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The effect of 6-benzylaminopurine on productivity of winter cereals under soil salinization conditions

Ivan V. Gorepekin[1] ✉, **Zulfiya S. Sultanova**[2], **Timofey G. Kalnin**[1], **Gennady N. Fedotov**[1], **Sergey A. Shoba**[1], **Shakhnoza P. Sabirova**[2], **Nigora P. Pirnazarova**[2]

[1]Lomonosov Moscow State University, *Moscow, Russian Federation*
[2]Karakalpak Institute of Agriculture and Agrotechnologies, *Nukus*, *Republic of Uzbekistan*
✉ decembrist96@yandex.ru

Abstract. 6-benzylaminopurine is a synthetic analogue of the natural phytohormone of the cytokinin group. A number of studies have shown that its use has a positive effect on plant development in conditions of soil salinization. Meanwhile, the authors have not found any field studies on the effect of 6-benzylaminopurine on the development of winter grain crops in the territory of the Republic of Uzbekistan. The aim of the study was to evaluate the effect of foliar treatment on productivity of winter grain crops with 6-benzylaminopurine under soil salinization conditions. The study was conducted on irrigated areas in the Republic of Uzbekistan (Republic of Karakalpakstan). Based on the results of the 2023–2024 experiment, it was found that when using the agent on the studied crops, spike weight and average grain weight per spike improve. As a result of the field experiment of 2024–2025, it was shown that phytohormone treatment of winter wheat and barley improves overall and productive tillering, which is reflected in increase in yields of the studied crops: 14% for winter wheat and 9% for winter barley.

Key words: phytohormones, leaf treatment, wheat, barley

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Introduction

Irrigated areas of Central Asia are at risk of secondary salinization, and the process of restoring salinized lands is practically non-existent. Analysis of salt content in the Jizzakh irrigation zone for the period from 1995 to 2016 revealed no significant improvements in the studied areas [1]. Average groundwater mineralization in 75.3% of irrigated areas ranged from 1.1 to 5.0 g/L. Under such conditions, maintaining stable yields is achieved primarily through the intensive use of fertilizers. Meanwhile, fertilizers can also be considered a factor contributing to soil salinization [2, 3].

Hydraulic engineering measures aimed at flushing the soil profile with good drainage are an effective [4, 5], but expensive, method for combating soil salinization. Therefore, another approach to increasing crop yields should be considered: increasing the resistance of agricultural plants to the negative effects of salts. According to plant physiologists [6–12], negative impact of salinity on plants is realized through suppression of photosynthetic activity, transpiration, stomatal conductance of plants, as well as changes in morphology, enzyme activity, and the ratio of K^+ and Na^+ ions in plants. Plant phytohormones, which regulate plant adaptation to stress factors, act as mediators of all these processes [13]. The ultimate result of salt stress on plants is a deterioration in both the quantity and quality of the crop yield [8].

Resistance of agricultural plants to the negative effects of salts can be increased in two ways: by breeding salt-tolerant varieties and by exogenous application of additives that enhance plant defense responses.

Selection of salt-tolerant varieties from existing ones [14, 15] and identification of genetic markers responsible for salt tolerance [16–18] are promising areas of research. Thus, one of the ways to implement them is to search for varieties that can avoid the accumulation of Na^+ ions in the above-ground parts of the plant [10]. However, breeding is a lengthy process, and quick results are difficult to expect.

The second approach involves applying additives that mitigate plant responses to salt stress. These additives include phytohormones [19–26], particularly 6-benzylaminopurine — a cytokinin-group hormone [19–21, 27, 28]. Under salt stress, 6-BAP reduces negative effects associated with the absorption of reactive oxygen species [29] and also helps maintain hormonal balance under salt stress [19].

Results from field experiments indicate an ambiguous effect of 6-benzylaminopurine on the development of grain crops under soil salinity. For example, the study [30] showed that foliar application of 6-benzylaminopurine to wheat increased yield only when combined with zinc. In contrast, other studies have shown that foliar treatment of wheat with 6-benzylaminopurine before flowering increased yield by increasing the number of fertile flowers in the basal and central spikelets [31]. Research by Kuznetsova S.A. demonstrated an improvement in the vegetative development of wheat with foliar treatment with 6-benzylaminopurine [20]: by 18–29% at the tillering stage and by 13–15% at the milking stage. However, we found no similar information for the irrigated lands of Uzbekistan, which are characterized by varying degrees of salinity.

