Bioregulators and microfertilizers: effects on lentil yield and seed quality

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Abstract. One of the promising areas in agriculture is the use of intensive technologies, which include the use of bioregulators and micronutrient fertilizers. These technologies are widely used in the cultivation of leguminous crops, particularly lentils, which are an important component of dietary and functional nutrition. The aim of this study was to evaluate the effect of certain bioregulators and micronutrient fertilizers on the yield and seed quality of the new winter lentil variety Erebuni. Over the course of three years of research, the preparations Epin-Extra, Zircon, and Humate+7 microelements were tested, with quadruplicate experiments. An evaluation was conducted on the effects of Epin-Extra, Zircon, and Humate+7 microelements on the yield of Erebuni winter lentils during pre-sowing seed treatment and foliar treatment of vegetative plants at the budding-flowering stage. It was shown that both a single foliar treatment of vegetative plants and a double treatment (seeds and vegetative plants) resulted in a significant yield increase compared to the control (0.46–1.02 t/ha). A slight decrease (0.4-2%) in crude protein content in seeds compared to the control is offset by an increase in crude protein yield per hectare compared to the control (8.7-12.2% with foliar treatment of vegetative plants only and 26.6-52.6% with dual treatment (seeds and vegetative plants). The research results showed that these preparations, which are low in cost and require small application rates, can be recommended to agricultural farms for increasing lentil productivity under the conditions of Armenia.

1 Introduction

Grain legumes occupy an important place in agriculture as a key source of high-quality plant-based protein, used both in the food industry and in animal feed production [1]. In addition to their nutritional value, legumes offer agronomic advantages: thanks to their symbiotic relationships with nodule bacteria, they enrich the soil with nitrogen and contribute to the increase of organic matter content in the root zone, which positively affects the stability and productivity of agroecosystems [2].

Lentil (Lens culinaris) is one of the most valuable grain legumes, with a high protein content (up to 28%) and a complete set of essential amino acids, complex carbohydrates, fiber, vitamins (especially B vitamins and folic acid), as well as macro- and microelements

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such as potassium, magnesium, iron, phosphorus, and others. In terms of biological value, the plant protein in lentils is comparable to animal protein, while being significantly easier for the human organism to digest, making it a promising component in functional and specialized nutrition systems [3, 4].

Among the key advantages of lentils is their environmental purity: the crop does not accumulate nitrates, heavy metals, or radionuclides, even when grown in ecologically unfavorable areas. This makes lentils suitable for the production of safe and natural food products.

The process of germination significantly enhances the nutritional and functional value of lentils. In sprouted seeds, the content of vitamin C, antioxidants, and biologically active compounds increases. This boosts the body's antioxidant defenses, helps prevent viral diseases, and improves overall health [5, 6]. Sprouted lentils are especially useful for sports and therapeutic nutrition, as they improve tolerance to physical exertion, reduce fatigue, and accelerate recovery after workouts.

Due to its low glycemic index, lentils help stabilize blood glucose and insulin levels, making them beneficial for people with diabetes and metabolic disorders [7]. The high fiber content supports digestive health, aids in weight control management and helps normalize metabolic processes.

Thus, lentils are a versatile and promising ingredient for creating functional food products [8]. Their inclusion in the diet helps prevent chronic diseases, maintain energy balance, and improve the quality of nutrition, especially under conditions of high physical or emotional stress. The development of lentil processing and the expansion of lentil-based product ranges align with current trends in healthy eating and sustainable agriculture.

In light of the above, the need to increase the yield and quality of lentils has become extremely relevant. In our country, the average lentil yield is 1.2–1.3 t/ha, which is close to the figures of leading global producers. However, further increases in productivity are possible through the implementation of innovative agricultural technologies and new varieties [9].

Modern agriculture is characterized by the widespread use of intensive technologies, including the application of bioregulators and micronutrients fertilizers [10]. These preparations are capable of not only stimulating plant growth but also enhancing their resistance to unfavorable environmental factors, thereby increasing the overall adaptive potential of crops. Cells of the embryonic meristem are particularly sensitive to the effects of these substances, and their stimulation at the early stages of ontogenesis can have a lasting positive impact on plant growth and development. Seed and plant treatment with adaptogens, such as Epin-Extra, Zircon, and humic preparations, is increasingly being considered as a promising direction in crop production.

Special attention is given to foliar (non-root) methods of applying fertilizers and growth regulators, which provide a faster and more efficient uptake of nutrients into plant tissues compared to traditional methods [11].

