The effect of combining plant growth regulators with chelated fertilizers on the yield and quality of soft spring wheat

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Abstract. The article shares resource-saving technologies of growing soft spring wheat (Triticum aestivum L.) in the non-chernozem zone of the Russian Federation based on modern agrotechnical methods involving combination application of plant growth regulators and chelated fertilizers Epin Plus, Epin Extra, and Cytovit. Such technics increase yields, improve the quality of grain, and increase biomass. Field studies for 2022 - 2024 years described positive effects on morphological parameters such as height of plants, length of ear, number of spikelets and grains per ear and weight of 1000 seeds. The greatest results were obtained when Epin Plus and Cytovit were used in aggregate. Grain yield increased by 35,16%, straw by 37,3%. Protein, gluten, and glassy content of grain have increased by 15,86%, 17,89%, and 22,19% respectively compared to the control group. The data obtained demonstrate the high efficiency of an integrated approach to agrochemicals aimed at improving the productivity and technological characteristics of grain crops. This contributes to the sustainable development of agriculture in the non-chernozem zone and the rational use of resources.

1 Introduction

The agriculture industry is critical toward food sufficiency and sustainable development at national and international levels. Due to fast population increase, climatic conditions plus limited land resources in this modern world improvement of agricultural productivity has gained more significance [1-2].

A major priority in modern agriculture is the practice of integrated agricultural technologies with the application of plant growth regulators and chelated fertilizers. It is these products that ever have potential effects on the energy physiological processes of plants, give better development of root systems, increase the formation of green mass, and more crop yield [3].

Grain crops take a key place in the farm mix and the world's food plan, being the main meal for most people and also as the top source of basic input for the food and feed business. Their importance stems from their high biological value, nutritional properties, and versatility

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of use, making cereals indispensable components in ensuring food security and sustainable agricultural development [4]. Among cereal crops, spring common wheat (Triticum aestivum L.) holds a special place, characterized by a wide range of applications and high adaptability to diverse agroclimatic conditions. Spring common wheat not only provides high-quality grain for the production of bakery and confectionery products but also serves as an important feed resource in animal husbandry, significantly increasing the profitability of agro-industrial production [5].

In light of the ongoing changes in climatic conditions and limited resources, optimizing technologies for growing soft spring wheat has become a crucial task for scientific and practical research. This includes controlling agrotechnical factors, selecting optimal varieties, and using modern biotechnological methods to increase yields, improve grain quality, and enhance plant resistance to adverse environmental conditions [6].

Agrotechnical tools, such as plant growth regulators, are substances that can influence physiological processes in plants and regulate their growth and development. These compounds can stimulate or slow down specific stages of growth, promote the development of the root system, increase the storage mass, and optimize fruit formation. A significant challenge for modern science is to investigate the effectiveness of combining these growth regulators with the use of chelated micronutrient fertilizers [7].

Chelated fertilizers are forms of microelements bound to organic ligands, which promotes their Plants absorb microelements more efficiently than inorganic forms. These microelements, including zinc, iron, magnesium, and copper, play crucial roles in photosynthesis, protein synthesis, and enzyme systems. They also help plants maintain their physiological resistance to stressors such as nutrient deficiency, drought, and temperature changes. Microelements are of particular importance in the formation of grain, its biochemical composition, and technological characteristics [8].

Research on the combined use of growth regulators and chelated micronutrients shows that their combined application significantly improves the physiological state of plants. Studies regarding the combined application of growth regulators and chelated micronutrients indicated that the combined Foliar Application significantly improved the physiological state of a more robust and branched root system plus biomass and photosynthetic activity as well as better metabolic processes in general which finally turn into higher yields with better quality of product expressed in grain weight, and protein content, gluten, vitamins, and micronutrient content. This method helps to decrease the negative influence of stress factors on plants, raising their resistance against any unfavorable condition [9].

Experimental data proved that the application of growth regulators together with chelated micro elements could result in great economic and technological advantages. Also, an increase in the protein and gluten contents of the grain improves its qualitative indicators thereby making it better for industrial use which will give high-quality flour and baked goods. Therefore, the application of growth regulators and chelated fertilizers in normal regulations opens new approaches to agriculture. It raises a yield increase as well as quality improvement of products plus the efficiency of using resources in agriculture with minimized environmental impact. Due to this fact and growing demand for food production with sustainable farming practices, such methods are likely to be some of the tools that can help facilitate food security as well as agricultural development over time [11].

The aim of this study is to investigate the most effective application methods of plant growth regulators and chelated fertilizers in order to enhance the productivity and quality of Radmira spring common wheat seeds.

