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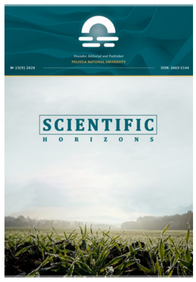

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Lipoperoxidation in Grain Sorghum under the Influence of Herbicides, Phytohormones, and Biopreparation

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Abstract. The use of herbicides for sowing grain cultures, including grain sorghum, is an integral condition for high yield indicators. However, upon penetrating into plant organisms, herbicides can intensify synthesis of the reactive oxygen species, which leads to the aggravation of lipid peroxidation and activates antioxidant systems, namely superoxide dismutase enzyme. It is known that phytohormones and microbial preparations, if included in the cultivation technology, can improve plants' ability to resist oxidative stress caused by xenobiotics. However, the integrative influence of herbicides, phytohormones, and microbial preparations on activity of superoxide dismutase enzyme as well as on lipid peroxidation intensity in plants of grain sorghum is understudied, which preconditioned the purpose of this study. The objects of this study were as follows: grain sorghum (*Sorghum bicolour* (L.) Moench) of the Milo W hybrid, herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal. The study was conducted following the requirements of vegetation method. The activity of lipid peroxidation was investigated according to the number of malondialdehyde formed in the plant tissues. The activity of superoxide dismutase enzyme (EC 1.15.1.1) was investigated according to its ability to compete with nitro blue tetrazolium for superoxide anions resulting from interaction between the reduced form of nicotinamide adenine dinucleotide phosphate and phenazine methosulfate. The study revealed that under the effect of the herbicide Cytadel 25 OD, indicators of the lipid peroxidation activity in plants averaged 26.2-93.2% higher than in control sample, depending on the herbicide rate and the day after application. Activity of superoxide dismutase in these conditions exceeded that in the control sample by 18.2-96.8% on average. However, provided the joint use of herbicides, phytohormones, and biopreparation, the plants demonstrated a decrease of the lipid peroxidation activity. It lowered by 14.5-19.1% against the background of superoxide dismutase increase by 22.0-38.7% relatively to the variants where only herbicide was used. Results of the experiment attest the positive influence of the phytohormone and biopreparation on the grain sorghum's resistance to the oxidative stress caused by herbicides. The observed data can become a cornerstone for the further development of biologised cultivation technologies of this culture

Keywords: superoxide dismutase, lipid peroxidation, antioxidant defence, biologisation, oxidative stress

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INTRODUCTION

In present-day agriculture, the cultivation of agricultural crops, including grain sorghum, is unimaginable without use of numerous preparations, among which, herbicides are the most common. However, it is known that active components of herbicides can substantially affect the physiological processes not only in weeds, but also in crop plants. Upon entering the endogenous system of plants, they interfere with physiological processes, causing accumulation of reactive oxygen species (ROS) in their tissues. It is proved that superoxide radical, one of the typical ROS representatives, can provoke lipid peroxidation (LPO) through numerous chemical reactions [1; 2]. As a result, polyunsaturated fatty acids break up while reactive aldehydes develop, disrupting the DNA and amino acids' structure in cells [3].

Scientists consider the functioning of antioxidant systems among the mechanisms of protection of cells from the adverse effects of ROS. Such systems contain numerous enzymes, including superoxide dismutase (SOD) (EC 1.15.1.1). This enzyme catalyses the dismutation of oxygen superoxide and hydrogen peroxide in the initial stages of neutralisation of active radicals [4]. The efficiency of this process affects the rate at which the plant overcomes oxidative stress and becomes able to fully restore its normal metabolism.

Thus, modern-day studies [5; 6] prove that SOD plays an important role in the ROS detoxification process and activity of this enzyme increases according to the level of stress affecting the plants. In this regard, researchers of searching methods to enforce the antioxidant activity of plants to make them overcome consequences of impact of stress factors more effectively. The use of phytohormones and microbial preparations are often highlighted among the relevant means of solving this issue [7; 8]. It is known that inclusion of these components into the grain cultures cultivation technology increases antioxidant activity in plant tissues and ultimately leads to declining intensity of lipid peroxidation processes [9; 10]. However, the impact of such preparations on the specified indicators of grain sorghum plants has not been studied before, which preconditioned the *purpose of this study*.

