Agricultural Research & Technology
Open Access Journal
ISSN: 2471-6774

Juniper Publishers
key to the Researchers

Research Article
Volume 29 Issue 2 - June 2025
DOI: 10.19080/ARTOAJ.2025.29.556445

Agri Res & Tech: Open Access J

Using Pyrimidine Derivatives to Enhance Soybean Growth Under Conditions of Heat and Drought

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Submission: June 23, 2025; **Published:** June 30, 2025

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Abstract

This work is devoted to the study of the regulatory effect of synthetic compounds, derivatives of pyrimidine, on the growth of soybean plants (*Glycine max* (L.) Merr.) of the Syaivo variety under conditions of heat and drought. The conducted experiments showed that the highest regulatory effect on such morphometric parameters as the average length of the shoots (mm) and roots (mm), average number of the roots (pcs), as well as the content of photosynthetic pigments: chlorophylls a and b, carotenoids (mg/g FW) in soybean plants is exerted by synthetic compounds, derivatives of 6-methyl-2-mercapto-4-hydroxypyrimidine sodium and potassium salts (Methyur and Kamethur) and compounds, derivatives of thioxopyrimidine № 1, 2, 5, 6, 7, 8, 10 та 11, used at a concentration of 10^{-6}M. Their regulatory effect on the growth of soybean plants was comparable to or higher than that of auxin NAA (1-Naphthylacetic acid) used at a similar concentration of 10^{-6}M. A correlation has been found between the regulatory effect of synthetic compounds, derivatives of thioxopyrimidine and their chemical structure. The obtained results confirm the prospects of practical application of the selected most physiologically active synthetic compounds for improving the growth and development of soybean plants during the vegetative phase and increasing the adaptation of plants to abiotic stress factors such as heat and drought.

Keywords: *Glycine max* (L.) Merr.; NAA, Methyur; Kamethur; Thioxopyrimidine; Heat and drought

Introduction

Soybean (*Glycine max* (L.) Merrill) is an important agricultural legume crop used in the food industry as a source of a number of vital nutrients such as amino acids (i.e. tryptophan, threonine, isoleucine, leucine, lysine, methionine, cystine, phenylalanine, tyrosine, valine, arginine, histidine, alanine, aspartic acid, glutamic acid, glycine, proline, serine), fat (i.e. saturated, monounsaturated, polyunsaturated omega 3 and omega 6 fatty acids), carbohydrates (i.e. sugars and dietary fiber), vitamins (i.e. A, B1, B2, B3, B4, B5, B6, B9, C, E), and minerals (i.e. copper, iron, magnesium, manganese, phosphorus, potassium, sodium, zinc) for human nutrition [1, 2]. Soybean also contains bioactive phytochemicals with therapeutic effects on human health, such as isoflavones, lectins, saponins, flavonoids, phytic acid, lipids, phytoalexins, and peptides that significantly reduce the risk of several types of cancers, including breast, prostate, lung, colon, liver, and bladder cancer, hypercholesterolemia, and cardiovascular disease, osteoporosis, hypertension, and blood pressure [3-5]. Consumption of soybean nutrients and phytochemicals has beneficial effects on human health, preventing cardiovascular diseases by lowering blood cholesterol levels, several types of cancers, osteoporosis in women, alleviating menopausal symptoms, and effectively controlling aging [2,3].

Soybean cultivation plays an important role in sustainable agriculture, enriching soil health by fixing atmospheric nitrogen through biological nitrogen fixation, which occurs through the rhizobium-legume symbiosis - the most productive and economical system for nitrogen fixation and crop production associated with more intensive production systems [3,6,7]. However, the efficiency of soybean cultivation depends on several factors, such as global climate change, environmental pollution, and declining soil fertility, which create significant difficulties in soybean cultivation and reduce its productivity [3,8].

Currently, crop yields are declining due to heat and drought stresses caused by extreme warming, low humidity and insufficient water availability, which adversely affect the growth of plant roots and shoots, impair cell division and expansion, disrupt metabolic processes and cell membrane stability in plants, inhibit water and nutrient uptake through the root system, reduce carbon accumulation, disrupt respiration and photosynthesis, reduce chlorophyll and water content in plant leaves, as well as reduce reproductive capacity [9-11].

As is known, plant hormones auxins and cytokinins play an important role in plant growth and development, controlling plant embryogenesis, seed germination, development of the root system, which provides plants with organic matter, micro- and macroelements from the soil, enhances the efficiency of water use, improving photosynthesis and increasing chlorophyll content, translocation of photoassimilates, as well as enhancing protein biosynthesis, which leads to improved formation and growth of vegetative and reproductive organs, increased plant productivity and their resistance to abiotic stress [12-20].

