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Research Article

Screening of Synthetic Auxin-Like and Cytokinin-Like Compounds, Derivatives of Thioxopyrimidine as New Plant Growth Regulators

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Abstract

This study is devoted to the development of new plant growth regulators based on synthetic low-molecular nitrogen-containing heterocyclic compounds, derivatives of thioxopyrimidine. The regulatory activity of synthetic compounds, derivatives of thioxopyrimidine was studied at the vegetative stage of wheat plants. A comparative analysis of plant growth regulatory activity was carried out between plant hormones such as auxin 1-Naphthylacetic Acid (NAA) and cytokinin N-(2-Furylmethyl)-7*H*-purin-6-amine (Kinetin), known synthetic compounds such as derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and new synthetic compounds such as derivatives of thioxopyrimidine. Morphometric parameters such as average shoot and root length (mm), average biomass of 10 plants (g) and biochemical parameters such as photosynthetic pigment content (mg/g FW) of wheat plants were measured at the 3rd week of the vegetative phase. As a result of the screening, new synthetic compounds, derivatives of thioxopyrimidine were selected that showed regulatory activity on morphometric and biochemical parameters of wheat plants that was similar to or exceeded the regulatory activity of auxin NAA and cytokinin Kinetin or the synthetic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur). The hormone-like specificity and selectivity of the regulatory activity of new synthetic compounds, derivatives of thioxopyrimidine, on wheat growth are discussed. An analysis of the relationship between plant growth regulatory activity and the chemical structure of synthetic compounds, derivatives of thioxopyrimidine, was carried out. Selected synthetic compounds, derivatives of thioxopyrimidine, which showed the highest auxin-like and cytokinin-like regulatory activity, are proposed for use in the agricultural industry as new wheat plant growth regulators.

Keywords: *Triticum aestivum* L; NAA; Kinetin; Methyur; Kamethur; Thioxopyrimidine derivatives

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops for human nutrition worldwide and wheat production leads all major cereal crops, including maize, rice, barley, oats and sorghum [1,2]. Wheat provides beneficial components, which are essential and beneficial for human health such as protein, B vitamins, minerals, dietary fiber, showing high digestibility and phytochemicals such as alkaloids, glycosides, flavonoids, saponins, steroids, terpenoids and tannins that exhibit therapeutic properties in the treatment of various diseases [1-4]. Global climate change, resulting in extreme temperatures, drought, heat, water scarcity and soil salinization, has dramatically altered global wheat production, reducing wheat yields [1,2,5-7]. Modern agriculture uses fertilizers, plant hormones, biostimulants and plant growth-promoting bacteria to improve wheat growth and photosynthesis efficiency, which contributes to better absorption of nutrients, enhanced wheat resistance to abiotic stress and phytopathogens and increased yields [8-13]. In recent years, considerable attention has been paid to studying the important role of plant hormones in regulating plant growth and development at all stages of the life cycle, including plant embryogenesis, seed germination, seedling growth, branching, flowering, fertilization, fruit formation, fruit ripening and senescence, as well as in regulating plant adaptation to abiotic and biotic stress factors [14-17]. The advantage of using plant hormones in agriculture as plant growth regulators is their environmental safety; in addition, plant hormones play a key role in signaling for plant-animal-microbe interactions and have physiological regulatory and therapeutic effects on human and animal health [14].

Among plant hormones, auxins and cytokinins play key roles in plant growth and development, controlling seed germination, the formation and development of root and shoot meristems during the vegetative stage, photosynthesis in plant leaves and plant productivity [18-21]. Currently, natural auxins and cytokinins such as IAA (indole-3-acetic acid), 4-Cl-IAA (4-chloro-IAA), PAA (phenyl acetic acid), 2-(2,4-dichloro-phenoxy) propionic acid (2,4-DP), IPA (indole-3-pyruvic acid), IBA (indole-3-butyric acid), indole-3-lactic acid (ILA), zeatin (N6-(4-Hydroxy-3-methyl-2-buten-1-yl)adenine) or synthetic analogues of auxins and cytokinins such as NAA (1-naphthylacetic acid), 2,4-D (2,4-dichlorophenoxyacetic acid), 3,4-D (3,4-dichlorophenoxyacetic acid), 4-CPA (4-chlorophenoxyacetic acid), 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), picloram (4-amino-3,5,6-trichloropyridine-2-carboxylic acid), dicamba (3,6-dichloro-2-methoxybenzoic acid), DAS534 (4-amino-3-chloro-6-(4-chlorophenyl)-5-fluoro-pyridine-2-carboxylic acid), quinclorac (3,7-dichloroquinoline-8-carboxylic acid), kinetin (6-furfurylaminopurine), BA (N6-benzyladenine), BAP (6-benzylaminopurine), BPA (N-benzyl-9-(2-tetrahydropyranyl)-adenine), 2iP (N6-(2-isopentenyl)adenine), TDS (thidiazuron) are used in agriculture to improve the growth and increase the yield of agricultural crops [21-31].

