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Influence of growth stimulants on photosynthetic activity of spring barley (*Hordeum vulgare* L.) crops

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Abstract

Well-timed and reliable forecasting of grain yields is a key condition for effective crop management. In this research, we evaluated the effect of natural growth stimulants Epin-extra, Zircon and Bischofite on the duration of the main vegetation phases of spring barley varieties ‘Helios’, ‘Parnas’ and ‘Vakula’ of Ukrainian selection. Field trials were carried out during the period of three years (2017–2019). Their aim was to determine the most effective stimulant for growing different spring barley varieties under the conditions of unstable moisture. It has been established that pre-sowing treatment of seed and spraying of crops in the tillering phase with these stimulants help to reduce the vegetation phases and enhance the photosynthetic activity of spring barley crops. Application of 1% Bischofite aqueous solution provided the maximum effect. The treatment of crops with this preparation increased the area of assimilation leaf surface of plants by 11.1%, photosynthetic potential by 5.7% and the photosynthesis productivity by 10%.

Keywords: growth stimulants, leaf surface area, photosynthetic potential, photosynthesis productivity

Introduction

Modern technologies of growing spring barley (*Hordeumvulgare L.*) highlight the great importance of seed treatment and plants with different methods especially with the use of environmentally friendly preparations in order to increase yield. Application of numerous plant growth stimulants is one of the most promising areas of the latest technology in crop production. The favourable effect of growth stimulants has been found in the cultivation of many crops [1, 2]. Their effect increases biomass and productivity of agricultural crops [3, 4], they can perform a protective function against plant diseases and pests [5, 6]. Growth stimulants, due to changes in hormonal status and activation of the plant antioxidant systems, are able to facilitate the plants response to biotic [7, 8] and water stress which not only affects seed germination, but also further increases the average ripening period of crops [9, 10]. They also reduce the impact of negative weather factors; provide resistance of plants to drought or excess moisture under high or low environment temperatures. Climatic factors adversely affecting growth and development of crops, include late spring frosts, heavy rainfall, snowfall and winds [11, 12]. However, according to the numerous studies, plants treated with growth stimulators suffer less from weather instability [13, 14]. Growth stimulants compensate for the deficiency of nutrients [15], which activate the fermentation activity of all plant cells and the formation of stimulating compounds by the plant itself. An increased permeability of the root cell membrane and an improved penetration of mineral nutrients of the soil solution to plants are the results. In addition, due to the application of growth stimulants, the absorption of oxygen by plants is accelerated, which, in turn, enhances photosynthesis and photosynthetic activity of grain crops agrocenoses and results in yields increase [16]. The effect of the growth stimulants use on grain crops is connected with the plants ability to increase the accumulation of macro- and microelements [17, 18], with growth of the assimilation surface area [19, 20], an increase in the chlorophyll content [21, 22] and, as a consequence, the activation of photosynthetic processes [23, 24] and the growth of crop productivity [25, 26, 27]. Due to this, growth stimulants are able to improve grain quality and yield [28, 29]. In addition, plant growth stimulants accelerate or slow down plant maturation, shorten the vegatation season, optimize plant growth, and help to improve crops affected by adverse environmental conditions [30]. The application of growth stimulants can reduce the amount of used mineral fertilizers and pesticides, which affect product safety and have negative impact on the natural environment. Known, the plants adaptation to the environment, including unfavorable environmental conditions, is accompanied by changes in metabolism with the participation of the NADPH enzyme [31]. Growth stimulants are mainly applied as foliar feeding and can be applied several times during the growing season [5, 32]. In many ways, the effect of these preparations also depends on the period of their application.

Today, a large number of different growth stimulants are known, which are widely used in agriculture, but their role in the yield formation still requires detailed research. The study of the individual phases of the growing season, application period, forms and rates of application is necessary in order to use growth stimulants reasonably. Therefore, the aim of this research is to assess the effect of the use of growth stimulants on the duration of phenological phases, as well as the photosynthetic activity of spring barley crops.