Furthermore, for barley, despite the studies on physiological mechanisms of role of phytohormones in salt stress tolerance — summarized, in particular, in the monograph [32] — no results of field studies on the effect of 6-benzylaminopurine on barley development under soil salinity conditions were found.

The aim of the study was to evaluate the effect of foliar treatment with 6-benzylaminopurine on productivity of winter grain crops under soil salinity conditions.

Materials and methods

The studies were conducted on plots of the Grain and Rice Scientific and Production Association in the Nukus District of the Republic of Karakalpakstan, Republic of Uzbekistan, during the growing seasons of 2023–2024 and 2024–2025.

The soil in the experimental area is irrigated meadow alluvial soil. Content: humus — 0.8–1.0%, available nitrogen — 0.28 mg/kg, available P_2O_5 — 27.0 mg/kg, available K_2O — 130 mg/kg. The soil texture class by the hydrometer method is medium loam. The soils in the study area are characterized by chloride-sulfate type of salinization with a total chloride and sulfate ion content of 0.14%, which, according to the soil extract method of V.S. Muratova and V.Y. Margulis corresponds to slightly saline soils [33].

Timing and rates of soil leaching for winter crops, depending on irrigation water supply and field salinity level, begin in August and end in early September. Water consumption for leaching slightly saline soil plots is 2000–2500 m^3/ha. During soil ripening, phosphorus-potassium fertilizers RMU-0.5 were applied using a TTZ-80-11 tractor. The fertilizer rate was according to the regional standard of $N_{150}P_{60}K_{40}$; the entire phosphorus-potassium fertilizer rate was applied under plowing, and 1/3 of the nitrogen fertilizer was applied during pre-sowing cultivation. Plowing was carried out using a Magnum tractor equipped with a PD-4–35 plow. Next, field edges were leveled using an RVN-3/8.5 or VP-8A machine and a T-4A-01 tractor. Plot compaction and leveling were performed with a TTZ-60.10 tractor. Sowing was carried out using a Brazilian seeder with a 2-meter working width and 12–13 cm row spacing. Before sowing, the seeds were treated with "Skarlik" at a rate of 350 ml of solution in 150 liters of water per 1 ton of seeds. Superphosphate was applied along with the sowing at a rate of 15 kg of active ingredient per hectare.

Early spring nitrogen fertilization was applied manually by evenly spreading ammonium nitrate. During the tillering stage and the beginning of grain formation, plantswas treated with an aqueous urea solution at a rate of 30 kg/ha of active ingredient in 400 liters of water in the morning or evening using motorized hand sprayers. Seeds of zoned winter wheat and winter barley varieties were sown on September 30 at a depth of 4–5 cm, with a seeding rate of 5.0 million viable seeds per hectare.

In the middle of the tillering stage, after water-supply irrigation, treatments against dicotyledonous weeds were applied using Granstar Super, Gold Star, and Entostar Plus at recommended rates, depending on weed development and composition.

In 2023–2024, a preliminary experiment was conducted to evaluate the effect of foliar treatment with 6-benzylaminopurine on the growth and development of winter crops: barley cv. 'Yantarny 3' and wheat cv. 'Karakalpakstan 100'.

Six plots of 1 m² each were established for the experiments.

The experiments were conducted on 25 m² plots in four replicates each. Plots were arranged in a checkerboard pattern, allowing alternation of control and experimental variants.

During the 2023–2024 growing season, the foliar treatment included 6-benzylaminopurine at a concentration of 0.01 g/L and polyethylene glycol (molecular weight 300 Da) at a concentration of 0.3 g/L. To increase the solubility of 6-benzylaminopurine, the working solution was prepared in 0.05 N potassium hydroxide. A backpack sprayer was used to treat plants, beginning at the tillering stage, with three sprayings performed at 14-day intervals.

Measured parameters included: spike weight per m², number of seeds per spike, 1000-seed weight, average grain weight per spike, plant height, and spike length.

During the 2024–2025 field season, experimental conditions were identical to those described previously in terms of irrigation rates, fertilizer application, and seed preparation for sowing.

Treatment of winter crops with 6-benzylaminopurine was performed twice. The first treatment was applied at mid-booting. Control plots were treated with water. The second treatment was applied at the heading stage using a hand sprayer at a rate of 50 liters per 100 m².

