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RESEARCH ARTICLE

The Role of Modern Biostimulants in Minimizing Crop Yield Losses under Abiotic Stress

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ABSTRACT

Global climate change is increasing the frequency of exposure of agricultural crops to abiotic stress factors such as drought and extreme temperatures. This article examines the effects of stress on plant physiology, in particular the development of oxidative stress and the formation of reactive oxygen species (ROS). Results are presented for testing a biostimulant that, in addition to amino acids, contains seaweed extract with phytohormones — auxins, which accelerate seed germination and break dormancy in dormant buds, seeds, and tubers; cytokinins, which are required for cell division, growth, and differentiation; and polysaccharides as an additional source of readily available energy. Biostimulants with a complex composition are effective in stimulating root system development and increasing plant resistance at the early stages of vegetative growth (Bezuglova, 2000).

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INTRODUCTION

The genetics of modern crop varieties is the basis on which the size and quality of yields depend [Posypanov et al., 2007; Shevelukha, 1992]. However, the potential of varieties in agronomic practice is far from fully realized. One of the main obstacles is the influence of growing conditions, including unregulated environmental conditions beyond the control of farmers, which often strongly limit yield growth. Unfortunately, because of environmental conditions — low soil fertility, cold and prolonged winters, regularly recurring spring–summer droughts, and a short growing season — most sown areas are exposed to risks. Modern agriculture faces unprecedented challenges caused by climate instability. According to current data, yield losses in major crops due to abiotic stresses reach critical values. Drought reduces maize yield by 63–87%, wheat by 57%, soybean by 46–71%, and sunflower by up to 60%. High temperatures also exert significant pressure, reducing crop potential by 42% or more.

MATERIALS AND METHODS

The critical developmental phase of crops such as maize and soybean often coincides with periods of drought, leading to irreversible losses in the structure of the future yield. At the early stages of ontogenesis, plants are especially vulnerable to oxidative stress caused by the accumulation of free radicals, which destroy cell membranes and inhibit photosynthetic activity (Yagodin et al., 2026). Traditional cultivation technologies based exclusively on the application of macronutrient fertilizers are often insufficiently effective in combating the consequences of climate stress. In this regard, there is an urgent need to integrate specialized biologically active preparations into the technological cycle. Biostimulants based on free amino acids of plant origin and specific microelements are becoming a tool that enables plants to maintain a high rate of metabolic processes (Bezuglova, 2000; Kovalev, 2003). These compounds act as triggers of the organism's defense systems, helping to mitigate the negative impact of the external environment at the earliest, decisive stages of seedling development, when the number of kernels per ear or productive nodes on the stem is established.

Organic biostimulants are concentrated water-soluble organic preparations for seed treatment and root and foliar fertilization of agricultural crops. They contain biologically active substances, including amino acids, humic and fulvic acids, vitamins, hormone precursors, peptides, proteins, enzymes, polysaccharides, and other active compounds, including microelements.

The composition of the biostimulant is presented in Table 1.

Biostimulants activate vital processes in plants and enhance protective functions. They also increase the efficiency of primary fertilizer use (Bezuglova, 2000; Kovalev, 2003). Biostimulants promote plant root system development, improve nutrient uptake, and increase stress resistance. The use of organic biostimulants improves the efficiency of primary fertilizers (NPK), mineral fertilizers, and micronutrient fertilizers in foliar and root applications.

Table 1: Composition of the Biostimulant

Composition	w/w	g/L
Amino acids, total	9.0%	106.6
Free L-amino acids	6.5%	77.0
Nitrogen (N)	3.0%	35.5
Organic substances, total	30.0%	355.2
Zinc (Zn)	1.0%	11.8
Seaweed extract	4.0%	47.4

It is necessary to clearly distinguish mineral micronutrient fertilizers of the "NPK + microelements"/"micronutrient fertilizers" type from organic biostimulants. The former act indirectly on plants by supplying them with primary nutrients and microelements, thereby compensating for their deficiency during the growing season, whereas the active components of biostimulants act directly on plants (Figure 1). These differences determine their complementarity in complex corrective fertilization systems. At present, the use of biostimulants in combination with water-soluble mineral fertilizers and micronutrient fertilizers is one of the most flexible methods for regulating the nutritional regime of agricultural plants.