Today, new substances have been developed based on synthetic low-molecular nitrogen-containing heterocyclic compounds that regulate plant growth and have a physiological effect on plant cell division, cell expansion and cell differentiation similar to natural auxins and cytokinins [32,33]. Among these compounds, pyrimidine derivatives represent the greatest potential for the development of auxin-like and cytokinin-like substances for the regulation of plant growth and productivity [34-37]. In addition to the properties that regulate plant growth, pyrimidine derivatives are widely used in medicine as therapeutic agents in the treatment of bacterial, fungal, viral, oncological, inflammatory, tuberculosis, diabetic, hypertensive, cardiological, nervous, malarial and helminthic diseases [38-48]. The new auxin-like and cytokinin-like substances based on synthetic low-molecular nitrogen-containing heterocyclic compounds, pyrimidine derivatives have been developed in the V.P. Kukhar Institute of Bioorganic Chemistry and Petrochemistry, National Academy of Sciences of Ukraine. The best-known representatives of these synthetic compounds are derivatives of the sodium salt and potassium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur and Kamethur), as well as new synthetic compounds, derivatives of pyrimidine, which have been studied on important agricultural and industrial crops [32,33].

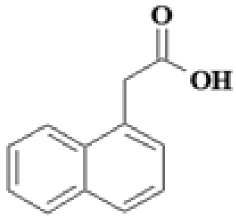
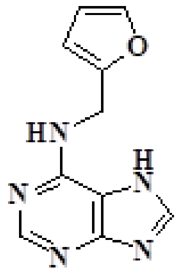
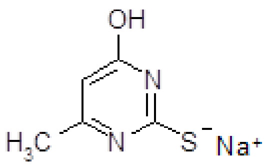
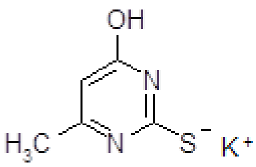
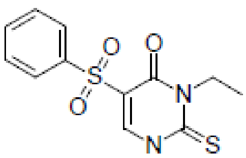
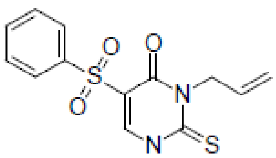
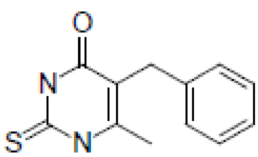
Numerous studies [49-65] have proven their high plant growth-regulating effect, equivalent or more pronounced compared to the effect, of natural and synthetic auxins and cytokinins, which is of great economic and environmental significance. The use of these new synthetic compounds, derivatives of pyrimidine, only for pre-sowing treatment of seeds in low concentrations from 10^{-5}M to 10^{-8}M, non-toxic to plants, humans and animals, allows reducing pollution of the environment and soil. Given the research results, the development of new effective and environmentally friendly plant growth regulators based on synthetic low-molecular-weight nitrogen-containing heterocyclic compounds, derivatives of pyrimidine, is of considerable interest for the economically important wheat crop. The aim of this work is screening of new synthetic low-molecular-weight nitrogen-containing heterocyclic compounds, derivatives of thioxopyrimidine with auxin-like and cytokinin-like activity for wheat growth regulation.