Foliar application of fertilizers, in which nutrients are delivered directly to the plant leaves, is an effective method that quickly provides plants with the necessary elements [12]. This method is especially useful in conditions of nutrient deficiency in the soil or when root access to nutrients is limited. Foliar application helps increase the yield and quality of agricultural crops, including lentils.

The aim of this study is to evaluate the effects of certain bioregulators and micronutrient fertilizers on the productivity of lentils using different methods of application — pre-sowing seed treatment and foliar treatment of vegetative plants. It is expected that the results of this research will help develop recommendations for the effective use of these preparations to enhance lentil productivity under the conditions of Armenia.

2 Materials and methods

The experiments took place over the three years - 2019, 2021-2022. The soils of the experimental plots are irrigated meadow brown soils, which are situated in the Ararat Valley's central area with the following agrochemical characteristics: pH – 7.8, humus – 2.1%, P_2O_5 content – medium (1.5-3 mg/100g of soil), K_2O – medium (20-30 mg/100g of soil), easily hydrolysable nitrogen – low (3-4 mg/100g of soil). The above data refer to the soil horizon A (0-40 cm), as the majority of lentil roots are located in this soil layer. The preceding crop in 2019 and 2022 was winter wheat, and in 2021 it was fallow. The experiments were laid out in four repetitions using the method of organized replications, with a plot size of 5 m². Irrigation of the experimental plots was carried out in all years of the experiment during the fall — immediately after sowing, in the spring — before the foliar treatment of vegetative plants, and two times during the summer coinciding with the seed filling stage.

The research focuses on winter lentils of the Erebuni variety, which were selectively bred from the global ICARDA collection at the Echmiadzin experimental base of the Scientific Center for Agriculture. Erebuni lentil seeds are characterized by their large size, green color, and plate-like shape. The sowing rate in our research was 750,000 viable seeds per hectare.

To enhance the productivity and quality of lentil grains, the following preparations were tested: Epin-extra (active ingredient - the phytohormone 24-epibrassinolide), Zircon (a mixture of hydroxycinnamic acids), and Humate+7 microelements (contains (%): Humate - 75, K – 5, Cu – 0.2, Mn – 0.17, Zn – 0.2, Mb – 0.018, Co – 0.02, B – 0.2, Fe – 0.4). The mechanisms of action of these preparations are extensively described in numerous studies [13]. The application guidelines for these products are recommended by the manufacturers (Nest-M, Irkutsk Humates).

Lentils compete poorly with weeds and are highly sensitive to most herbicides. To control grass weeds (cereal weeds) in lentil crops, all recommended graminicides can be applied during the post-emergence period. Therefore, in our studies, the herbicide Targa Super (active ingredient: quizalofop-p-ethyl) was used in all treatments at a rate of 1 L/ha against grass weeds, while broadleaf weeds were removed by hand weeding. During all three years of the study, organomineral fertilizers were not used.

Prior to conducting field studies, we investigated in laboratory conditions the effects of Epin-extra, Zircon, and Humate+7 microelements on the biometric and cytogenetic parameters of lentils to determine the phytotoxicity of the tested preparations. It was found that these preparations promote better growth and development of the crop, while the mitotic index and the frequency of chromosomal aberrations remained at the control level.

Experimental Scheme:

1. Control (no treatment)
2. Foliar treatment of vegetative plants with Epin-Extra (0.02%)
3. Pre-sowing seed treatment with Epin-Extra (0.05%) + foliar treatment of vegetative plants with Epin-Extra (0.02%)
4. Foliar treatment of vegetative plants with Zircon (0.01%)
5. Pre-sowing seed treatment with Zircon (0.025%) + foliar treatment of vegetative plants with Zircon (0.01%)
6. Foliar treatment of vegetative plants with Humate+7 (0.02%)
7. Pre-sowing seed treatment with Humate+7 (0.1%) + foliar treatment of vegetative plants with Humate+7 (0.02%)

Before sowing, seeds were treated with Epin-Extra and Zircon for 4 hours, and with Gumat+7 for 14 hours. After treatment, the seeds were dried and then sown. Vegetative plants were treated during the budding-flowering phase.

Sowing (late October) and harvesting (late June) were carried out manually, and yield was measured on a plot-by-plot basis. For structural analysis, 10 plants from each variant in all replications, were selected.

The crude protein content of the seeds was determined using the Kjeldahl method. The experimental data were processed mathematically using analysis of variance. The results of the studies—the averages for all replicates—are shown in all tables.