In recent years, new auxin and cytokinin related substances have been created on the basis of synthetic low-molecular-weight nitrogen-containing heterocyclic compounds, which have been proposed for practical use as new environmentally friendly plant growth regulators in agriculture and plant biotechnology [21,22]. Among these compounds, the most promising are synthetic azaheterocyclic compounds, derivatives of pyridine and pyrimidine, which exhibit auxin- and cytokinin-like regulatory effects, enhancing the growth and development of various important agricultural and industrial crops, increasing their productivity and promoting plant resistance to abiotic stress [21-33].

Based on the results of our previous studies on the influence of different classes of synthetic azaheterocyclic compounds on the growth and development of various agricultural crops [21-33], the development of new effective regulators based on pyrimidine derivatives to improve soybean growth and enhance adaptation to abiotic stresses such as heat and drought is highly relevant. This important issue is the subject of this work.

Materials and Methods

Tested compounds and plant treatment methods

The seeds of soybean plants (*Glycine max* (L.) Merr.) of the Syaivo variety were sterilized with 1 % $KMnO_4$ solution for 15 min, then treated with 96 % ethanol for 2 min, after which they were washed three times with sterile distilled water. The sterilized seeds were then placed in the plastic containers each containing 15-20 seeds on the perlite moistened with solutions of plant hormone auxin NAA (1-Naphthylacetic acid), or synthetic compounds, derivatives of sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur) and potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Kamethur), or derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M. Seed germination was carried out in a thermostat in the dark at a temperature of 21-23 °C for 48 hours.

Chemical structure, name and relative molecular weight of plant hormone auxin NAA, synthetic compounds, derivatives of sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur) and potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Kamethur), and derivatives of thioxopyrimidine (compounds № 1-11) are presented in Table 1. Plant hormone auxin NAA (1-Naphthylacetic acid) was manufactured by Sigma-Aldrich, USA, synthetic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur Kamethur), as well as derivatives of thioxopyrimidine (compounds № 1-11) were synthesized at the Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds, V.P. Kukhar Institute of Bioorganic Chemistry and Petrochemistry of the National Academy of Sciences of Ukraine.

Growing conditions for plants

Growing of soybean plants (*Glycine max* (L.) Merr.) of the Syaivo variety was carried out in a climate chamber, in which the plants were grown for 3 weeks under a light intensity of 3000 lux, a light/dark regime of 16/8 hours, and under conditions of abiotic stress factors: heat (at an increased temperature to 35-40 °C) and drought (with reduced watering by 50%). Control seeds were moistened with distilled water, and soybean plants were grown under similar conditions of exposure to these abiotic stress factors.

Comparative analysis of plant growth parameters (average length of the shoots (mm) and roots (mm), average number of the roots (pcs)) was performed according to the methodical manual [34]. Plant growth parameters determined at the end of the 3-week period on experimental plants, compared with similar parameters of control plants, were expressed in %.

Method of analysis of photosynthetic pigment content

To extract photosynthetic pigments (chlorophylls and carotenoids) from soybean leaves, we homogenized the sample (500 mg) of leaves in the porcelain mortar in a cooled at the temperature 10 °C 96 % ethanol at the ratio of 1:10 (weight:volume) with addition of 0.1-0.2 g $CaCO_3$ (to neutralize the plant acids). The 1 ml of obtained homogenate was centrifuged at 8000 g in a refrigerated centrifuge K24D (MLW, Engelsdorf, Germany) during 5 min at the temperature 4 °C. The obtained precipitate was washed three times, with 1 ml 96 % ethanol and centrifuged at above mentioned conditions. After this procedure, the optical density of chlorophyll a, chlorophyll b and carotenoid in the obtained extract was measured using spectrophotometer Specord M-40 (Carl Zeiss, Germany).

The content of chlorophyll a, chlorophyll b, and carotenoids (mg/g fresh weight) in plant leaves was calculated in accordance with formula [35,36]:

$$Cchl\ a = 13.36 \times A664.2 - 5.19 \times A648.6,$$

$$Cchl\ b = 27.43 \times A648.6 - 8.12A \times 664.2,$$

$$Cchl\ (a + b) = 5.24 \times A664.2 + 22.24 \times A648.6,$$

$$Ccar = (1000 \times A470 - 2.13 \times Cchl\ a - 97.64 \times Cchlb)/209,$$

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Where, Cchl - concentration of chlorophylls (µg/ml), Cchl a - concentration of chlorophyll a (µg/ml), Cchl b - concentration of chlorophyll b (µg/ml), Ccar - concentration of carotenoids (µg/ml), A - absorbance value at a proper wavelength in nm.