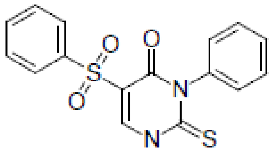
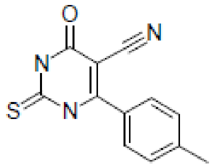
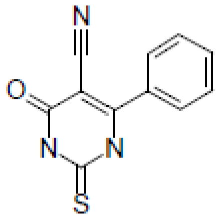
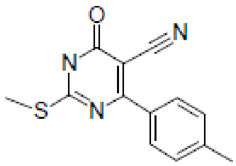
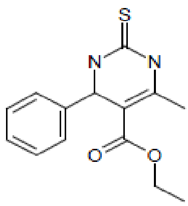
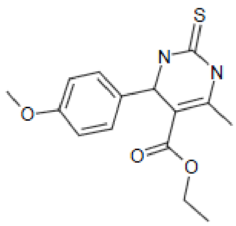
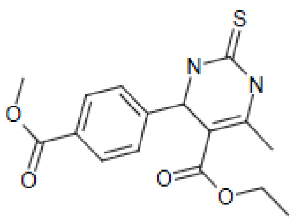
Materials and Methods

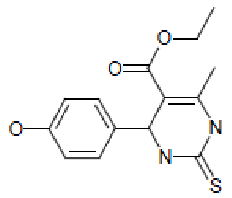
Chemical name and structure of the studied compounds

In our study, the plant growth regulatory activity of new synthetic compounds, derivatives of thioxopyrimidine (compounds № 1-11), was compared with the plant growth regulatory activity of synthetic plant hormones auxin NAA (1-Naphthylacetic acid) and cytokinin Kinetin (N-(2-Furylmethyl)-7*H*-purin-6-amine) or known 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). All tested synthetic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur Kamethur) and 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. Synthetic plant hormones auxin NAA (1-Naphthylacetic acid) and cytokinin Kinetin (N-(2-Furylmethyl)-7*H*-purin-6-amine) were manufactured by Sigma-Aldrich, USA. Chemical structure, name and relative molecular weight of synthetic plant hormones NAA and Kinetin, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur Kamethur) and derivatives of thioxopyrimidine (compounds № 1-11) are given in Table 1.

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

Chemical Compound	Chemical Structure	Chemical Name and Relative Molecular Weight (g/mol)
NAA		1-Naphthylacetic acid, MW=186.21
Kinetin		N-(2-Furylmethyl)-7*H*-purin-6-amine, MW=215.22
Methyur		Sodium salt of 6-methyl-2-mercapto-4-hydroxypyrimidine, 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
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

Seed treatment and plant cultivation

The seeds of winter wheat (*Triticum aestivum* L.) variety Zysk were sterilized with 1 % KMnO4 solution for 15 min, then treated with 96% ethanol solution for 1 min, after which they were washed three times with sterile distilled water. After this procedure, wheat seeds were placed in the plastic cuvettes (each containing 25-30 seeds) on the perlite moistened with distilled water (control sample) or water solutions of synthetic plant hormones auxin NAA (1-Naphthylacetic acid) or cytokinin Kinetin (N-(2-Furylmethyl)-7*H*-purin-6-amine), or 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 (experimental samples). Then the wheat seeds were placed in a thermostat for germination in the dark at a temperature of 20-22 °C for 48 hours. After germination, the wheat seedlings were placed in a climate chamber, where they were grown for 3 weeks at the 16/8h light/dark conditions, at the temperature 20-22 °C, light intensity of 3000 lux and air humidity 60-80%. Comparative analysis of morphometric parameters of wheat plants (average length of shoots and roots (mm), average biomass of 10 plants (g)) was carried out at the end of the 3-week period according to methodological guidelines [66].

Extraction and measurement of the content of photosynthetic pigments

To perform the extraction of photosynthetic pigments, we homogenized a sample (500mg) of wheat 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 0,1-0,2g $CaCO_3$ (to neutralize the plant acids). The 1ml of obtained homogenate was centrifuged at 8000g in a refrigerated centrifuge K24D (MLW, Engelsdorf, Germany) during 5 min at the temperature 4 °C. The obtained precipitate was washed three times, with 1ml 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 in wheat leaves was calculated in accordance with formula [67,68].