LITERATURE REVIEW

It is proved that herbicides, as chemical substances, intensify the production of ROS in cultivated plants. In particular, herbicides based on pyrimidine and paraquat cause oxidative stress in plants via the production of ROS. The dicationic nature of these compounds contributes to their reduction to radical cations. Reduction of dications occurs involving the first photosystem to form monocation radical, which, reacting with the atomic oxygen, forms the superoxide radical [11]. Herbicide Diuron blocks electron transport in the process of photosynthesis, Norflurazon inhibits biosynthesis of carotenoids as a consequence of photooxidative processes caused by synthesis of oxygen in cells [12].

A.S. Lukatkin et al. [13] state that increased concentrations of ROS activate LPO in cells resulting in their damage. For example, treatment of winter wheat, rye, and maize plants with herbicide Topic at a concentration of 800 mg/l led to increase of lipoperoxidation activity on the first day of experiment by 16-56% depending on the crops. However, there was no substantial LPO increase at a Topic concentration of 8 and 80 mg/l. On the second day after the herbicide application, LPO level increased in the leaves of winter wheat by 90% compared to the control sample, but the same effect did not occur in rye and maize. On the third day of the experiment, all the variants showed the LPO increase, especially at herbicide concentration of 800 mg/l.

N.H. Song et al. [14] discovered that the SOD and LPO activity processes increased when herbicide Chlorotoluron was applied into the soil at concentrations of 5, 10, 15, 20, and 25 mg/kg. At the herbicide concentration of 10 mg/kg of soil, the number of thiobarbituric acid reactive substances increased two times in the plant tissue compared to the control sample. During the further increase of preparation concentration to 25 mg/kg of soil, the number of reactive substances decreased. However, histological examination of the plants using nitro blue tetrazolium proved the further increase of the oxidative stress. The SOD activity, in turn, also increased along with the preparation concentration in the soil. In particular, activity of this enzyme was 1.2-3.5 times higher than in control sample with the concentration of Chlorotoluron at 5-15 mg/kg of soil. However, further preparation concentration increase to 25 mg/kg of soil decreases the SOD activity to the control level.

V.P. Karpenko et al. [7] note that the herbicide Kalibr 75 at the concentration of 30-70 g/ha in different combinations with the phytohormone Ahrostymulin and microbial preparation Ahat-25K changed the SOD and LPO activity in plants of spring barley. The amount of malondialdehyde in the tissues of plants increased by 26.2-126.8% on the third day after the herbicide application which testifies to the rise of the LPO level. However, when the herbicide was applied jointly with the phytohormone on the background of pre-sowing seed treatment by the microbial preparation, the LPO activity was lower by 14.8-22.5% compared to the variants where only herbicide was used. The SOD activity increased by 29.9-123.9% upon treating the plants with Kalibr 75, but when it was combined with the phytohormone and applied on the background of pre-sowing seed treatment it was 16.0-27.6% which testifies to the increased ability of plants to resist the oxidative stress.

Therefore, herbicides, phytohormones, and microbial preparations can directly or indirectly impact the activity of the LPO processes and the activity of the SOD in plants. However, there is a lack of research related to the influence of preparations on the given indicators in grain sorghum plants, which mainstreamed the study in this area.

MATERIALS AND METHODS

The objects of vegetative [15] experiment were as follows: grain sorghum (*Sorghum bicolour (L.) Moench*) of the Milo B hybrid [16], herbicide Cytadel 25 OD (penoxsulam 25 g/l), phytohormone) Endofit L1 (auxins, gibberellins, cytokinins – 0.26-0.52%) and biopreparation Bioarsenal (*Beauveria Bassiana* fungi, strain MG 301 (GHA), CFU 2x10^{10}; *Beauveria Bassiana*, strain MG 302 (DB-1), CFU 2x10^{10}; bacteria *Azospirillum spp*. – MG 401, CFU 1.5x10^{10}; and *Azotobacter spp*. – MG 402, CFU 1.5x10^{10} per 100 g of preparation) [17].

Plants were grown in plastic containers with capacity of 12 kg of absolutely dry soil, typical for the field experiments. Soil – podzolised heavy-loamy chernozem. Humus content in the topsoil – 3.5%, alkaline hydrolysed nitrogen (according to the Cornfield method) – 103 mg/kg of soil, mobile phosphorus and potassium compounds (according to the Chirikov method) – 88 and 132 mg/kg, respectively. Hydrolytic acidity – 2.26 cmol/kg of soil, soil pH – 6.2 [18]. Soil humidity was maintained at the level of 60% according to the gravimetric method. Additional lighting was provided by fluorescent lamps. Temperature was maintained at the level of 25°C. Relative air humidity – 60%.