Materials and Methods

The field experiment was conducted during the period of 2017–2019 in the experimental field of the Poltava State Agrarian Academy (Ukraine), and the spring barley varieties ‘Helios’, ‘Vakula’ and ‘Parnas’ were used as testing crops. All varieties are of Ukrainian selection recommended to be cultivated in the Forest-Steppe zone of Ukraine. The Plant Production Institute nd. a. V.Ya. Yuryev of National Academy of Agrarian Sciences of Ukraine is the author of barley varieties. The soil of the experimental plots is sod-podzolic medium-loamy with pH 6.0 and content of P_2O_5 205 mg kg^{-1}, K_2O 117 mg kg^{-1} and slightly hydrogenated nitrogen 81 mg kg^{-1}. The arable horizon 0–20 cm contains up to 5% humus, 0.15% nitrogen and 0.10% phosphorus. The experiment was conducted in the form of divided plots, placed in a randomized complete project of the block with three repetitions. The area of sown plots is 100 m^2, and the accounting area is 50 m^2. Sunflower was a forecrop for barley. After harvesting sunflower, the stubble was broken with a disc harrow to a depth of 22–25 cm in order to bring weeds under control and reduce moisture evaporation. Spring tillage involved harrowing and pre-sowing tillage, during which the mineral fertilizer Nitroamophos ($N_{30}P_{30}K_{30}$) was applied at a rate of 150 kg per hectare. The main technique of soil preparation was deep tillage up to 20–22 cm. After plowing, sowing was carried out with obligatory covering the seeds with a moist layer of soil to a depth of 3–4 cm. Barley was sown in the first decade of May with John Deere seeder 730 with a row-spacing of 15 cm. The sowing rate was 4.5 million viable seeds per hectare. Before sowing, barley seed was not treated with fungicides, only with natural growth regulators: Epin-extra (epibrassinolide is an active substance, 0.025 g l^{-1}), Zircon (0.1 g l^{-1} mixture of chlorogenic and chicory acids) and Bischofite. Bischofite is a natural chlormagnesium complex containing potassium, calcium, sodium, copper, iron, silicon, titanium, molybdenum, lithium, boron, bromine, iodine, etc. The active substance in Bischofite is magnesium chloride $MgCl_2 \cdot 6H_2O$ (99 g l^{-1}). Inoculation with Epin-extra and Zircon was performed at a rate of 20 ml per 200 kg of seed, and with 1% Bischofite solution at a rate of 2 liters per 200 kg of seed. In addition, spring barley was sprayed in the tillering phase with STS12 Hagie sprayer with growth stimulants Epin-extra and Zircon at a rate of 50 g of the preparation per 300 liters of water per hectare, Bischofite solution was applied at a rate of 2 liters per hectare.