2 Materials and methods

2.1 Field testing methodology

The studies were conducted in the field conditions of the non-chernozem zone (The central region of the Russian Federation), the Moscow region, at the Field experimental station of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy during 2022 - 2024. The climate in this area is characterized as moderately continental. The soil on the station is sod-podzolic with medium and light loam textures. The agrochemical profile of the soil during the research years (2022–2024) is as follows: humus content (according to Tyurin) – 1.9%; pH (saline extract) – 6.1; P_2O_5 (according to Kirsanov) – 240 mg/kg; K_2O (according to Kirsanov) – 120 mg/kg; easily hydrolyzable nitrogen (according to Cornfield) – 95 mg/kg.

The object of the study was a mid-early variety of soft spring wheat (Triticum aestivum L.) – Radmira. The seeds were produced at the Federal Research Center "Nemchinovka" in Moscow region, Russia, and three formulations developed by the autonomous non-profit organization "NEST M" were used.

Epin-Extra is a multifunctional plant growth regulator that stimulates seed germination, plant growth and development, and induces protective responses to stress conditions during the vegetative phase. Its active substance is 24-epibrassinolide (a plant hormone from the brassinosteroid group), which is synthesized and present in the cytoplasm of all plant organs, regulating hormonal activity. The preparation has systemic action and is incorporated into plant metabolic processes within 1–2 hours after application.

Citivit is a preparation containing microelements in chelated form. It regulates various metabolic processes, enhances the synthesis of growth substances, carbohydrates, and vitamins, and improves the assimilation of macroelements. Its composition includes: total nitrogen – 30 g/l; potassium – 25 g/l; phosphorus – 5 g/l; and microelements: sulfur – 40 g/l; manganese – 30 g/l; iron – 35 g/l; magnesium – 10 g/l; boron – 8 g/l; zinc – 6 g/l; molybdenum – 4 g/l; copper – 6 g/l; cobalt – 2 g/l.

Epin Plus is a complex organomineral fertilizer containing nitrogen (2%), phosphorus (2.1%), potassium (3%), boron (0.64%), fulvic acids (2.5%), and 24-epibrassinolide (0.012 g/l). Additionally, it includes fucoid extract and other essential nutrients. The product is used for both root and foliar application, aiming to increase yield and soil fertility. It enhances micronutrient absorption, activates soil beneficial microflora, and promotes plant metabolism. Epin Plus also provides protection against various stresses and facilitates rapid recovery throughout the vegetative period.

The experiment involved a double foliar treatment of spring wheat at the stem elongation (booting) and tillering phases across the following treatment variants: 1. Control (no treatment); 2. Epin Plus (70 ml/ha); 3. Epin Plus (70 ml/ha) combined with Epin Extra (50 ml/ha); 4. Epin Plus (70 ml/ha) combined with Citivit (1 l/ha). The spraying rate of working solution was 300 l/ha. At the booting stage, herbicide application (Magnum 10 g/ha) was performed. The experiment was arranged with four replicates, with randomized placement of treatments within each replicate.

The experiment was conducted with four replicates, and treatments were randomly assigned within each replicate. Harvested yield data and key grain quality indicators were evaluated using standardized methods in accordance with Russian GOST 9353-2016 "Wheat. Technical Specifications." Grain quality assessment was performed using near-infrared spectroscopy (SpectraStar XT device).

2.2 Statistical evaluations

The collected data were subjected to statistical analysis using the statistical package (Statistica 8.1). The results are presented as mean values of measurements obtained from three experimental samples. To determine the significance of differences between treatment means, the least significant difference (LSD) test at a 5% probability level was employed.

3 Results and Discussion

Our research findings indicate that the use of growth regulators, organic minerals, and chelated fertilizers, as well as their combinations, led to an increase in the biometric parameters of spring wheat plants of the Radmira variety over a three-year average period (Figure 1).

Specifically, treatment with Epin Plus resulted in an increase in plant height by 5.36 cm and spike length by 1.5 cm relative to the control. The combined application of Epin Plus and Epin Extra further enhanced plant height by 3.22 cm and spike length by 1.1 cm compared to treatment with Epin Plus alone.

Over the three-year study period, the most favorable results were observed in the treatment combination of Epin Plus and Cytovit. This treatment increased spike length and plant height by 2.38 cm and 5.87 cm, respectively, compared to the Epin Plus-only treatment. Relative to the control, these increases amounted to 12.57% for plant height and 49.75% for spike length.