Cchl a = 13.36×A664.2 - 5.19×A648.6,

Cchl b = 27.43×A648.6 - 8.12A×664.2,

Cchl (a + b) = 5.24×A664.2 + 22.24×A648.6,

Ccar = (1000×A470 - 2.13×Cchl a - 97.64×Cchlb)/209,

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.

Chlorophylls and carotenoids extracted from wheat leaves were calculated per 1g of Fresh Weight (FW) using the following formula (separately for chlorophyll a, chlorophyll b and carotenoids):

A_1=(C×V)/(1000×a1),

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 wheat leaves (g).

The content of chlorophyll a, chlorophyll b, and carotenoids (%) determined in experimental wheat leaves was calculated according to similar parameters determined in control wheat leaves. Statistical processing of the experimental data, performed in triplicate, was carried out according to the student's t-test with a significance level of $P \leq 0.05$; mean values ± Standard Deviation (± SD) [69].

Result and Discussion

Determination of morphometric parameters of wheat plants

Comparative analysis of plant growth regulatory activity between synthetic plant hormones auxin NAA (1-Naphthylacetic acid) or cytokinin Kinetin (N-(2-Furylmethyl)-7*H*-purin-6-amine), or 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 was carried out. Morphometric parameters of experimental wheat plants treated with plant hormones and all synthetic compounds were compared with those of control wheat plants treated with distilled water. The results obtained confirmed the positive effect of plant hormones NAA and Kinetin, as well as the synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine on the growth of wheat seedlings for 3 weeks. A significant increase in the growth of shoots and roots of wheat plants treated with the plant hormones NAA and Kinetin, as well as the synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine at a concentration of 10^{-6}M, was observed (Figure 1).

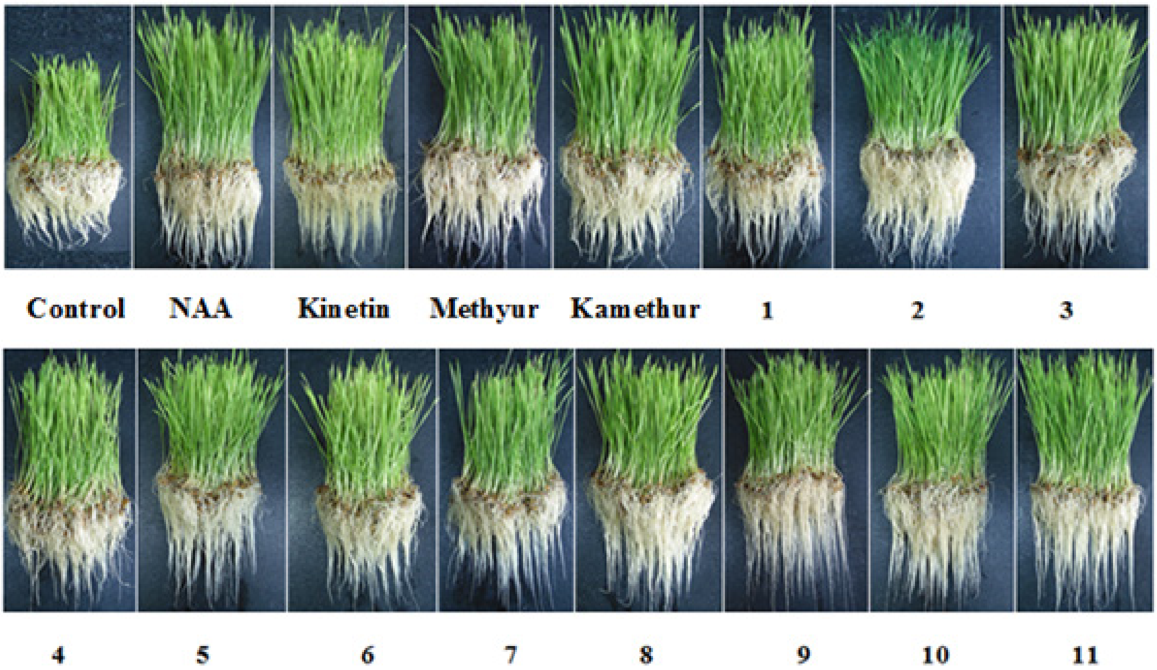


Figure 1: The 3-week-old seedlings of winter wheat (*Triticum aestivum* L.) variety Zysk, grown under treatment with plant hormones NAA and Kinetin or synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1 - 11) at a concentration of 10^{-6}M compared to control plants.