The chlorophyll and carotenoids content per 1 g of fresh weight of extracted from soybean leaves was calculated by the following formula (separately for chlorophyll a, chlorophyll b and carotenoids):

$$A_1=(C\times V)/(1000\times a_1),$$

Where, A_1 - content of chlorophyll a, chlorophyll b, or carotenoids (mg/g FW), C - concentration of pigments (µg/ml), V - volume of extract (ml), a_1 - sample of leaves (g).

The ratio of chlorophyll and carotenoid content in experimental and control soybean plants was expressed in %.

Statistical analysis of the obtained experimental data

Each experiment was performed three times. Statistical processing of the obtained experimental data was carried out using Student's t-test with a significance level of P≤0.05; mean values ± standard deviation (± SD) [37].

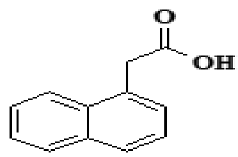
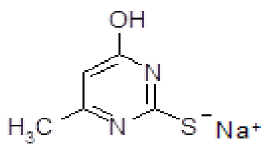
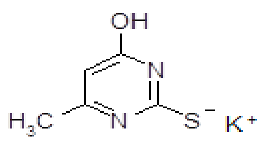
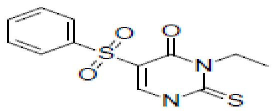
Results and Discussion

Evaluation of morphometric parameters of soybean plants

Currently, screening is underway for new biologically active synthetic compounds capable of exhibiting regulatory activity on plant growth and development similar to the natural phytohormones auxins and cytokinins [38-45]. In recent years, the greatest attention has been paid to the development of new plant growth regulators based on synthetic azaheterocyclic compounds, among which the most promising for practical use are pyrimidine derivatives, which, like the natural phytohormones auxins and cytokinins, improve the growth and development of roots, shoots, leaves and fruits of plants, increase plant productivity and adaptation to abiotic stresses [21-33].

This work investigated the regulatory effects of synthetic azaheterocyclic compounds, pyrimidine derivatives such as Methyur, Kamethur and derivatives of thioxopyrimidine (Table 1) on the growth and development of soybean plants (*G. max* (L.) Merr.) of the Syaivo variety under conditions of heat and drought. Improvement of morphological traits of soybean plants grown under conditions of heat and drought was observed when plants were treated with auxin NAA, as well as synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine at a concentration of 10^{-6}M. Soybean plants grown under the effect of the most active synthetic compounds, such as Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1, 2, 5, 6, 7, 8, 10 and 11), had more developed roots and shoots, as well as improved adaptive properties to heat and drought compared to control plants (Figure 1).

Table 1: Chemical structure, name and relative molecular weight of the tested compounds.

Chemical compound	Chemical structure	Chemical name and relative molecular weight (g/mol)
NAA		1-Naphthylacetic acid MW=186.21
Methyur		Sodium salt of 6-methyl-2-mercapto-4-hydroxy-pyrimidine MW=165.17
Kamethur		Potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine MW=181.28
1		5-Benzenesulfonyl-3-ethyl-2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one MW=296.3690