One of the most significant factors in the resistance of an agrophytocenosis to moisture deficit is the morphology and functional activity of the root system (Avdonin, 1972). The root system not only performs an anchoring function but also serves as the main organ for absorbing water and dissolved mineral salts. Under drought conditions, the upper soil layers dry out very rapidly, making it impossible to use fertilizers located in the arable horizon. The use of biostimulants is aimed at activating cell division in root meristems and increasing root penetration capacity. Long-term field trials show a very large difference in the growth dynamics of the underground part of plants. When preparations that activate root formation are used, considerable elongation of the main root and stimulation of second- and third-order lateral roots are observed. This qualitative change in root architecture enables the plant to reach deeper soil horizons where available capillary moisture remains. An increase in the total area of the absorbing surface not only protects the crop from wilting during peak temperatures but also substantially increases the utilization coefficient of nitrogen, phosphorus, and potassium from the soil complex. The use of amino acid complexes at the stage of seed treatment or early foliar fertilization creates the basis for vigorous initial growth, ensuring the dominance of the crop plant over weeds and better overwintering of winter species.

Mechanisms of Stress Effects on Plants and the Role of Biostimulants in Stress Tolerance

Abiotic stress triggers a cascade of negative biochemical reactions. The main mechanism of cell damage is oxidative stress. Under the influence of adverse factors, plants increase the production of toxic molecules — reactive oxygen species (ROS). These molecules lack one electron, which they "take" from healthy molecules, causing destabilization of cellular components and membrane destruction (Aliev, 2021).

In addition, stress leads to:

- Disruption of photosynthesis.
- Changes in osmotic pressure.
- Reduced efficiency of mineral nutrition, for example, inhibition of zinc uptake at pH > 7.

Table 2: Climate Changes and Types of Stress

Crop	Stress Type	Yield Loss, %
Maize	Drought	63–87
	High temperature	42
Wheat	Drought	57
Soybean	Drought	46–71
Sunflower	Drought	60

A toxic molecule is a molecule that lacks one electron and "borrows" this electron from healthy molecules, thereby causing their instability.

Toxic molecules are oxidative and toxic compounds that decompose cellular components and are shown in Figure 2.

Figure1: Toxic Molecules

The use of specialized preparations is required to compensate for the plant's energy costs in combating stress. Amino acid-based biostimulants are aimed at:

- Mobilizing metabolism: activating the transport of amino acids and phosphates.
- Energy support: reducing energy expenditure on the degradation of storage proteins.
- Osmoprotection: maintaining water balance in cells.

Due to the ability of free amino acids to chelate microelements, all components are rapidly and fully absorbed by plants. They provide germinating seeds with nitrogen nutrition, increase germination energy and field germination, improve root system development, increase resistance and viability under stress factors, enhance bacterial viability during seed inoculation, increase plant productivity, increase yield, and improve product quality (Yagodin et al., 2026; Aliev, 2021).

Results of Experimental Studies and Effectiveness of Biostimulant Use

Nitrogen use efficiency is one of the most important parameters to consider in modern agriculture. Nitrogen use efficiency depends on the crop species and external factors.

Rice, for example, is characterized by a low nitrogen use efficiency. Table 3.

Table 3: Nitrogen Use Efficiency (NUE) Worldwide

Country	Страна	Variable	Wheat	Rice	Maize
China		Fertilizer rate (kg N/ha)	202	211	182
		NUE (kg/kg N)	23.2	30.8	29.2
India		Fertilizer rate (kg N/ha)	113	70	48
		NUE (kg/kg N)	34.9	47.3	49.1
USA		Fertilizer rate (kg N/ha)	71	177	163
		NUE (kg/kg N)	41.2	46.7	58.2
European Union		Fertilizer rate (kg N/ha)	105	na	127
		NUE (kg/kg N)	50.9	na	54.6
Argentina		Fertilizer rate (kg N/ha)	61	na	76
		NUE (kg/kg N)	40.5	na	37.2
Brazil		Fertilizer rate (kg N/ha)	35	57	57
		NUE (kg/kg N)	66.4	73.1	67.8

Experimental studies were conducted to evaluate the effectiveness of organic biostimulants based on free amino acids of plant origin, seaweed components (auxins, cytokinins, polysaccharides), and microelements.

Sunflower and soybean were selected as the study objects. Field trials of sunflower were conducted in the San Pedro del Paraná region, Paraguay.

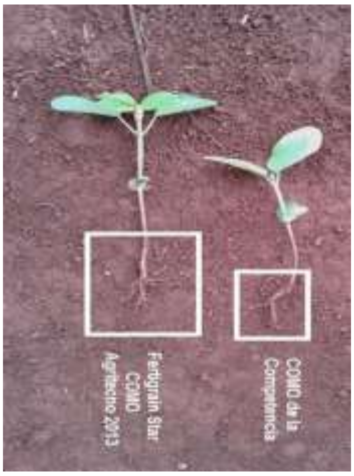
During the field trials conducted in Paraguay (San Pedro del Paraná), the effect of seed treatment with the biostimulant on sunflower development was evaluated.

Root system development parameters:

Control group: root length was 3–5 cm.

Experimental group (150 mL/bag treatment): root length reached 6–10 cm.