Harvesting was carried out at the stage of full maturity when the external signs of plant ripening appeared and grains acquired firmness characteristic of fully ripened grain. Wheat was harvested by direct combine harvesting. Common winter wheat and winter barley grains were manually cleaned of impurities after harvesting.

Results and discussion

During the 2023–2024 growing season, foliar treatment of winter barley with 6-benzylaminopurine increased: grain weight per square meter — from 414.5 to 481.5 g m^2, or by 16%; number of grains per spike — from 28 to 36, or by 29%; average grain weight per spike — from 1.2 to 1.6 g, or by 33% (Table 1).

Table 1

Productivity indicators of winter grain crops after foliar treatment with 6-benzylaminopurine-based composition

Crop, variety	Treatment	Plants height, cm	Grain weight, g/m^2	Spike length, cm	Grains per spike	Grain weight per spike, g	1000-seed weight, g
Winter barley, Yantarny 3	No	86.7	414.5	8.3	28.0	1.2	38.1
	Yes	88	481.2	7.4	36.7	1.6	40.2
Winter wheat, Karakalpakstan 100	No	86.4	673	10.4	40.7	2.1	52.0
	Yes	99.7	817.5	10.0	41.9	2.3	55.8

Source: experimental design by I.V. Gorepekin, Z.S. Sultanova, S.A. Shoba, G.N. Fedotov; field experiments and data processing by T.G. Kalnin, S.P. Sabirova, N.P. Pirnazarova.

Foliar treatment with 6-benzylaminopurine also improved winter wheat parameters: grain weight per square meter increased from 673 to 817.5 g (21%), and average weight per spike increased from 2.1 to 2.3 g (10%).

Thus, the positive results of the first phase of the study allowed continued testing of 6-benzylaminopurine effectiveness in the 2024–2025 field season. To evaluate the effect of the composition with fewer treatments, the number of sprayings was reduced from 3 to 2.

Analysis of 2024–2025 experimental data showed that reducing the number of treatments did not reduce the composition's effectiveness. We will examine the results in more detail (Table 2).

The number of plants per m^2 before harvest in wheat cv. 'Utkir' increased from 306.0 in the control to 318.0 after treatment. Barley (cv 'Yantarny 3') also showed positive dynamics: plant number per m^2 increased from 320.0 to 337.0. This indicates that the treatment contributed to improved plant survival prior to harvest.

For both crops, treatment resulted in a slight decrease in plant height (wheat from 99.7 to 92.0 cm; barley from 87.8 to 84.1 cm). This may indicate some inhibition of stem height growth, which sometimes correlates with lodging resistance.

Total tillering in wheat increased from 4.0 to 4.5, and in barley — from 3.0 to 3.6, indicating that the treatment stimulated tillering. Moreover, the number of stems producing yield increased proportionally to total tillering rate: from 4.0 to 4.3 for wheat, and from 2.9 to 3.6 for barley. Based on the data presented, it can be concluded that the product not only increases tillering rate but also improves the productivity of these stems (i.e., they do not remain sterile).

Table 2

Plant productivity indicators after treatment with 6-benzylaminopurine in the full ripeness stage (2025)

Crop, variety	Number of plants		Height of plants, cm	Average total tillering	Number of productive stems per plant	Grain weight per 1 m^2, g
	At the beginning of the growing season in spring, plants/ m^2	Before harvesting plants/m^2				
Winter wheat cv. 'Utkir', no treatment	327	306.0	99.7	4.0	4.0	550.8
Winter wheat cv.'Utkir', with treatment		318.0	92.0	4.5	4.3	628.8
Winter barley cv. 'Yantarny 3', no treatment	342	320.0	87.8	3.0	2.9	477.2
Winter barley cv. 'Yantarny 3', with treatment		337.0	84.1	3.6	3.6	521.6

Source: experimental design by I.V. Gorepekin, Z.S. Sultanova, S.A. Shoba, G.N. Fedotov; field experiments and data processing by T.G. Kalnin, S.P. Sabirova, N.P. Pirnazarova.

Grain weight per 1 m² — a key productivity indicator — increased from 550.8 to 628.8 g/m² for 'Utkir' wheat, and from 477.2 to 521.6 g/m² for 'Yantarny 3' barley. In fact, the results of the experiments indicate that treatment with 6-benzylaminopurine (6-BAP) at the stage of full maturity led to increase in yield: in winter wheat the increase was 78 g/m² (about 14.2%), and in winter barley — 44.4 g/m² (about 9.3%).