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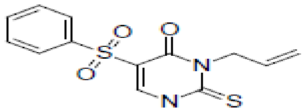
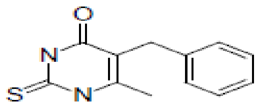
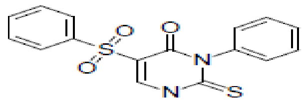
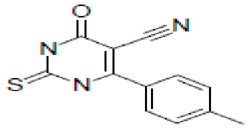
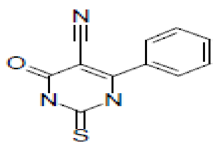
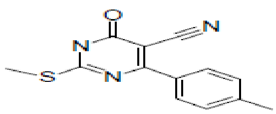
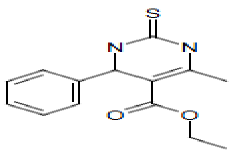
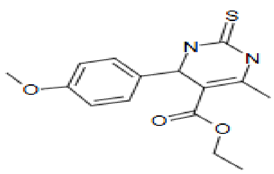
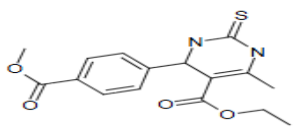
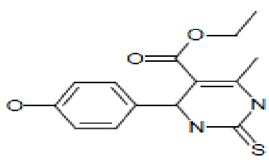
2		3-Allyl-5-benzenesulfonyl-2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one MW=308.3802
3		5-Benzyl-6-methyl-2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one MW=232.3062
4		5-Benzenesulfonyl-3-phenyl-2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one MW=344.4136
5		4-Oxo-2-thioxo-6-*p*-tolyl-1,2,3,4-tetrahydro-pyrimidine-5-carbonitrile MW=243.2890
6		4-Oxo-6-phenyl-2-thioxo-1,2,3,4-tetrahydro-pyrimidine-5-carbonitrile MW=229.2619
7		2-Methylsulfanyl-6-oxo-4-*p*-tolyl-1,6-dihydro-pyrimidine-5-carbonitrile MW=257.3161
8		6-Methyl-4-phenyl-2-thioxo-1,2,3,4-tetrahydro-pyrimidine-5-carboxylic acid ethyl ester MW=276
9		4-(4-Methoxy-phenyl)-6-methyl-2-thioxo-1,2,3,4-tetrahydro-pyrimidine-5-carboxylic acid ethyl ester MW=306
10		4-(4-Methoxycarbonyl-phenyl)-6-methyl-2-thioxo-1,2,3,4-tetrahydro-pyrimidine-5-carboxylic acid ethyl ester MW=334
11		4-(4-Hydroxy-phenyl)-6-methyl-2-thioxo-1,2,3,4-tetrahydro-pyrimidine-5-carboxylic acid ethyl ester MW=292

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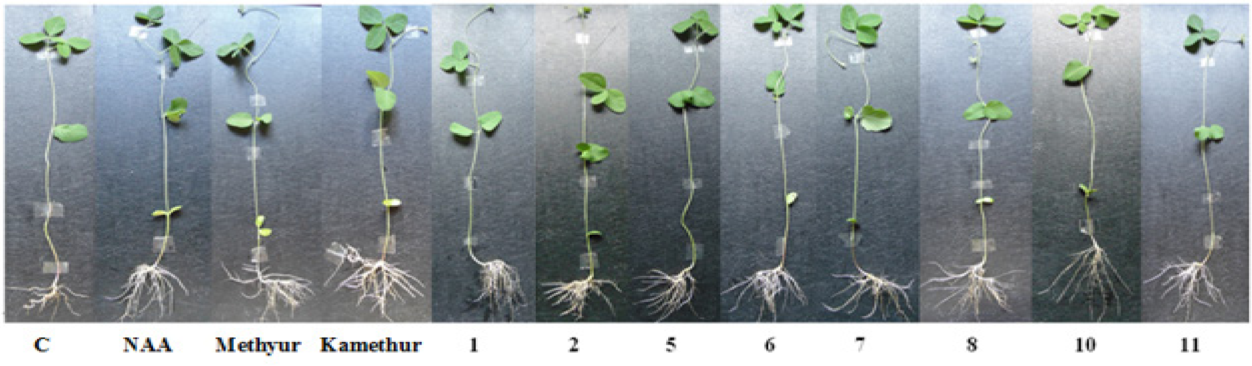

Figure 1: The 3-week-old soybean plants (*G. max* (L.) Merr.) of the Syaivo variety, grown under conditions of heat and drought and under the effect of auxin NAA, as well as the most active synthetic compounds: Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1, 2, 5, 6, 7, 8, 10 and 11) at a concentration of 10^{-6}M, compared to control (C) soybean plants.

A comparative analysis of morphometric parameters (average length of the shoots (mm) and roots (mm), average number of the roots (pcs)) of soybean plants grown under conditions of heat and drought, treated with the plant hormone auxin NAA (1-Naphthylacetic acid) or synthetic compounds, derivatives of sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur) and potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Kamethur), or derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M, and control soybean plants treated with distilled water was carried out.

The highest parameters of the length of the shoots (mm) were found in soybean plants treated with auxin NAA and synthetic compounds Methyur, Kamethur and compounds, derivatives of thioxopyrimidine № 1, 2, 3, 5, 6, 7 and 8, under the effect of which these parameters increased: by 42,14 % - under the effect of auxin NAA, by 82,1 % - under the effect of Methyur, by 53,85 % - under the effect of Kamethur, by 42-60 % - under the effect of compounds № 1, 2, 3, 5, 6, 7 and 8, respectively, compared with similar parameters in control soybean plants (Figure 2).

