayuk-Semenyuk M. 2017. Molybdenum and soybean: opportunities and problems. *Propos* 2: 60–62.

Dalmolin AK, da Silva Almeida A, Rodrigues DB,Martins AB, Gewehr E, Denardin ND, de Tunes LVM. 2021. Foliar application of molybdenum and cobalt in soybean crop: yield and seed quality. *Braz J Dev* 7: 43873–43885.

de Sousa RTX, Henrique BCM, Henrique LCM, Henrique H. 2020. Use of controlled release organic mineral fertilizer in soybean crop. *J Eng Exact Sci* 6: 0513–0519.

Didorenko SV, Abugaliyeva AI, Yerzhebayeva RS, Plotnikov VG, Ageyenko AV. 2021. Monitoring quality and yield capacity of soybean varieties during the creation of various ecotypes in Kazakhstan. *Agrivita J Agric Sci* 43: 558–568.

Didorenko SV. 2019. *Soybean breeding in Kazakhstan. Almaty: Asyl Kytap*.

Dospekhov BA. 2012. Technique of field experience (with basics of statistical processing of research results). *Moscow: Book on Demand*.

Fehr W, Caviness C. 1977. Stages of soybean development. Ames, *IA: Iowa State University*.

Golov VI, Kazachkov YN. 1973. The entry of molybdenum into soybean plants and its aftereffect when molybdenum fertilizers are applied to the soils of the Far East. *Agrochemistry* 10: 103–109.

Golov VI. 2012. Antagonism of sulfur and molybdenum in soybean plants and the possibility of their joint use as fertilizers. Oil Cultures. *Sci Tech Bull VNIIMK* 2: 151–152.

GOV.KZ. 2022. *Bureau of National statistics of the agency for strategic planning and reforms of the Republic of Kazakhstan*. Available from https://www.gov.kz/memleket/entities/stat?lang=en (last consult: 2023/23/05).

Karayev NV, Aksenov MP. 2017. Application of mineral fertilizers in crop production. *Sci Time* 5: 202–207.

Kazachkov YN. 1987. Evaluation of the results and adjustment of the use of molybdenum for soybeans. *In: Ways to improve the productivity of crop production, fodder production and horticulture in the Far East. Vladivostok: Far Eastern Branch of the Academy of Sciences of the USSR*, pp. 49–57.

Khadikov AY. 2012. Influence of fertilizers on productivity, quality of soybean grain and fertility of leached chernozem of North Ossetia-Alania. Cand. diss. *Vladikavkaz: Federal State Budget Educational Institution of Higher Education "Mountain State Agrarian University"*.

Khairullina SG. 2018. Value of soy in the national economy. In: Proceedings of the Ist International Scientific Practice Conference "Digitalization of the agro-industrial complex". Tambov: FGBOU VO TSTU, pp. 115–118.

Khasanov E, Khamaletdinov R, Gabitov I, Mudarisov S, Gallyamov F et al. 2020a. Efficiency improvement of the layered seed movement when using drum-type seed disinfectant. *Int Rev Model Simul* 13: 125–131.

Khasanov E, Khamaletdinov R, Mudarisov S, Shirokov D, Akhunov R. 2020c. Optimization parameters of the spiral mixing chamber of the device for pre-sowing seed treatment with biological preparations. *Comput Electron Agric* 173: 105437.

Khasanov E, Mudarisov S, Khamaletdinov R, Mukhametdinov A, Maskulov D et al. 2020b. Substantiation of work quality indicators of the universal seeds scarificator of the eastern galega (*Galega Orientalis*). *J Agric Eng* 51: 169–175.

Kudaibergenov MS, Didorenko SV. 2014. Technology of soybean cultivation in the irrigated lands of the south-east of Kazakhstan. *Almaty: Asyl Kytap*.

Latifundist, 2021. *Soybean oil production in Ukraine 2020/21: Largest processors.* Available from https://latifundist.com/en/novosti/57208-nazvano-top-6-krupnejshih-proizvoditelej-soevogo-masla-v-202021-mg (last consult: 2023/23/05).

Levkina OV, Vassiliev VV. 2017. Modern trends to develop the world soy market. *Bull Belarus State Agric Acad* 3: 12–18.

Lukin SM, Zolkina EI, Marchuk EV. 2021. Influence long-term use of fertilizers on productivity crop rotation, content and qualitative composition of soil organic matter. *Fertility* 3: 93–98.