Supplementing the results of Table 2 with yield structure indicators (Table 3), the following conclusions can be drawn.

For 'Utkir' winter wheat, 6-BAP treatment had a comprehensive positive effect on all components of spike productivity. Thus, the number of grains per spike increased from 41.0 to 43.0. The average grain weight per spike demonstrated a significant increase, from 2.4 to 3.2 g. This explains the resulting yield increase (see Table 2). Furthermore, 1000-seed weight increased from 48.7 to 50.6 g, indicating that the treatment contributed to grain filling, making it fuller and heavier. Spike length also increased from 7.6 to 8.8 cm, correlating with the increased number of grains per spike.

For 'Yantarny 3' winter barley, the response to treatment was more specific. The number of grains per spike increased from 34.0 to 37.0 (a trend similar to wheat), as did the average grain weight, from 3.3 to 3.5 g, while 1000-seed weight decreased from 41.8 to 40.3 g.

Comparing the data in Tables 2 and 3 allows explaining the nature of the yield increase.

Table 3

The effect of 6-benzylaminopurine treatment on yield structure indicators of winter crops (2025)

Crop, variety	Treatment	Grains per spike	Average grain weight per spike, g	1000-seed weight, g	Spike length, cm
Winter wheat cv. 'Utkir'	Yes	43	3.2	50.6	8.8
	No	41.0	2.4	48.7	7.6
Winter barley cv. 'Yantarnyy 3'	Yes	37.0	3.5	40.3	11.8
	No	34.0	3.3	41.8	11.0

Source: experimental design by I.V. Gorepekin, Z.S. Sultanova, S.A. Shoba, G.N. Fedotov; field experiments and data processing by T.G. Kalnin, S.P. Sabirova, N.P. Pirnazarova.

For Utkir wheat, the yield increase (+78 g/m²) was driven by two factors: an increase in productive stems (from 4.0 to 4.3 stems/m² (see Table 2)) and increased productivity per spike (grain weight per spike increased by 33%: from 2.4 to 3.2 g (see Table 3)). This was the most significant effect. The increase in 1000-seed weight confirms that the grains became larger.

For Yantarny 3 barley, the yield increase (+44.4 g/m²) was driven by a different mechanism: an increase in productive stems played a decisive role (from 2.9 to 3.6 stems/m², i.e., the increase in productive stems was approximately 24% (see Table 2)). Spike productivity increased slightly (from 3.3 to 3.5 g). Moreover, 1000-seed weight even decreased slightly, suggesting a possible "competition effect": the plant formed more spikes (due to tillering), but the grains in them were slightly smaller than in the control. However, the total biological weight of the grain was still higher.

Therefore, the use of 6-benzylaminopurine may represent a significant potential for increasing crop yields under the irrigated soil conditions of the Republic of Karakalpakstan, characterized by varying degrees of salinity.

Conclusion

The positive effect of foliar treatment of winter wheat with 6-benzylaminopurine on yield has been confirmed. In field experiments, yields from sampling plots increased by 14%.

The positive effect of foliar treatment of winter barley with 6-benzylaminopurine on yield was demonstrated for the first time. In field experiments, yields from sample plots increased by 9%.

6-Benzylaminopurine treatment proved effective for both crops, but the mechanism of action differed between the varieties. For 'Utkir' wheat, the agent acts as a powerful stimulator of spike productivity (increasing grain number, 1000-seed weight, and spike length), resulting in maximum yield gains. For 'Yantarny 3' barley, the treatment worked primarily as a stimulator of productive tillering (increased the number of yield-bearing stems), while spike parameters changed less significantly, and grain fullness (1000-seed weight) even decreased slightly.

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About the authors:

Gorepekin Ivan Vladimirovich — PhD (Biology), Researcher, Department of Soil Geography, Faculty of Soil Science; Researcher, Eurasian Center for Food Security, Lomonosov Moscow State University, 1/12 Leninskie Gory, Moscow, 119991, Russian Federation; e-mail: decembrist96@yandex.ru
ORCID: 0009-0000-1016-1906 SPIN-code: 1761-6603

Sultanova Zulfiya Sultanovna — Doctor of Agricultural Sciences, Professor, Department of Technology of Production, Storage, and Processing of Agricultural and Medicinal Products, Karakalpak Institute of Agriculture and Agrotechnology, 140/1 Darbent st., Nukus, 230100, Republic of Uzbekistan; e-mail: z_sultanova@yahoo.com
ORCID: 0000-0001-9273-026X