The results of statistical analysis of morphometric parameters of wheat plants (average length of shoots and roots (mm), average biomass of 10 plants (g)) are shown in Figures 2-4. The morphometric parameters of experimental wheat plants treated with plant hormones and synthetic compounds were higher with those of control wheat plants treated with distilled water. The activity of the synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine on the growth of wheat seedlings was similar to or higher than the activity of the plant hormones NAA and Kinetin.

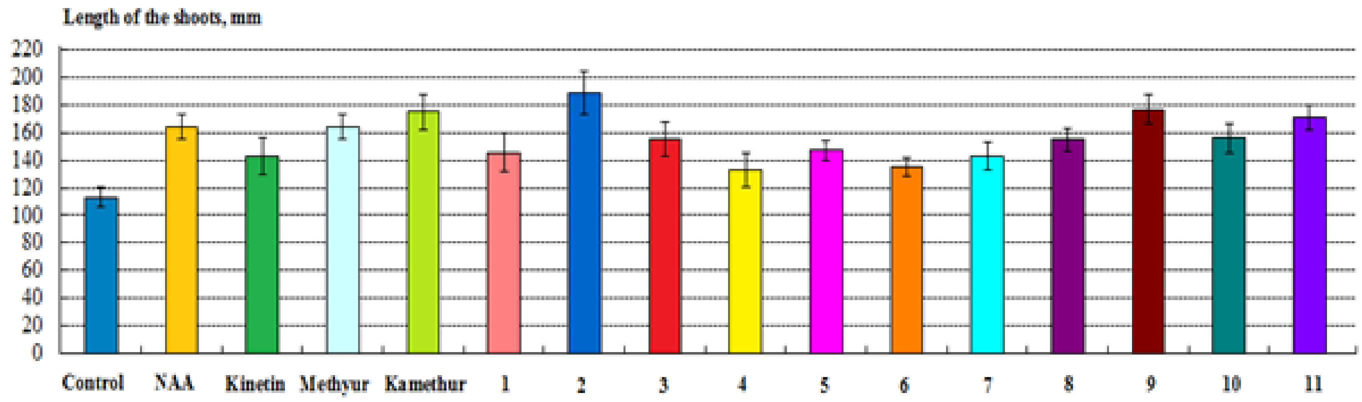


Figure 2: The average length of shoots (mm) of 3-week-old seedlings of winter wheat (*Triticum aestivum* L.) variety Zysk, grown under treatment with plant hormones NAA and Kinetin or synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1 - 11) at a concentration of 10^{-6}M compared to control plants.

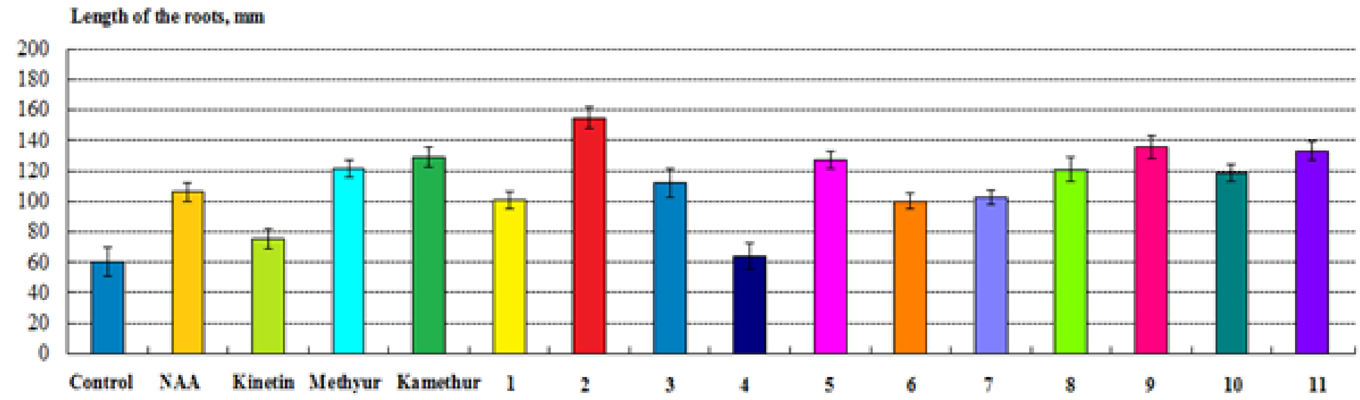


Figure 3: The average length of roots (mm) of 3-week-old seedlings of winter wheat (*Triticum aestivum* L.) variety Zysk, grown under treatment with plant hormones NAA and Kinetin or synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1 - 11) at a concentration of 10^{-6}M compared to control plants.