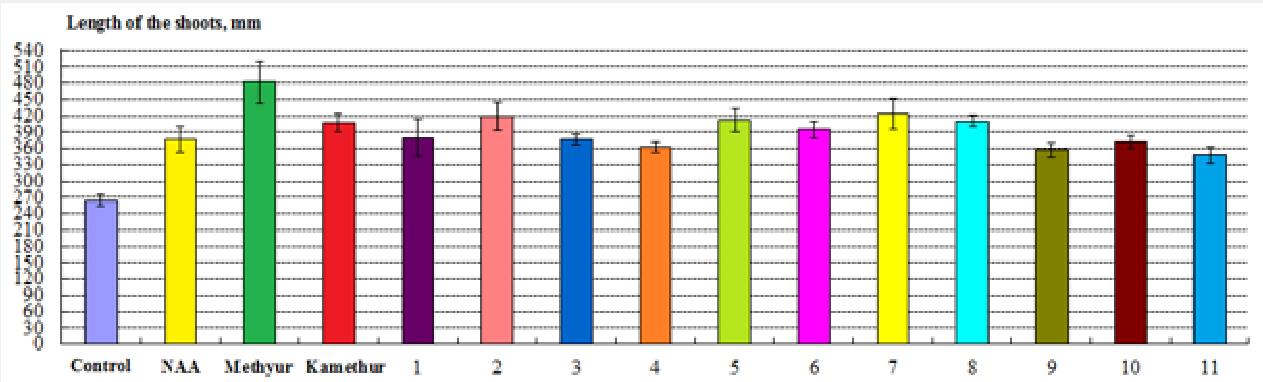

Figure 2: Average length of the shoots (mm) of 3-week-old soybean plants (*G. max* (L.) Merr.) of the Syaivo variety, grown under conditions of heat and drought and under the effect of auxin NAA, as well as synthetic compounds: Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M, compared to control soybean plants.

The lower parameters of the length of the shoots (mm) were found in soybean plants treated with the synthetic compounds, derivatives of thioxopyrimidine № 4, 9, 10 and 11, under the effect of which these parameters increased: by 31,33-40,38 %, respectively, compared with similar parameters in control soybean plants (Figure 2).

The highest parameters of the length of the roots (mm) were found in soybean plants treated with synthetic compounds Methyur, Kamethur and compounds, derivatives of thioxopyrimidine № 1, 2, 5, 6, 7 and 11, under the effect of which these parameters increased: by 338,1 % - under the effect of Methyur, by 413,1 % - under the effect of Kamethur, by 239,4-359,8 % - under the effect of compounds № 1, 2, 5, 6, 7 and 11, respectively, compared with similar parameters in control soybean plants (Figure 3).

The lower parameters of the length of the roots (mm) were found in soybean plants treated with the auxin NAA and synthetic compounds, derivatives of thioxopyrimidine № 3, 4, 8, 9 and 10, under the effect of which these parameters increased: by 168,36 % - under the effect of auxin NAA, by 154,55-195,98 % - under the effect of compounds № 3, 4, 8, 9 and 10, respectively, compared with similar parameters in control soybean plants (Figure 3).

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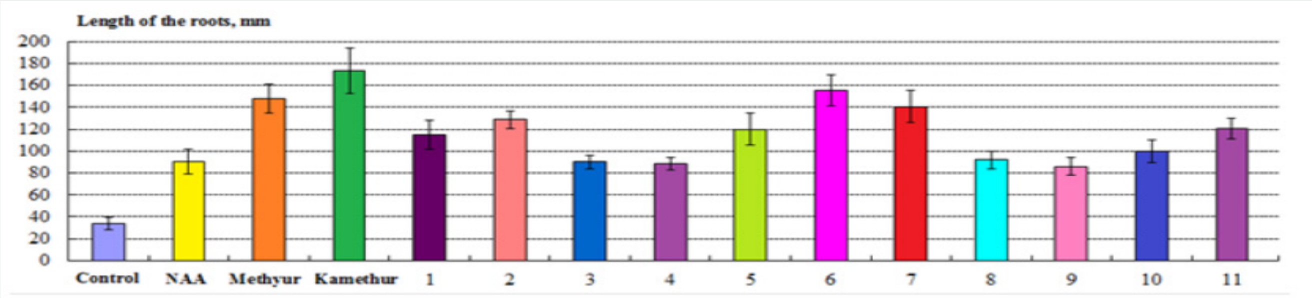

Figure 3: Average length of the roots (mm) of 3-week-old soybean plants (*G. max* (L.) Merr.) of the Syaivo variety, grown under conditions of heat and drought and under the effect of auxin NAA, as well as synthetic compounds: Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M, compared to control soybean plants.