The scheme of the experiment included 16 variants in threefold repetition: without the preparations (control sample), Cytadel 25 OD at a concentration of 0.6, 0.8, and 1.0 l/ha separately and in combinations with the phytohormone Endofit L1 (30 ml/ha) on the background of pre-sowing seed treatment by the biopreparation Bioarsenal (800 g/100 kg) and without it.

Lipid peroxidation activity was evaluated according to the number of formed malondialdehyde (MDA) in the plant tissues [19]. Solution of triton X-100, hydrochloric acid, and thiobarbituric acid (TBA) were successively added to the test tube containing the plant material (supernatant). The mixture was heated up in the heated bath for 10 minutes. Cooling was carried out at the temperature of 15°C for 30 minutes. For colour stabilisation, solutions of trilon B and ethanol were added to the reaction mixture. A sample to which all the same solutions were added, except the TBA, was used as the control sample. The resulting solutions were analysed on a spectrophotometer at the wavelength of 532 nm and with further calculations of the LPO level (in μmol/g) according to the following formula (1):

$$LPO = \frac{D * V_1 * V_3}{156 * P * V_2} \qquad (1)$$

where D is the light absorption of the sample, conventional units; V_1 is the overall volume of the tissue homogenate, ml; V_2 is the volume of the supernatant that was added to the test tube, ml; V_3 is the final volume of the sample in the test tube, ml; 156 is the coefficient of the micromolar light absorption; P is the mass of the plant material sample, g.

Superoxide dismutase (EC 1.15.1.1) activity was evaluated by its ability to compete with the nitro blue tetrazolium for superoxide anions which form as a result of interaction between reduced nicotinamide adenine dinucleotide and phenazine methosulfate [20]. As a result of this reaction, nitro blue tetrazolium reduces forming hydrazine tetrazolium. In the SOD presence, the percentage of the reduced nitro blue tetrazolium decreases, which reflects on the optical density of the reaction mixture. Supernatant was prepared in the way of homogenisation of the examined material with 0.05 M solution of potassium phosphate pH 7.8 and further centrifugation at 20,000 g for 10 minutes [21]. When all components were mixed, the initial extinction of the reaction mixture was assessed using a spectrophotometer at the wavelength of 540 nm and thickness of the optical layer of 10 mm. The assessment was repeated after 10 minutes, registering the increase of the optical density of the mixture. Further calculations were performed according to the following formula (2):

$$\%\text{ of blockage} = \frac{E_0 - E_{pr}}{E_0} * 100 \qquad (2)$$

where E_0 is the extinction of reaction mixture while there is no SOD (null sample); E_{pr} is the extinction of the reaction mixture in a state of equilibrium.

In the studied samples, the SOD content (conventional units/g of raw material) was determined based on the calibration curve according to the calculated percentage of inhibition of the nitro blue tetrazolium reduction.

Statistical analysis was performed according to B. Dospehov's method [22] using Microsoft Office Excel 2019.

RESULTS AND DISCUSSION

This study found that the LPO intensity in the tissues of grain sorghum depended on the concentration of the herbicide and its combination with the phytohormone and biopreparation (Table 1).

***Table 1**. Activity of the LPO processes in the grain sorghum leaves under the effect of the herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal*

Variant of the experiment	MDA content, μmol/g of raw substance	
	On the third day	On the tenth day
Without use of the preparations (control)	14.6	23.7
Cytadel 25 OD 0.6 l/ha	19.5	29.9
Cytadel 25 OD 0.8 l/ha	23.1	32.8

Table 1, Continued

Variant of the experiment	MDA content, μmol/g of raw substance	
	On the third day	On the tenth day
Cytadel 25 OD 1.0 l/ha	28.2	37.4
Endofit L1 30 ml/ha	12.1	20.3
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha	17.2	26.7
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha	21.0	30.2
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha	26.3	34.6
Bioarsenal 800 g/100 kg (pre-sowing seed treatment, background)	11.0	18.8
Cytadel 25 OD 0.6 l/ha + background	16.2	25.1
Cytadel 25 OD 0.8 l/ha + background	20.1	28.0
Cytadel 25 OD 1.0 l/ha + background	25.2	32.8
Endofit L1 30 ml/ha + background	9.9	17.3
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha + background	15.0	24.2
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha + background	18.7	26.7
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha + background	24.1	31.5
LSD_{01}	0.7	0.9