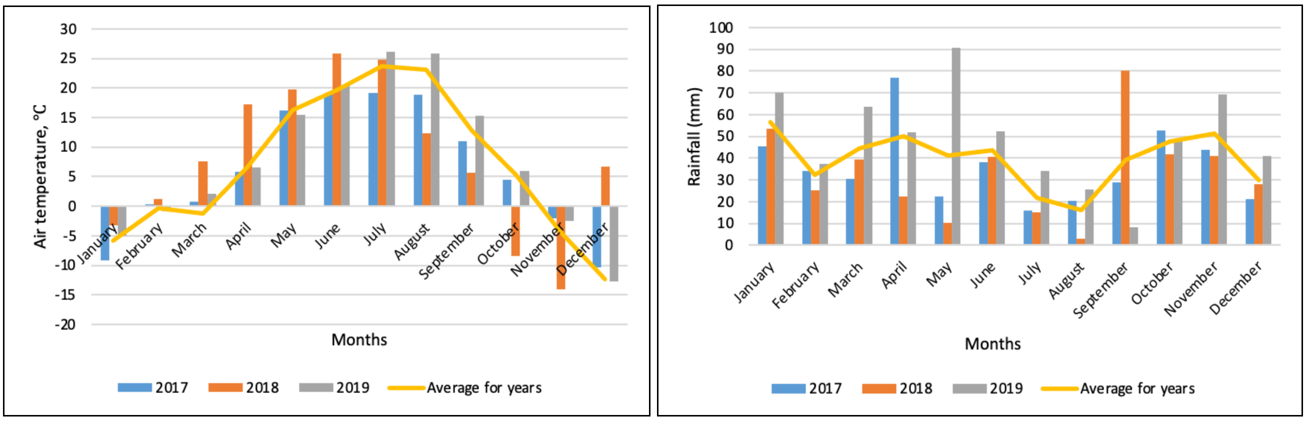

Fig 1: Rainfall and temperature regime of 2017–2019 (Poltava, Ukraine)

Vegetation periods in 2017–2019 varied according to precipitation intensity and distribution, as well as temperature compared to the average duration, but in general they were favorable for growing spring barley. The first season (2017) was quite warm and humid. The average monthly air temperature was at a level of the long-term average temperature (6.6 °C). The highest precipitation of 76.8 mm was in April, which is more than twice the long-term average. In the second season (2018) at the time of sowing, unfavorable soil moisture conditions prevailed (22.3 mm), but the air temperature was 7.6 °C with an average long-term temperature of 6.6 °C. The last year of the research (2019) was characterized by adequate precipitation. Compared to the average annual index, it was 17.7 mm higher. On the other hand, the average temperature for the whole growing season was 1.2 °C higher (Fig. 1).

The effectiveness of growth stimulants was analyzed by the following indicators: leaf surface area, photosynthetic potential of crops, photosynthesis productivity of crops.

Results and Discussion

Rapid change of weather conditions and frequent repetition of spring-summer droughts in the forest-steppe of Ukraine require the development of effective technological measures to mitigate the negative impact of adverse climatic conditions in order to improve the spring barley grain yields. That is why agronomic measures are very important for reduction of the main phases of the growing season. In our research, the study of the effect of growth stimulants Epin-extra, Zircon and Bischofite on the main vegetation phases of of spring barley provided for pre-sowing seed treatment and spraying of the leaf-stem mass in the tillering phase. The results are shown in Figure 2–4 for barley varieties ‘Helios’, ‘Parnas’ and ‘Vakula’, respectively.

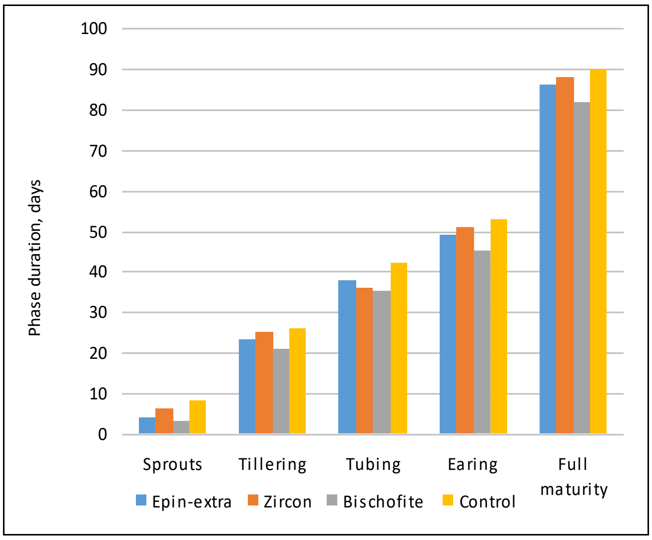

Fig 2: Influence of growth stimulants on the onset of phenological phases in spring barley of the ‘Helios’ variety