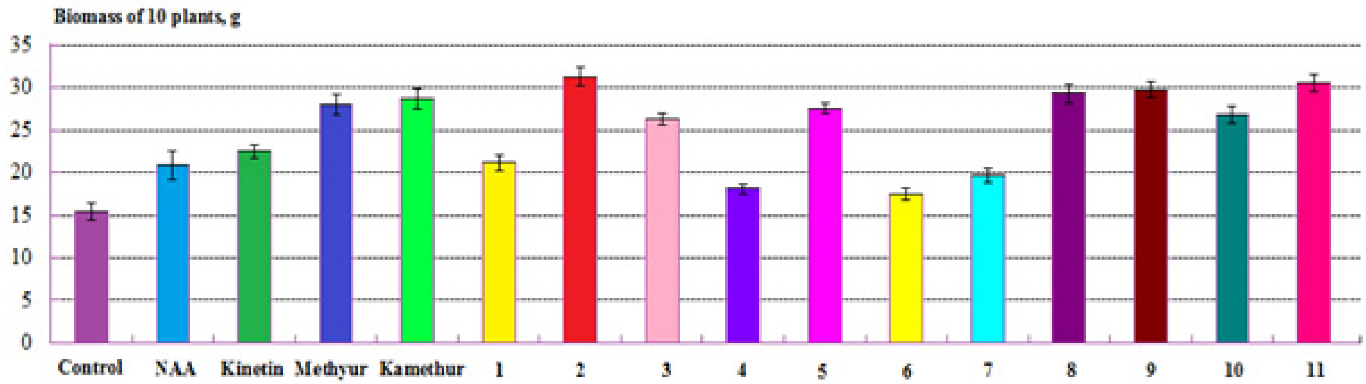


Figure 4: The average biomass of 10 plants (g) of 3-week-old seedlings of winter wheat (*Triticum aestivum* L.) variety Zysk, grown under treatment with plant hormones NAA and Kinetin or synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1 -11) at a concentration of 10^{-6}M compared to control plants.

Auxin NAA and synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine № 2, 3, 5, 7, 8, 9, 10 and 11 demonstrated the highest regulatory activity on the growth of wheat shoots. The average length of wheat shoots (mm) increased: by 45,14% - in wheat treated with NAA, by 45,14% - in wheat treated with Methyur, by 54,87% - in wheat treated with Kamethur, by 26,55-67,26% - in wheat treated with derivatives of thioxopyrimidine № 2, 3, 5, 7, 8, 9, 10 and 11 compared to control plants (Figure 2). Cytokinin Kinetin and synthetic compounds, derivatives of thioxopyrimidine № 1, 4 and 6 demonstrated the lower regulatory activity on the growth of wheat shoots. The average length of wheat shoots (mm) increased: by 26,55% - in wheat treated with Kinetin, by 17,73-28,94% - in wheat treated with derivatives of thioxopyrimidine № 1, 4 and 6 compared to control plants.

The studies have shown that auxin NAA and synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 demonstrated the highest regulatory activity on the growth of wheat roots. The average length of wheat roots (mm) increased: by 76,67% - in wheat treated with NAA, by 103,1% - in wheat treated with Methyur, by 115,28% - in wheat treated with Kamethur, by 86,67-158,33% - in wheat treated with derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 compared to control plants (Figure 3). Cytokinin Kinetin and synthetic compounds, derivatives of thioxopyrimidine № 1, 4, 6 and 7 demonstrated the lower regulatory activity on the growth of wheat roots. The average length of wheat roots (mm) increased: by 25% - in wheat treated with Kinetin, by 6,68-71,21% - in wheat treated with derivatives of thioxopyrimidine № 1, 4, 6 and 7 compared to control plants.