The highest parameters of the number of the roots (pcs) were found in soybean plants treated with the auxin NAA and synthetic compounds Methyur, Kamethur and compounds, derivatives of thioxopyrimidine № 1, 3, 4, 6, 7, 8, 10 and 11, under the effect of which these parameters increased: by 76,44 % - under the effect of auxin NAA, by 70,1 % - under the effect of Methyur, by 48,32 % - under the effect of Kamethur, by 49,59-215,8 % - under the effect of compounds № 1, 3, 4, 6, 7, 8, 10 and 11, respectively, compared with similar parameters in control soybean plants (Figure 4).

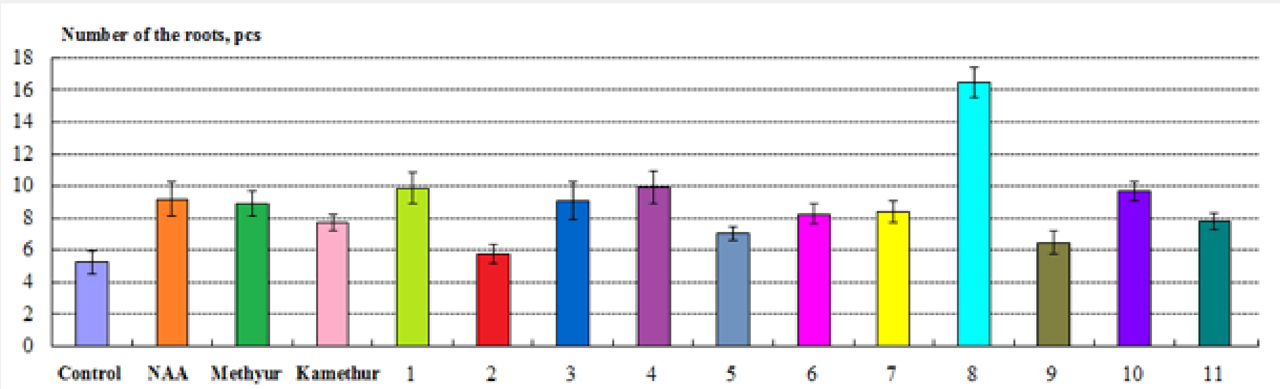

Figure 4: Average number of the roots (pcs) of 3-week-old soybean plants (*G. max* (L.) Merr.) of the Syaivo variety, grown under conditions of heat and drought and under the effect of auxin NAA, as well as synthetic compounds: Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M, compared to control soybean plants.

The lower parameters of the number of the roots (pcs) were found in soybean plants treated with the synthetic compounds, derivatives of thioxopyrimidine № 2, 5 and 9, under the effect of which these parameters increased: by 9,95-34,25 %, respectively, compared with similar parameters in control soybean plants (Figure 4).

Based on the obtained data, it can be assumed that the regulatory effect of synthetic compounds, derivatives of pyrimidine, on growth and development of soybean plants in the vegetative phase is due to their specific auxin- and cytokinin-like regulatory effect on enhancing the proliferation, elongation and differentiation of root and shoot meristem cells, as well as improving the cellular metabolism of soybean plants, grown under conditions of heat and drought [2,15,46,47].

Evaluation of photosynthetic pigment content in soybean plants

As is known, photosynthetic pigments of plants, such as chlorophylls and carotenoids, play an important role in photosynthesis, photoprotection and ensuring plant productivity [35,36,48-50]. In addition to their important role in plant life, it should be noted that chlorophylls have valuable nutritional and therapeutic properties that make them beneficial to human health such as antioxidants, anti-mutagens, anti-cancer, anti-inflammatory and detoxifying agents [51-53]. That is why an important issue for modern agriculture is the development of new plant growth regulators capable of enhancing photosynthesis and increasing the content of photosynthetic pigments in plant.

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In this work, a comparative analysis was carried out of the content of photosynthetic pigments: chlorophylls a and b, carotenoids (mg/g FW) in the leaves of soybean plants grown under conditions of heat and drought, treated with the plant hormone auxin NAA (1-Naphthylacetic acid) or synthetic compounds, derivatives of sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur) and potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Kamethur), or derivatives of thioxopyrimidine (compounds № 1 - 11) at a concentration of 10^{-6}M, and control soybean plants treated with distilled water.