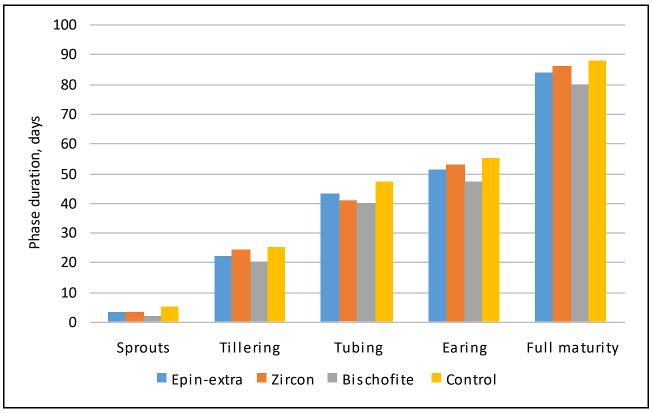

Fig 3: Influence of growth stimulants on the onset of phenological phases in spring barley of the ‘Parnas’ variety

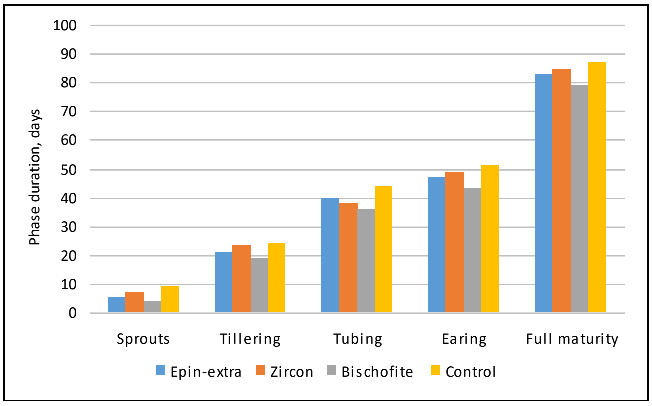

Fig 4: Influence of growth stimulants on the onset of phenological phases in spring barley of the ‘Vakula’ variety

An important stage in the cultivation of spring barley under the conditions of the Forest-Steppe zone of Ukraine is to obtain a high field germination of the crop, since the further care of the crops and future yield depend on it. Therefore, favourable climatic conditions and the application of growth stimulants are of great importance.

Due to sufficient soil moisture and optimal climatic conditions (18 °C), the germination phase (BBCH 09) of barley variety ‘Helios’ started in 3 days after sowing seed treated with Epin-extra and Zircon stimulants. Treatment of seed with Bischofite solution contributed to this variety germination 3 days earlier compared to the control (after 5 days) (Fig. 2). Seedlings of barley variety ‘Parnas’ on the control plot germinated in 8 days after sowing. On the plots, where seed was treated with Bischofite solution, seedlings appeared in 3 days, and stimulants Epine-extra and Zircon in 4 and 6 days, respectively (Fig. 3).

Barley variety ‘Vakula’ had the longest phase of germination. So, on the control plot, seedlings appeared in 9 days, on the plot where seed was treated with Bischofite solution in 4 days after sowing, and seed treated with growth stimulants Epin-extra and Zircon provided seedlings 2 and 3 days later than seed treated with Bischofite (Fig. 4).

An ability to tiller is a distinctive biological trait of barley and other grain crops. The ability of plants to form tillering shoots enables to use vegetation factors in formation of the maximum grain yields more effectively. The temperature regime significantly affects this phase of development. The most optimal temperature for barley tillering is 12-15 °C. In our experiment, the temperature of the tillering phase beginning (BBCH 21**)** was 15 °C. Therefore, the favorable temperature regime and pre-sowing seed treatment accelerated the beginning of the tillering phase of all studied varieties. It has been found that as a result of seed treatment with Epin-extra and Zircon, the beginning of the tillering phase was decreased in comparison to the control by 3 and 1 day, respectively. The plots with treated seed with Bischofite provided the best result. The beginning of the tillering phase was reduced by 5 days compared to the control (24 days).

Re-treatment of barley seed in the tillering phase by spraying crops with growth stimulants Epin-extra, Zircon and Bischofite led to the beginning of the phase “stem elongation” (BBCH 30) 4, 6 and 7-8 days earlier in comparison to the control plot, respectively. On the control plot, the beginning of the “stem elongation” phase began only on day 41.