Kalnin Timofey Gennadievich — Candidate of Biological Sciences, Junior Researcher, Department of Soil Physics, Faculty of Soil Science; Researcher, Eurasian Center for Food Security, Lomonosov Moscow State University, 1/12 Leninskie Gory, Moscow, 119991, Russian Federation; e-mail: kalnintg@my.msu.ru
ORCID: 0000-0001-5063-4624 SPIN: 6323-4325
Fedotov Gennady Nikolaevich — Doctor of Biological Sciences, Leading Researcher, Department of Soil Geography, Faculty of Soil Science, Lomonosov Moscow State University, 1/12 Leninskie Gory, Moscow, 119991, Russian Federation; e-mail: gennadiy.fedotov@gmail.com
ORCID: 0000-0001-8910-3433 SPIN-code: 1451-7807
Shoba Sergey Alekseevich — Doctor of Biological Sciences, Corresponding Member of the Russian Academy of Sciences, Head of the Soil Geography Department, Faculty of Soil Science, Director of the Eurasian Center for Food Security, Lomonosov Moscow State University, 1/12 Leninskie Gory, Moscow, 119991, Russian Federation; e-mail: office@ecfs.msu.ru
ORCID: 0000-0001-9889-5831 SPIN-code: 8978-1851
Sabirova Shakhnoza Pamirovna — doctoral student, Department of Plant Growing, Forestry and Landscape Design, Karakalpak Institute of Agriculture and Agrotechnologies, 140/1 Darbent st., Nukus, 230100, Republic of Uzbekistan; e-mail: sahnozasabirova6@gmail.com
ORCID: 0009-0004-7163-7153
Pirnazarova Nigora Pulatovna — doctoral student, Department of Plant Growing, Forestry and Landscape Design, Karakalpak Institute of Agriculture and Agrotechnologies, 140/1 Darbent st., Nukus, 230100, Republic of Uzbekistan; e-mail: pirnazarova@tdaunukus.uz
ORCID: 0009-0006-4686-9889

Влияние 6-бензиламинопурина на продуктивность озимых зерновых в условиях почвенного засоления

И.В. Горепекин[1] ✉, З.С. Султанова[2], Т.Г. Калнин[1], Г.Н. Федотов[1], С.А. Шоба[1], Ш.П. Сабирова[2], Н.П. Пирназарова[2]

[1]Московский государственный университет имени М.В. Ломоносова, *г. Москва, Российская Федерация*
[2]Каракалпакский институт сельского хозяйства и агротехнологий, *г. Нукус, Республика Узбекистан*
✉ decembrist96@yandex.ru

Аннотация. 6-бензиламинопурин является синтетическим аналогом природного фитогормона группы цитокининов. В ряде исследований показано, что его использование положительно влияет на развитие растений в условиях почвенного засоления. Между тем полевых исследований по влиянию 6-бензиламинопурина на развитие озимых зерновых культур для территории Республики Узбекистан не обнаружено. Цель исследования — оценка влияния фолиарной обработки на показатели продуктивности озимых зерновых культур 6-бензиламинопурином в условиях почвенного засоления. Исследование проводилось на орошаемых участках в Республике Узбекистан (Республика Каракалпакстан). По результатам опыта 2023–2024 г. установлено, что при использовании состава на изученных культурах увеличиваются масса зерна с квадратного метра и средняя масса зерна с колоса. Полевой опыт 2024–2025 г. показал, что обработка фитогормонами озимых пшеницы и ячменя улучшает общую и продуктивную кустистость и это сказалось на повышении урожайности изученных культур: 14 % для озимой пшеницы и 9 % для озимого ячменя.

Ключевые слова: фитогормоны, листовая обработка, пшеница, ячмень

Вклад авторов: Горепекин И.В. — дизайн исследования, обработка материалов, написание текста статьи; Султанова З.С. — сбор и обработка материалов, анализ результатов, написание текста; Калнин Т.Г. — сбор материалов, анализ результатов; Федотов Г.Н. — дизайн исследования, обработка материалов, редактирование статьи; Шоба С.А. — концепция статьи, редактирование статьи; Сабирова Ш.П. — сбор материалов, анализ результатов; Пирназарова Н.П. — сбор материалов, анализ результатов. Все авторы одобрили окончательную версию статьи.

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