Thus, on the third day after applying the herbicide Citadel 25 OD at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha, the LPO intensity increased compared to the control sample by 33.6%, 58.2%, and 93.2%, respectively; on the tenth day – by 26.2%, 38.4%, and 57.8%, respectively. Apparently, such LPO intensification is a consequence of increased ROS formation during xenobiotic detoxification by the plants, in particular, involving the cytochrome P450 complex, which catalyses the penoxsulam neutralisation – an active compound of the herbicide Cytadel 25 OD [2; 23; 24]. However, upon applying the same herbicide concentrations together with the phytohormone Endofit L1, the LPO activity in the grain sorghum plants decreased by 11.8%, 9.1%, and 6.7%, respectively – on the third day, and by 10.7%, 7.9%, and 7.5%, respectively – on the tenth day compared to the variants where only herbicide was used. It is consistent with experimental results of other scientists [7; 25] which also registered a considerable decrease of the LPO intensity under the influence of phytohormones. A similar effect was also observed when the herbicide was applied at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha against the background of pre-sowing seed treatment by the biopreparation Bioarsenal. Thus, on the third day after the herbicide application, the LPO activity in these variants was lower than in the variants with only herbicide use by 16.9%, 13.0%, and 10.6%, respectively. On the tenth day, this indicator decreased by 16.1%; 14.6%; and 12.3%, respectively.

The lowest LPO indicators were observed in the variants where the herbicide Cytadel 25 OD was applied together with the phytohormone Endofit L1 against the background of pre-sowing seed treatment by the Bioarsenal. Under these conditions, the intensity of lipoperoxidation processes on the third and tenth day, was by 23.1% and 19.0%, 14.5% and 19.1%, 18.6% and 15.8%, respectively, lower than in the variants with only herbicide. However, it remained higher than the control sample by 2.7-65.1% and 2.1-43.9%, respectively. Evidently, the stress level was lower upon the complex use of the preparations under study than in the variants where only herbicide was used. Such changes in the LPO intensity can possibly be connected to the intensive functioning of the antioxidant systems. In this regard, to determine the reasons of the LPO activity decrease upon the complex use of preparations, the authors investigated the SOD activity.

According to the experiment results (Table 2), the SOD activity also altered in different combinations of the preparations under study.

***Table 2**. SOD activity in the grain sorghum leaves under the effect of the herbicide Cytadel 25 OD, phytohormone Endofit L1 and biopreparation Bioarsenal*

Variant of the experiment	SOD, CU/g of raw substance	
	On the third day	On the tenth day
Without use of the preparations (control)	1.24	2.36
Cytadel 25 OD 0.6 l/ha	1.56	2.79
Cytadel 25 OD 0.8 l/ha	1.97	3.45
Cytadel 25 OD 1.0 l/ha	2.44	4.12
Endofit L1 30 ml/ha	1.40	2.68
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha	1.93	3.33
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha	2.34	3.95

Table 2, Continued

Variant of the experiment	SOD, CU/g of raw substance	
	On the third day	On the tenth day
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha	2.78	4.60
Bioarsenal 800 g/100 kg (pre-sowing seed treatment, background)	1.43	2.71
Cytadel 25 OD 0.6 l/ha + background	1.99	3.42
Cytadel 25 OD 0.8 l/ha + background	2.46	4.06
Cytadel 25 OD 1.0 l/ha + background	2.91	4.74
Endofit L1 30 ml/ha + background	1.49	2.79
Cytadel 25 OD 0.6 l/ha + Endofit L1 30 ml/ha + background	2.16	3.62
Cytadel 25 OD 0.8 l/ha + Endofit L1 30 ml/ha + background	2.68	4.31
Cytadel 25 OD 1.0 l/ha + Endofit L1 30 ml/ha + background	3.18	5.03
LSD_{01}	0.14	0.17