The treatment of barley crops with these stimulants greatly affected the beginning of phases “earing” (BBCH 51) and “full maturity” (BBCH 73). Thus, on the plots treated with Bischofite solution, the beginning of these phases was observed 8 days earlier than on the control, and treated with Epine-extra and Zircon solutions 4 and 2 days early, respectively.

In general, the application of stimulant Epin-extra reduced the growing season by 4 days, the application of Zircon by 2 days, and Bischofite by 8 days compared to the control. But there was a slight difference between varieties in the growing season duration.

Thus, although the dates of phenological phases and duration of the growing season largely depend on weather and climatic conditions and genetic characteristics of varieties, they can be regulated by appying these growth stimulants.

Growth stimulants are also one of the factors that have a positive effect on the formation of the leaf apparatus of plants. Their effect results in intensive formation of leaf surface, activation of the main processes of photosynthesis, improvement of the conditions of plant growth and development and intensified resistance to phytopathogens [16]. In order to assess the effectiveness of growth stimulants impact on the photosynthetic apparatus of barley plants, we used the following indicators: leaf surface area, photosynthetic potential of crops, productivity of crops photosynthesis, as the area and duration of assimilation surface of leaves are crucial for yield formation. The results are given in Table 1.

Table 1: Main indicators of photosynthetic activity of the ‘Helios’, ‘Vakula’ and ‘Parnas’ barley varieties

Stimulator	Leaf surface area, thousand m^2 ha^{-1}			Photosynthetic potential of crops, million m^2 * day ha^{-1}			Crop photosynthesis productivity, g m^{-2} * day		
	‘Helios’	‘Vakula’	‘Parnas’	‘Helios’	‘Vakula’	‘Parnas’	‘Helios’	‘Vakula’	‘Parnas’
Control	35.1	36.5	36.2	1.62	1.86	1.56	2.27	2.59	2.74
Epin-extra	36.8	36.7	37.1	1.65	1.95	1.59	2.32	2.64	2.80
Zircon	35.4	36.9	37.5	1.71	1.77	1.72	2.29	2.66	2.82
Bischofite	39.4	39.1	38.3	1.70	1.74	1.69	2.33	2.75	2.86
LSD_{05}	0.8	0.8	0.8	0.08	0.08	0.13	0.07	0.08	0.07

Barley varieties ‘Helios’, ‘Parnas’ and ‘Vakula’ had the maximum area of assimilation leaf surface in the earing phase, so the observations of assimilation surface of the leaves are presented at this phase.

As can be seen from Table 1, the integrated use of stimulants Epin-extra, Zircon and Bischofite (pre-sowing seed treatment and spraying of crops) increased the plant leaf surface area of variety ‘Helios’ by 1.7; 0.3 and 4.3 thousand m^2 ha^{-1}, which is 4.6; 0.8 and 10.9% more compared to the control. Variety of spring barley ‘Vakula’ showed slightly different results. Pre-sowing seed treatment and spraying of crops in the tillering phase increased leaf surface area of plants compared to the control by 0.2; 0.4 and 2.6 thousand m^2 ha^{-1} or 0.5; 1.0 and 6.6%. Plants of barley variety ‘Parnas’ provided similar results. Double application of these stimulants and Bischofite also increased leaf surface area compared to the control by 0.9; 1.3 and 2.1 thousand m^2 ha^{-1} or 2.4; 3.4 and 5.4%. It should be noted that, assimilation surface of plants works the most intensively under the influence of Bischofite solution. The application of Bischofite resulted in maximum increase in leaf surface area of plants of variety ‘Helios’ by 10.9%, variety ‘Vakula’ by 6.6%, and variety ‘Parnas’ by 5.4%.

Since growth stimulants also affect the photosynthetic potential of crops, which characterizes leaf surface of spring barley plants during the growing season, we have analyzed the effect of Epin-extra, Zircon and Bischofite on all studied varieties. It has been established that the photosynthetic potential of spring barley crops changed on average over three years of the research similarly to the dynamics of leaf surface formation. So, application of the solutions Epin-extra, Zircon and Bischofite while growing variety ‘Helios’ increased indicators of photosynthetic potential by 0.03; 0.09 and 0.08 million м^2 days ha^{-1} or by 1.8; 5.2 and 4.7 % in comparison to the control one.