The highest indicators of content of photosynthetic pigments were found in the leaves of soybean plants treated with the plant hormone auxin NAA and synthetic compound Kamethur and compounds, derivatives of thioxopyrimidine № 1, 2, 7, 8, 10 and 11. An increase in the content of photosynthetic pigments was observed under effect of these compounds as follows: chlorophyll a increased: by 13,99 % - under the effect of NAA, by 44,81 % - under the effect of Kamethur, by 4,62-26,61 % - under the effect of compounds № 1, 2, 7, 8, 10 and 11; chlorophyll b increased: by 67,56 % - under the effect of NAA, by 94,99 % - under the effect of Kamethur, by 34,23-101,51 % - under the effect of compounds № 1, 2, 7, 8, 10 and 11; chlorophylls a+b increased: by 26,76 % - under the effect of NAA, by 56,77 % - under the effect of Kamethur, by 25,16-41,14 % - under the effect of compounds № 1, 2, 7, 8, 10 and 11; carotenoids increased: by 8,52 % - under the effect of compound № 8, respectively, compared to control plants (Figure 5).

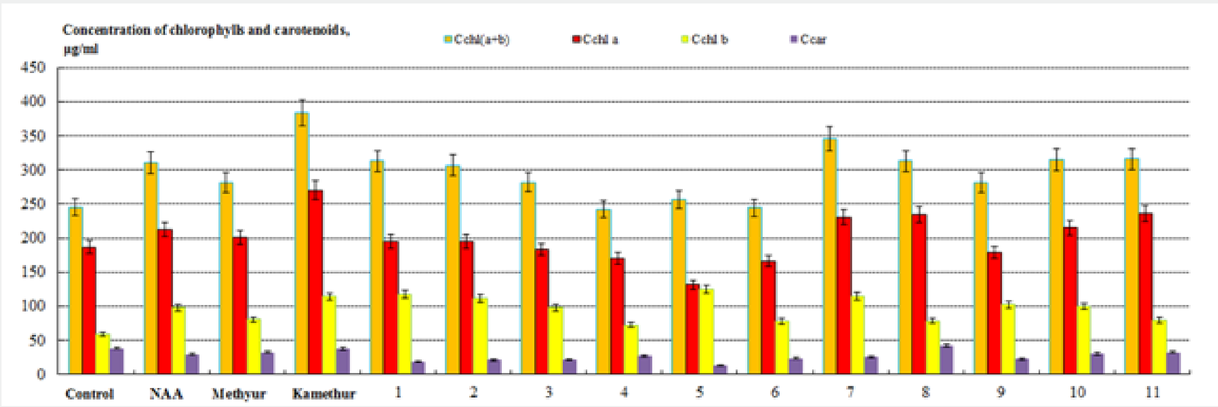

Figure 5: The content of chlorophyll a, chlorophyll b, and carotenoids (µg/ml) in the leaves of 3-week-old soybean plants (*G. max* (L.) Merr.) of the Syaivo variety, grown under conditions of heat and drought and under the effect of auxin NAA, as well as synthetic compounds: Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1-11) at a concentration of 10^{-6}M, compared to control soybean plants.

The lower indicators of content of photosynthetic pigments were found in the leaves of soybean plants treated with the synthetic compound Methyur and compounds, derivatives of thioxopyrimidine № 3, 4, 5, 6 and 9. An increase in the content of photosynthetic pigments was observed under effect of these compounds as follows: chlorophyll a increased: by 7,66 % - under the effect of Methyur; chlorophyll b increased: by 37,47 % - under the effect of Methyur, by 23,91-113,86 % - under the effect of compounds № 3, 4, 5, 6 and 9; chlorophylls a+b increased: by 14,77 % - under the effect of Methyur, by 4,65-14,97 % - under the effect of compounds № 3, 4, 5, 6 and 9, respectively, compared to control plants (Figure 5).

At the same time, auxin NAA, synthetic compounds Methyur, Kamethur and compounds, derivatives of thioxopyrimidine № 1, 2, 3, 4, 5, 6, 7, 9, 10 and 11 did not show stimulating activity on indicators of carotenoid content, which statistically did not differ significantly or were slightly lower than the indicators of control plants (Figure 5).

It should be noted that the results obtained confirmed the positive effect of synthetic compounds Methyur, Kamethur, and derivatives of thioxopyrimidine № 1, 2, 7, 8, 10 and 11 on increasing the chlorophyll content in the leaves of soybean plants, which play a key role in photosynthesis and ensuring plant productivity [35, 36,48-50].

The increase in the content of photosynthetic pigments is likely due to the cytokinin-like effect of the tested compounds on increasing chlorophyll synthesis and slowing down their degradation in soybean plants grown under conditions of heat and drought [54,55].