Messina M. 2022. Perspective: Soybeans can help address the caloric and protein needs of a growing global population. *Front Nutr* 9: 909464.

Novikova NE. 2018. Physiological substantiation of foliar feeding for optimizing the nutrition of grain legumes in plant ontogenesis (review). *Sci Prod J "Grain Legumes and Cereals"* 1: 60–67.

Ossipov AI. 2020. Role of fertilizers in soil fertility and plant nutrition. *Health – Basis of Human Potential: Problems and Their Solutions* 2: 874–887.

Rizzo G, Baroni L. 2018. Soy, soy foods and their role in vegetarian diets. *Nutrients* 10: 43.

Rizzo G. 2020. The antioxidant role of soy and soy foods in human health. *Antioxidants* 9: 635.

Sandrakirana R, Arifin Z. 2021. Effect of organic and chemical fertilizers on the growth and production of soybean (*Glycine max*) in dry land. *Rev Fac Nat Agron Medellín* 74: 9643–9653.

Shabalkin AV, Dubinkina YeA. 2022. Soya is an economically profitable crop. *Agrarian Russia* 1: 17–21.

Shekhovtsova LV, Perepelitsa YS. 2021. Nutritional value of soy. *Proc Int Student Sci Conf* 1: 288–289.

Statista. 2022. *Leading soybean producing countries worldwide from 2012/13 to 2022/3*. Available from https://www.statista.com/statistics/263926/soybean-production-in-selected-countries-since-1980/ (last consult: 2023/23/05).

Stobaugh B, Florez-Palacios L, Chen P, Orazaly M. 2017. Agronomic evaluation of high-protein and high-oil soybean genotypes for specialty markets. *J Crop Improv* 31: 247–260.

Syaranamual S, Baan S, Martanto EA, Metubun M. 2022. Enhancing soybean (*Glycine max* (L.) Merr.) yield on Inceptisol through the application of organic fertilizers to promote sustainable agriculture. *Technium Sustainability* 2: 61–73.

Sychev VG. 2021. The influence of long-term use of mineral and organic fertilizers on the main indicators of various types of soils. *Fertility.* 4: 3–5.

Timotiwu PB, Nurmiaty N, Pramono E, Maysaroh S. 2020. Growth and yield responses of four soybean (*Glycine max* (l.) Merrill.) cultivars to different methods of NPK fertilizer application. *Planta Tropika Jurnal Agrosains (J Agro Sci)* 8: 39–43.

Tishkov NM, Tilba VA, Dryakhlov AA. 2017. The efficiency of foliar feeding of soybeans with microelements on leached chernozem of the Krasnodar Territory with long-term accounting of the dynamics of changes in temperature and moisture conditions. *Oilseeds* 2: 37–54.

Tkachenko MA, Volkova AS, Gnenny YeYu, Vussik AS. 2021. Application of mineral and organic fertilizers for various types of crops in dynamics. *Proc VII Int Sci Pract Conf* 1: 56–58.

Tsyganov AR, Wildflush IR, Mizhui SM. 2007. The effectiveness of the complex application of UAN with fungicides and microelements in cultivation of barley on sod podzolic light loamy soil. *News Natl Acad Sci Belarus* 4: 64–67.

Vishnyakova MA, Buravtseva TV, Buravtseva TV, Burlyaeva MO, Seferova IV et al. 2010. Collection of world genetic resources of grain legume crops VIR: Addition, preservation and study. Methodological guidelines. *St. Petersburg: VIR*.

Yussova OA, Assanov AM, Omelyanyuk LV. 2018. Characteristics of promising soybean sources with improved seed quality and crop yield in the southern forest-steppe conditions of Western Siberia. Oilseeds. *Sci Tech Bull All-Russian Res Inst Oil Crops* 3: 40–45.

Zherukov TB, Kishev AYu, Tutukova DA. 2019. Features of application of micronutrients in agricultural production. *Adv Mod Nat Sci* 6: 18–22.

Cite this article as: Kabylbekova G, Didorenko S, Kassenov R, Dalibaeva A, Alikulov Z. 2024. Effect of pre-sowing treatment of soybean seeds with inoculant and microelements for yield and quality in the conditions of south-east of Kazakhstan. *OCL* 31: 3.