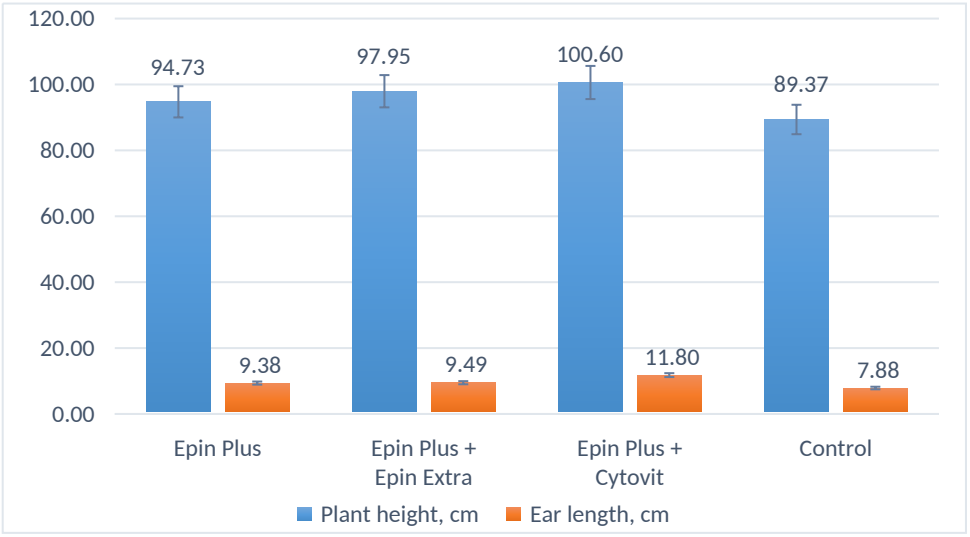

Fig. 1. Biometric indicators of spring wheat plants of the Radmir variety, average values for 2022-2024.

Analysis of yield components of spring wheat Radmira across all experimental variants revealed that, on average, there was an increase in the number of spikelets per spike, grain number per spike, and 1000-grain weight compared to the control (Table 1).

The most significant influence on spike fertility, spikelet count, and 1000-grain weight was exerted by the combined application of Epin Plus and Cytovit: spikelet number increased by 2.35 units, grain number per spike by 3.92 units, and 1000-grain weight by 3.52 g relative to the control.

Table 1. The elements of the structure of the spring wheat crop of the Radmir variety, averaged over the years 2022 - 2024.

Treatments	Number of spikelets, pcs	Quantity of grain, pcs	Weight of 1000 grains, g
Epin Plus	12,23	23,63	28,82
Epin Plus + Epin Extra	12,97	24,83	29,60
Epin Plus + Cytovit	13,67	26,43	31,02
Control	11,32	22,51	27,50
LSD 0.05	0,64	1,23	1,46

Grain yield (Figure 3) in all treatment variants significantly exceeded that of the control (3.11 t/ha). Treatment with Epin Plus alone increased grain yield by 23.55%, reaching 3.83 t/ha. The highest yield was achieved with the combination of Epin Plus and Cytovitt, reaching 4.19 t/ha, representing a 35.16% increase relative to the control and a 9.4% increase compared to Epin Plus alone. The joint application of Epin Plus and Epin Extra also resulted in a significant yield increase—by 3.92% over Epin Plus alone and by 27.97% over the untreated control.

Straw yield also increased with combined treatments. In particular, plant application of Epin Plus alone led to an increase of 23.54% in straw yield. The combination of Epin Plus and Epin Extra resulted in an increase of 29.37% in straw yield, and Epin Plus and Cytovit resulted in a rise of 37.3% compared to the control group.

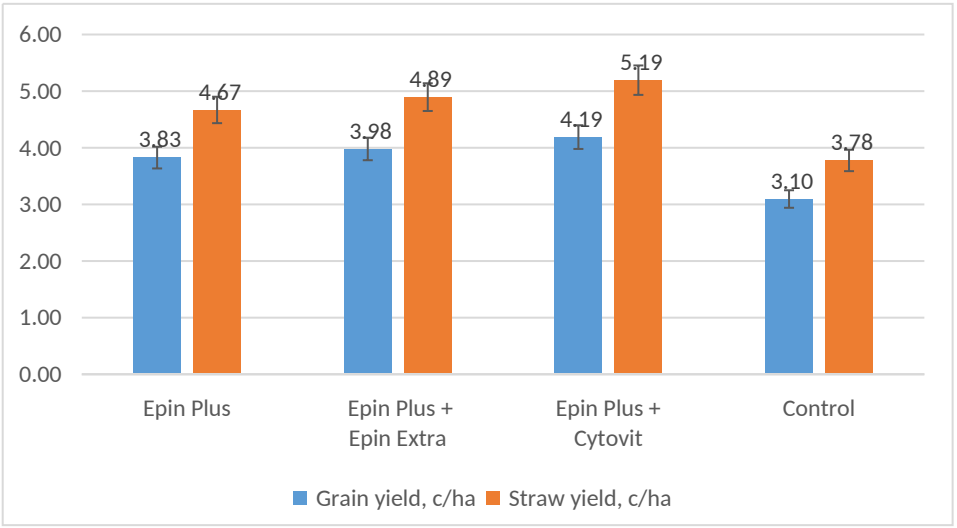

Fig. 3. Yield of spring wheat Radmir variety, average values for 2022-2024.