Therewith, the activity of this enzyme increased upon the herbicide treatment of plants by 25.8%, 58.9%, and 96.8% – on the third day and by 18.2%, 46.2%, and 74.5% – on the tenth day of the experiment compared to the control sample. These changes in the SOD activity could possibly be caused by the increase of the ROS concentration in the plant tissues against the background of the xenobiotic influence. A similar effect was also described by other researchers [4; 26], who studied activity of this enzyme in plants under the influence of herbicides. In addition, application of the herbicide at the concentrations of 0.6 l/ha, 0.8 l/ha, and 1.0 l/ha in combination with the phytohormone Endofit L1 increased the SOD activity by 14.2-24.1% (third day) and 11.6-19.3% (tenth day) relatively to the samples treated exclusively by herbicides. Intensification of the antioxidant processes, namely the SOD activity, under the influence of exogenous phytohormones on plants is reflected in numerous studies [27-30], which associate this process with strengthening of the metabolism in plants. Experimental samples, where herbicide was applied against the background of pre-sowing seed treatment by the Bioarsenal demonstrated a similar tendency – on the third and tenth day, the SOD activity increased by 19.6-27.5% and 14.9-22.5%, respectively. The highest indicators of the SOD activity were observed at the compatible use of the herbicide and phytohormone against the background pre-sowing seed treatment by the biopreparation. On the third and tenth day of the experiment, the activity of this enzyme exceeded control by 0.92 CU/g, 1.44 CU/g, 1.94 CU/g, and 1.26, CU/g, 1.95 CU/g, 2.67 CU/g of raw substance, respectively, which was higher than indicators of the variants treated exclusively by herbicides 30.7-38.7% and 22.0-29.6%.

To establish the nature of the dependence between the two researched indicators, the authors of this study performed a correlation analysis, which resulted in the discovery of a strong positive connection between the SOD and LPO activity. On the third and tenth day of experiments it was 0.78 and 0.72, respectively.

The results of the study suggest that the herbicide Cytadel 25 OD at the concentrations of 0.6 l/ha; 0.8 l/ha, and 1.0 l/ha cause the increase of the ROS production, particularly superoxide radical, in the grain sorghum plants, which is accompanied by intensified lipid peroxidation. Such effect is expected, because xenobiotics cause numerous malfunctions in cells, leading to their damage [31]. As a result, antioxidant systems activate in plants, and their functions are implemented by numerous specific enzymes. Thus, the SOD activity, as one of the key antioxidants, increase along with the concentration of herbicide Cytadel 25 OD.

Phytohormones and microbial preparations allow fulfilling a genetic potential of agricultural crops better, which manifests in increasing their resistance to various forms of stress [7]. In this regard, samples under study that were treated with herbicide in combination with phytohormone Endofit L1 and biopreparation Bioarsenal demonstrate a substantial increase in the SOD activity compared to the samples treated exclusively by herbicides. Therewith, increase in the SOD activity was accompanied by simultaneous decrease of the lipid peroxidation activity, which testifies to the increase of the ROS neutralisation efficiency in the plants.

Other researchers have also observed similar results in their studies. For example, Z.M. Hrytsaienko et al. [32] note that treatment of spring barley plants with herbicide Hranstar 75 at the concentrations of 10, 15, 20 and 25 g/ha increases the SOD activity by 25.6-126.5% compared to the control sample. However, application of the herbicide in combination with phytohormone Emistym C led to a more pronounced activation of the SOD, which manifested itself in an increase of this enzyme activity by 17.6-31.7% compared to the samples treated exclusively by herbicides. Lipid peroxidation processes also altered in the experiment conditions. At the herbicide concentrations of 10-25 g/ha malondialdehyde content in the leaves of the spring barley was 32.8-130.2% higher than in the control sample. Application of the herbicide in mixtures with the phytohormone caused decrease of the LPO activity in plants compared to the samples without the phytohormone. This effect was the most pronounced in the samples with the lower herbicide concentrations (10-15 g/ha) and weakened when the concentration increased to 25 g/ha. A possible explanation to such a regularity is a particular levelling of the protective action of the phytohormone upon higher herbicide concentrations.

N. Khan et al. [33] also observed similar results in the chickpea crops. In the stress conditions, the activity of the LPO in the plants increased, but when the seeds were pre-treated with microbial preparations before sowing and the crops were sprayed with a phytohormone – lipid peroxidation activity decreased.

W. Zhang et al. [34] discovered analogous tendencies upon treating wheat plants by phytohormones in the abiotic stress conditions. The LPO level in the wheat plants decreased by 12.6-48.6% compared to the control in the samples treated with phytohormones. Therewith, in these conditions, a substantial increase in the SOD activity was observed – by 4.7-12.4% compared to the control sample.