Thus, the conducted studies showed that the highest regulatory effect on morphometric parameters and content of photosynthetic pigments in soybean plants was found in synthetic compounds, derivatives of 6-methyl-2-mercapto-4-hydroxypyrimidine sodium and potassium salts (Methyur and Kamethur) and derivatives of thioxopyrimidine № 1, 2, 5, 6, 7, 8, 10 та 11.

Analyzing the relationship between the chemical structure and regulatory effect of synthetic compounds, derivatives of thioxopyrimidine № 1, 2, 5, 6, 7, 8, 10 and 11, which showed the highest effect according to morphometric parameters and content of photosynthetic pigments in soybean plants, it is possible to suggest that their high activity similar to phytohormones auxins and cytokinins is associated with the presence of substituents in the

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chemical structures of the compounds (Table 1): compound № 1 contains a benzenesulfonyl group in position 5, an ethyl group in position 3 of the 2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one ring; compound № 2 contains an allyl substituent in position 3, a phenylsulfonyl group in position 5 of the 2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one ring; compound № 5 contains a *p*-tolyl group in position 6, a cyano group in position 5 of the 4-oxo-2-thioxo-1,2,3,4-tetrahydropyrimidine ring; compound № 6 contains a phenyl group in position 6, a cyano group in position 5 of the 4-oxo-2-thioxo-1,2,3,4-tetrahydropyrimidine ring; compound № 7 contains a methylsulfanyl group in position 2, a *p*-tolyl group in position 4, and a cyano group in position 5 of the 6-oxo-1,6-dihydropyrimidine ring; compound № 8 contains a methyl group in position 6, a phenyl group in position 4, and an ethoxycarbonyl group in position 5 of the 2-thioxo-1,2,3,4-tetrahydropyrimidine ring; compound № 10 contains a methyl group in position 6, a 4-methoxycarbonylphenyl group in position 4, and an ethoxycarbonyl group in position 5 of the 2-thioxo-1,2,3,4-tetrahydropyrimidine ring; compound № 11 contains a methyl group in position 6, a 4-hydroxyphenyl group in position 4, and an ethoxycarbonyl group in position 5 of the 2-thioxo-1,2,3,4-tetrahydropyrimidine ring.

At the same time, the synthetic compounds, derivatives of thioxopyrimidine № 3, 4 and 9 showed less auxin- and cytokinin-like effects according to morphometric parameters and content of photosynthetic pigments in soybean plants, which is possible due to the presence of substituents in the chemical structures of the compounds (Table 1): compound № 3 contains a benzyl substituent in position 5, a methyl group in position 6 of the 2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one ring; compound № 4 contains a phenyl group in position 3, a benzenesulfonyl group in position 5 of the 2-thioxo-2,3-dihydro-1*H*-pyrimidin-4-one ring; compound № 9 contains a methyl group in position 6, a 4-methoxyphenyl group in position 4, and an ethoxycarbonyl group in position 5 of the 2-thioxo-1,2,3,4-tetrahydropyrimidine ring.

The results of this work correlate with our previous research on synthetic derivatives of 6-methyl-2-mercapto-4-hydroxypyrimidine sodium and potassium salts (Methyur and Kamethur) and other derivatives of pyrimidine on various important agricultural crops such as cereals, legumes and industrial crops [21-33,56-63]. The use of these synthetic compounds for pre-sowing treatment of seeds before planting in an artificial substrate - perlite in laboratory conditions, or in soil in field conditions, in the most optimal physiologically active concentrations of 10^{-5}M-10^{-7}M, contributed to improving the growth and development of the root system and shoots during the vegetative stage and increasing plant yield [21-33, 56-63]. It should be noted that the regulatory activity of synthetic compounds, derivatives of pyrimidine, was differentiated depending on the species and variety of plants. That is, we can conclude about the selectivity of their regulatory activity on different crops. However, the protective effect of these compounds on plant growth and development under stressful abiotic factors such as drought and heat has not been previously investigated.

Conclusion

The results obtained in this work confirmed the fact that pre-sowing treatment of soybean seeds with the most active synthetic compounds, derivatives of 6-methyl-2-mercapto-4-hydroxypyrimidine sodium and potassium salts (Methyur and Kamethur) and derivatives of thioxopyrimidine № 1, 2, 5, 6, 7, 8, 10 та 11, used at a concentration of 10^{-6}M, before planting seeds in an artificial substrate - perlite in laboratory conditions, considerably improves the growth and development of roots and shoots of soybean plants in the vegetative phase, enhances the biosynthesis of photosynthetic pigments in plant leaves, which contributes to the adaptation of plants to such abiotic stress factors as heat and drought.

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DOI: 10.19080/ARTOAJ.2025.29.556445

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