The main quality parameters of soft wheat grain—protein content, gluten content, and vitreosity—play crucial roles in determining technological and baking properties. The analysis of the effects of the treatments on these grain quality traits showed that the use of combined preparations promotes increases in protein content, gluten content, and vitreosity (Figure 4). The combination of Epin Plus and Epin Extra resulted in the highest protein

content, reaching 16.88%, which exceeds the values of Epin Plus alone by 12.99% and the control by 27.49%. The combination of Epin Plus and Cytovit yielded a protein content of 15.34%, also higher than both Epin Plus and control variants.

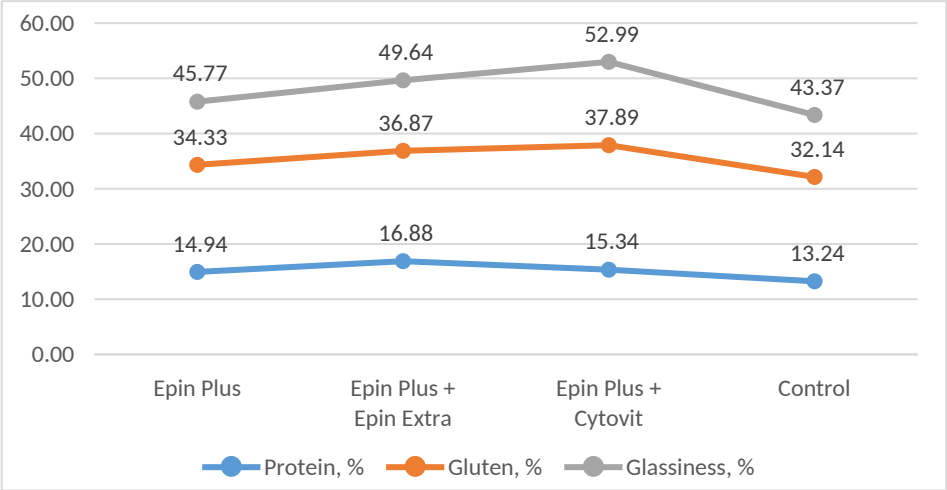

Fig. 4. Quality indicators of spring wheat grain under the influence of biological preparations of various nature, depending on the growing conditions of the Radmir variety of spring wheat, average values for 2022-2024.

Gluten is a crucial component that determines the quality of wheat flour and bread. A high gluten content (typically between 23% and 40%) leads to better dough rheology and higher bread quality. Gluten consists of gliadin and glutenin, and its quality is measured by its ability to form a strong network. The gluten content significantly influences the technological potential of wheat. The highest gluten content of 37.89% was observed in plants treated with Epin Plus in combination with Cytovit, surpassing the level in Epin Plus treatment alone by 10.37% and the control level by 17.89%. Moreover, the combined use of Epin Plus and Epin Extra had a positive effect on gluten content compared to using Epin Plus alone or the untreated control.

Vitreosity, which reflects the structural and mechanical properties of endosperm, has an impact on milling and baking quality. Higher vitreosity (typically above 75%) indicates better grain quality and improved technological properties. This parameter affects flour yield and quality, consequently influencing market value. Additionally, it correlates with gluten content and other technological characteristics. In our research, the highest vitreosity was achieved through the combined use of Epin Plus and Cytovit, achieving 52.99%. This represented an increase of 15.77% compared to using Epin Plus alone, and 22.19% compared to the control group. The combination of Epin Plus and Epin Extra also improved vitreosity by 8.46% compared to Epin Plus alone, and by 14.5% compared to the control.

4 Conclusions

During a three-year field experiment from 2022 to 2024, the impact of the combined use of plant growth regulators and chelated fertilizers on the yield and quality of soft spring wheat was studied. The findings from the experiment revealed that the application of these agricultural techniques can significantly enhance plant height, ear length, the number of spikes per plant, grain per ear, and the weight of 1,000 seeds. This, in turn, resulted in an increase not only in grain and straw yield, but also in protein content and technological

properties of the grain. The best outcome was achieved with the treatment of plants with Epin Plus and Cytovit. Grain and straw yield increments over the control were 35.16% and 37.3%, respectively. Protein content was higher by 15.86%. Gluten is raised to 17.89% more vitreous index value increases by 22.19% than un- treated version.

This brings to the fore that the merger of those agrotechnologies with sustainable agricultural systems can be taken as a very proactive approach toward enhancing the productivity of soft spring wheat. The positive changes in both the quantitative parameters of yield and the quality of grain prove once again how important it is to consider comprehensively the concept of agrochemical practices.

In the future, further research may be aimed at clarifying dosages, application methods and interactions with other cultivation technologies, which will increase the effectiveness of agrochemical techniques and adapt them to specific soil and climatic conditions.

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