Therefore, the results of this study are consistent with the data observed by other researchers regarding the impact of phytohormones and microbial preparations on the intensity of lipid peroxidation processes and the SOD activity in cultural plants under herbicide stress conditions. However, the highest efficiency was registered in the samples treated by the herbicide Cytadel 25 OD in combination with the phytohormone Endofit L1 application against the background of pre-sowing seed treatment by Bioarsenal preparation.

CONCLUSIONS

Application of the herbicide Cytadel 25 OD at the concentrations of 0.6, 0.8, and 1.0 l/ha intensifies the lipoperoxidation in plants of grain sorghum. However, when the herbicide is combined with the phytohormone Endofit L1, as well as when it is used against the background of pre-sowing seed treatment by the biopreparation Bioarsenal, the LPO intensity decreases compared to the samples treated exclusively by the herbicide, which is one of the consequences of the antioxidant activity increase in plants, namely the activity of the SOD enzyme.

The most favourable conditions for overcoming consequences of the xenobiotic influence on the grain sorghum plants form in the combined use of the herbicide Cytadel 25 OD and phytohormone Endofit L1 against the background of pre-sowing seed treatment by Bioarsenal. The SOD activity in such experimental samples exceeded that of the control sample by 99.3% on average, which is 30.3% higher than in the samples treated exclusively by herbicides. The LPO reactions were suppressed against the background of the SOD activity increase and their intensity decreased by 17.2% compared to the herbicide-only samples.

Thus, integrated use of the herbicide Cytadel 25 OD, phytohormone Endofit L1, and biopreparation Bioarsenal is an expedient measure that allows decreasing the harmful influence of the herbicides on the grain sorghum plants.

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Ліпопероксидаційні процеси в сорго зерновому за дії гербіциду, регулятора росту рослин і біопрепарату

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Анотація. Використання гербіцидів у посівах зернових культур, в тому числі й сорго зернового, є неодмінною умовою досягнення високих показників урожайності. Проте, проникаючи до організму рослин вони здатні інтенсифікувати синтез активних форм кисню, що призводить до посилення процесів ліпопероксидації та активізації антиоксидантних систем, зокрема й ферменту супероксиддисмутази. Відомо, що регулятори росту рослин та мікробні препарати, за їх включення до технологій вирощування зернових культур, можуть підвищувати здатність рослин протистояти оксидативному стресу, спричиненому дією ксенобіотиків. Утім інтегрований вплив гербіцидів, регуляторів росту рослин і мікробних препаратів на активність ферменту супероксиддисмутази та інтенсивність проходження реакцій ліпопероксидації в рослинах сорго зернового вивчено недостатньо, що й обумовило мету цього дослідження. Об'єктами вивчення слугували рослини сорго зернового (*Sorghum bicolour (L.) Moench*) гібриду Майло В, гербіцид Цитадель 25 OD, регулятор росту рослин Ендофіт L1 і біопрепарат Біоарсенал. Дослід було закладено з дотриманням вимог вегетаційного методу. Активність пероксидного окислення ліпідів визначали за кількістю утвореного в тканинах рослин малонового диальдегіду. Активність ферменту супероксиддисмутази (КФ 1.15.1.1.) встановлювали за його здатністю конкурувати з нітросиним тетразолієм за супероксидні аніони, що утворюються в результаті взаємодії відновленої форми нікотинамідаденіндинуклеотиду і феназинметасульфату. В ході досліджень було встановлено, що за дії гербіциду Цитадель 25 OD показники активності пероксидного окиснення ліпідів у рослинах були в середньому на 26,2–93,2 % вищими ніж у контролі, залежно від норми гербіциду і доби після внесення. Активність супероксиддисмутази за таких умов перевищувала контроль у середньому на 18,2–96,8 %. Проте, за сумісного використання гербіциду, регулятора росту рослин і біопрепарату спостерігалось зниження активності ліпопероксидаційних процесів у рослинах на 14,5–19,1 % відносно варіантів самостійного внесення гербіциду при одночасному зростанні активності супероксиддисмутази на 22,0–38,7 %. Результати досліджень засвідчують позитивний вплив регулятора росту рослин і біопрепарату на здатність сорго зернового протистояти оксидативному стресу, що виникає внаслідок дії гербіциду. Отримані дані можуть стати підґрунтям для подальшої розробки біологізованих технологій вирощування цієї культури

Ключові слова: супероксиддисмутаза, пероксидне окиснення ліпідів, антиоксидантний захист, біологізація, оксидативний стрес