The increase in root system volume enables the plant to absorb moisture and nutrients more effectively from deeper soil layers, which is critically important under drought conditions (Figure 3).



Agritecno	**Competencia**
- **Fertigrain Star Como 200 cc/100kg**	- Fertigrain Star Como 200 cc/100kg
- **Vitavax (Carboxim 20% +**	- Vitavax (Carboxim 20% +
Thiram 20%) 250 cc/100kg	Thiram 20%) 250 cc/100kg
- **Fipronil 70% 200 cc/ 100 kg.**	- Fipronil 70% 200 cc/ 100 kg.

Figure 2: Root System Development of Sunflower Seeds

Experimental design for sunflower:

Control: traditional technology without the use of biostimulants.

Experimental group: seed treatment with Fertigrain Star, a preparation containing amino acids and zinc, at a dose of 150–200 mL per sowing unit (bag).

Experimental design for soybean:

The compatibility of the biostimulant in tank mixtures was studied. The following combination was used:

Biostimulant (200 mL/100 kg);

Fungicide protection (Carboxim 20% + Thiram 20%, 250 mL/100 kg);

Insecticide protection (Fipronil 70%, 200 mL/100 kg).

The assessment method included measuring the morphometric parameters of seedlings (main root length) and visual monitoring of phytotoxicity. Mathematical data processing was performed using standard statistical analysis methods.

Soybean trials also showed high selectivity and absence of phytotoxicity when tank mixtures with fungicides (carboxim, thiram) and insecticides (fipronil) were used (Figure 4).

Figure 3: Trials during Soybean Cultivation

RESULTS AND DISCUSSION

Analysis of the effects of abiotic stress factors showed that drought and extreme temperatures are critical determinants of yield. According to the summarized data obtained (Table 2), maize yield losses under drought reach 87%, wheat losses reach 57%, and soybean losses reach up to 71%, which correlates with the intensity of oxidative stress and the accumulation of reactive oxygen species (ROS).

Effect of Biostimulants on Sunflower Root System Development
During field trials in Paraguay, it was found that the use of the biostimulant at the seed treatment stage significantly intensified the initial growth of the crop. In control plants, root system length ranged from 3 to 5 cm. In the experimental group, where a dosage of 150 mL/bag was used, root length reached 6–10 cm (Figure 3). This indicates a twofold increase in the absorbing surface of the root, enabling the plant to use moisture from deeper soil horizons more effectively under precipitation deficit.

Compatibility and Selectivity in Soybean Crops
During soybean cultivation, the phytotoxicity factor was assessed when biostimulants were used together with seed protectants. The results showed

High selectivity of the preparation with respect to the crop

No inhibitory effect (retardant effect) of the chemical active ingredients (carboxim, thiram, and fipronil) when the amino acid complex was added to the tank mixture

Increased seed germination energy.

Nitrogen Use Efficiency (NUE)

Theoretical analysis and experimental data confirm that the use of biostimulants contributes to an increase in NUE. This is especially important for crops with physiologically low nitrogen use efficiency, such as rice (Table 3). Biostimulants act as catalysts of metabolic processes, reducing the plant's energy costs for nutrient assimilation and thereby helping preserve the genetic productivity potential even under unfavorable external conditions.

Thus, the use of biostimulants with a complex composition (amino acids + phytohormones + microelements) at the early stages of vegetation ensures the formation of a strong "anchor" in the form of a developed root system and minimizes damage caused by oxidative processes.

In summary, the transition to intensive and sustainable farming is impossible without a deep understanding of plant stress physiology. The use of specialized biostimulant lines enriched with amino acids and zinc is a scientifically sound method for managing the production process. These preparations do not replace standard mineral nutrition but serve as catalysts of its efficiency, enabling plants to realize their potential as fully as possible under severe environmental pressure. The formation of a powerful root system, increased resistance to oxidative processes, and seamless integration into modern plant protection schemes make biostimulants a key factor in the profitability of agricultural business. Under conditions of global warming and soil degradation, such biotechnological solutions will determine the competitiveness of farms by ensuring stable production of high yields of quality products regardless of weather variability. The further development of agricultural technologies will inevitably expand the use of amino acid complexes as the most environmentally friendly and effective method for supporting soil and crop health.

CONCLUSION

The use of biostimulants enriched with amino acids and specific microelements, particularly zinc at the early stages, is a necessary element of modern cultivation technology. Biostimulants help mitigate the negative effects of oxidative stress, ensure vigorous initial root system development, and preserve the genetic yield potential under changing climate conditions. The use of biostimulants in modern agriculture is one response to the challenges facing the sector (Calvo et al., 2014; Du Jardin, 2015; Rouphael and Colla, 2020; Shukry et al., 2018).

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