Indicators of the photosynthetic potential of ‘Vakula’ plants also exceeded the control by 0.09 million m^2 days ha^{-1} or 4.6% when treated with the stimulant Epin-extra. However, treatment with Zircon and Bischofite proved to be less effective and, as a result, reduced the photosynthetic potential in comparison with control by 0.09 and 0.12 million m^2 days ha^{-1} or by 5.0 and 6.8%, respectively.

The variety ‘Parnas’ had the growth of the photosynthetic potential of crops with the use of stimulants Epin-extra, Zircon and Bischofite in comparison with the control by 0.03; 0.16 and 0.13 million m^2 day ha^{-1} or 1.8; 9.3 and 7.6%, respectively.

However, the photosynthetic activity of barley plants depends not only on the size of leaf surface, but also on its efficiency, that is the productivity of photosynthesis. A comparative study of photosynthesis productivity of spring barley crops proved that intensity of dry matter accumulation per unit of leaf surface is significantly changing due to the application of growth stimulants Epin-extra, Zircon and Bischofite. Thus, the indicator of the photosynthesis productivity of barley plants of variety ‘Helios’ with the use of Epin-extra and Bischofite was increased in comparison with the control by 2.1 and 2.5%, respectively. A slight increase in this indicator (0.8%) was observed with the use of Zircon.

The indicators of photosynthesis productivity of the ‘Vakula’ and ‘Parnas’ plants varieties, which were treated with Bischofite solution are substantially different. The increase in these indicators is 5.8% of the ‘Vakula’ variety and 4.1% of the ‘Parnas’ variety. Statistical processing of the obtained results shows that the photosynthesis productivity of barley crops is mostly affected by such factors as the conditions of the research years, the treatment option, as well as the interaction of variety and year, variety and treatment option. The calculation data are presented in Table 2. As can be seen from the data, the conditions of the year and the treatment with Bischofite solution, which involved pre-sowing seed treatment and treatment of crops in the tillering phase had the highest impact.

Table 2: Result of the variance analysis to determine the photosynthesis productivity

Effect	Univariate Tests of Significance for photosynthesis productivity, %				
	SS	Degree of freedom	MS	*F*	*p*
Intercept	297064.9	1	297064.9	16115.0	<0.001
Year	356.9	2	178.4	9.68	<0.001
Cultivar*	2.10	2	1.05	0.06	0.94
Treatment variant*	513.72	3	171.24	9.29	<0.001
Cultivar* year	231.85	4	57.96	3.14	0.02
Cultivar*treatment	338.94	6	56.49	3.06	0.01
Year*treatment	182.39	6	30.40	1.65	0.15
Error	884.83	48	18.43	–	–

Note: The table shows the main results of the analysis: Sum-of-Squares (SS), Mean Squares (MS), Degree of freedom, value of F criterion (F), significance levels (p).

The value of *F* criterion in calculating of the net photosynthesis productivity for the year factor and for the treatment variant factor was 9.68 and 9.29, respectively that is the value of net photosynthesis productivity depended on these characteristics almost equally. The interaction of Cultivar*year and Cultivar*treatment factors at the effect on the net photosynthesis productivity was $F = 3.14$ at $p<0.02$ and 3.06 at $p<0.01$.

Conclusions

Pre-sowing seed treatment and spraying of spring barley crops in the tillering phase with growth stimulants Epin-extra and Zircon at a rate of 50 g ha^{-1} and 1% Bischofite solution at a rate of 2 l ha^{-1} accelerated the beginning of phenological phases and, in general, reduced the duration of vegetation period compared to control. The application of these preparations at the tillering stage increased leaf surface area of plants, which resulted in growth of the photosynthetic potential of barley crops and photosynthesis productivity. Application of bischofite solution provided the greatest effect.

Conflict of interest statement

We declare that we have no conflict of interest

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