Table 1. Effects of Bioregulators and Micronutrient Fertilizers on Lentil Yield

Variant	T/ha				Increase	
	2019	2021	2022	Average	t/ha	%
1	2.37	2.19	2.45	2.33	-	-
2	2.9	2.57	2.9	2.79	0.46	19.7
3	3.22	2.91	3.23	3.12	0.79	33.9
4	2.92	2.63	3.08	2.88	0.55	23.6
5	3.49	3.12	3.44	3.35	1.02	43.8
6	2.89	2.81	2.79	2.83	0.5	21.5
7	3.17	3.06	3.07	3.1	0.77	33.0
LSD_{05}				0.2		

Table 2. Yield Structure of Winter Lentils Under the Influence of Bioregulators and Micronutrient Fertilizers (average over three years)

Variants	Plant height, cm	Number of stems, pcs.	Number of branches, pcs	Number of pods, pcs	Number of seeds, pcs.	Seed weight, g.	Weight of 1000 seeds, g.
1	44.36	2.93	7.3	120.3	134.56	8.23	62.03
2	44.2	2.99	7.6	144.36	162.4	10.01	63.69
3	40.05	3.13	9.33	131.75	157.05	10.68	69.65
4	43.7	2.86	7.98	140.53	160.76	9.55	61.4
5	40.75	3.13	10.1	141.6	166.7	11.39	70.45
6	42.78	2.71	7.45	137.3	156.08	9.58	62.53
7	40.2	3.05	8.92	134.3	156.15	10.73	70.69
LSD_{05}						0.99	2.59

Table 3. Effect of Growth Regulators and Micronutrient Fertilizers on Crude Protein Content in Lentil Seeds (% of dry matter basis)

Variants	2019	2021	2022	Average over three years			
				Content, %	Yield per 1 ha, kg	Increase	
						kg/ha	%
1	24.6	23.68	24.1	24.13	629.31	-	-
2	21.6	23.5	20.9	22.00	684.20	54.89	8.7
3	23.1	23.8	22.8	23.23	874.74	245.43	39.0
4	21.3	23.08	21.4	21.93	706.04	76.73	12.2
5	24.2	24.0	23.1	23.77	960.17	330.86	52.6
6	21.9	23.42	22.0	22.44	695.64	66.33	10.5
7	21.2	24.08	22.5	22.59	796.42	167.11	26.6

3 Results and discussion

The lentil yield assessment showed that in all treatments, there was an increase compared to the control, ranging from 0.46 to 1.02 t/ha (Table 1). The influence of the "foliar treatment" and "seed treatment" factors was 19.7% and 14.2% for Epin-extra, 23.6% and 20.1% for

Zircon, and 21.45% and 11.59% for Humate+7, respectively. As seen, the impact of the "foliar treatment" factor on lentil yield was higher by 3.5-5.5% for Epin-Extra and Zircon, and about 10% for Humate+7, compared to the "seed treatment" factor. Overall, with all types of active substances and treatments, the lentil yield was significantly higher than in the control variant. The highest yield was obtained with the double treatment using Zircon, both in all years of the study and on average across the years.

The higher yields in 2019 and 2022 compared to 2021 can be explained by the aftereffect of the previous year's background treatment, as $N_{80}P_{60}K_{80}$ is applied to winter wheat as a background treatment before sowing.

Analysis of the yield structure (Table 2) showed that the increase in yield, depending on the type of treatment and active substance, was due to an increase in productive branches (4-38%), number of pods (9.5-20%), number of seeds (16.7-23.8%), and seed weight (16-38.4%). In other words, there was an increase in the intensity of growth processes and biomass accumulation.

Table 3 presents data on the crude protein content in lentil seeds. Depending on the treatment, crude protein content in seeds decreased by 0.4-2.2% on average over the three years compared to the control. However, the crude protein yield per hectare was significantly higher due to the increased overall yield. It is well known that protein content in seeds can vary significantly depending on both the variety and growing conditions [14]. Under the hot and dry weather conditions of 2021, the crude protein content in the variants was higher and remained at the same level as the control.

Thus, as a result of the three-year study on the effects of micronutrient fertilizers and bioregulators on seed treatment before sowing and foliar treatment of vegetative plants during the budding-flowering phase, the following was demonstrated:

- An increase in lentil yield across all years of the study and for all types of active substances, with the greatest effect achieved using Zircon.
- The use of micronutrient fertilizers and bioregulators influenced not only lentil yield but also the protein yield per unit area. The highest protein yield on average over the three years of the study was obtained with the double treatment using Zircon, which was 52.6% higher than the control.
- Humate+7 microelements and Zircon and Epin-Extra, which are inexpensive and require small application amounts, significantly increase lentil yield, making them economically beneficial and feasible for widespread use in farming enterprises.
- The results of this study highlight the importance of selecting the most appropriate physiologically active substances tailored to the specific needs of each crop.

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