The studies have also shown that synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 demonstrated the highest regulatory activity on wheat biomass growth. The average biomass of 10 plants (g) increased: by 81,99% - in wheat treated with Methyur, by 86,25% - in wheat treated with Kamethur, by 71,54-103,5% - in wheat treated with derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 compared to control plants (Figure 4). Auxin NAA, cytokinin Kinetin and synthetic compounds, derivatives of thioxopyrimidine № 1, 4, 6 and 7 demonstrated the lower regulatory activity on wheat biomass growth. The average biomass of 10 plants (g) increased: by 35,42%

- in wheat treated with NAA, by 46,62% - in wheat treated with Kinetin, by 13,77-37,75% - in wheat treated with derivatives of thioxopyrimidine № 1, 4, 6 and 7 compared to control plants(Figure 4).

Determination of the content of photosynthetic pigments in wheat plants

The regulatory activity of synthetic plant hormones auxin NAA (1-Naphthylacetic acid), cytokinin Kinetin (N-(2-Furylmethyl)-7*H*-purin-6-amine), 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) at a concentration of 10^{-6}M on the content of photosynthetic pigments (mg/g FW) in wheat plants was investigated. The results obtained showed that the content of photosynthetic pigments (chlorophyll a, chlorophyll b, chlorophylls a+b and carotenoids) in wheat plants was increased in wheat plants treated with plant hormones and all synthetic compounds, compared to similar indicators in control wheat plants treated with distilled water. Auxin NAA, cytokinin Kinetin and synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine № 1, 2, 5, 8, 9, 10 and 11 demonstrated the highest regulatory activity on the content of photosynthetic pigments in wheat plants.

The content of chlorophyll a increased: by 43,99% - in wheat treated with NAA, by 32,53% - in wheat treated with Kinetin, by 4,97% - in wheat treated with Methyur, by 37,32% - in wheat treated with Kamethur, by 10,32-104,03% - in wheat treated with derivatives of thioxopyrimidine № 1, 2, 5, 8, 9, 10 and 11 compared to control plants. The content of chlorophyll b increased: by 49,73% - in wheat treated with NAA, by 9,43% - in wheat treated with Kinetin, by 100,29% - in wheat treated with Methyur, by 23,03% - in wheat treated with Kamethur, by 14,88-57,32% - in wheat treated with derivatives of thioxopyrimidine № 1, 2, 5, 8, 9, 10 and 11 compared to control plants. The content of chlorophylls a+b increased: by 45,98% - in wheat treated with NAA, by 24,54% - in wheat treated with Kinetin, by 37,96% - in wheat treated with Methyur, by 32,38% - in wheat treated with Kamethur, by 11,9-86,16% - in wheat treated with derivatives of thioxopyrimidine № 1, 2, 5, 8, 9, 10 and 11 compared to control plants. The content of carotenoids increased: by 7,89 % – in wheat treated with NAA, by 27,28 % – in wheat treated with Kinetin, by 11,81 % – in wheat treated with Kamethur, by 2–76,65 % – in wheat treated with derivatives of thioxopyrimidine № 2, 9, 10 and 11 compared to control plants. At the same time, the synthetic compounds Methyur and derivatives of thioxopyrimidine № 1, 5 and 8 did not show regulatory activity on the content of carotenoids in wheat, which did not statistically significantly differ from similar indicators in control plants (Figure 5). The studies have also shown that synthetic compounds, derivatives of thioxopyrimidine № 3, 4, 6 and 7, demonstrated lower regulatory activity on the content of photosynthetic pigments in wheat plants. The content of chlorophyll a increased: by 2,65-6,78%, the content of chlorophyll b increased: by 5,56-28,5%, the content of chlorophylls a+b increased: by 2-12,66% - in wheat treated with synthetic compounds, derivatives of thioxopyrimidine № 3, 4, 6 and 7 compared to control plants. At the same time, the synthetic compounds, derivatives of thioxopyrimidine № 3, 4, 6 and 7 showed the lowest regulatory activity on the content of carotenoids in wheat, which decreased by 9,8-31,4% compared to control plants.

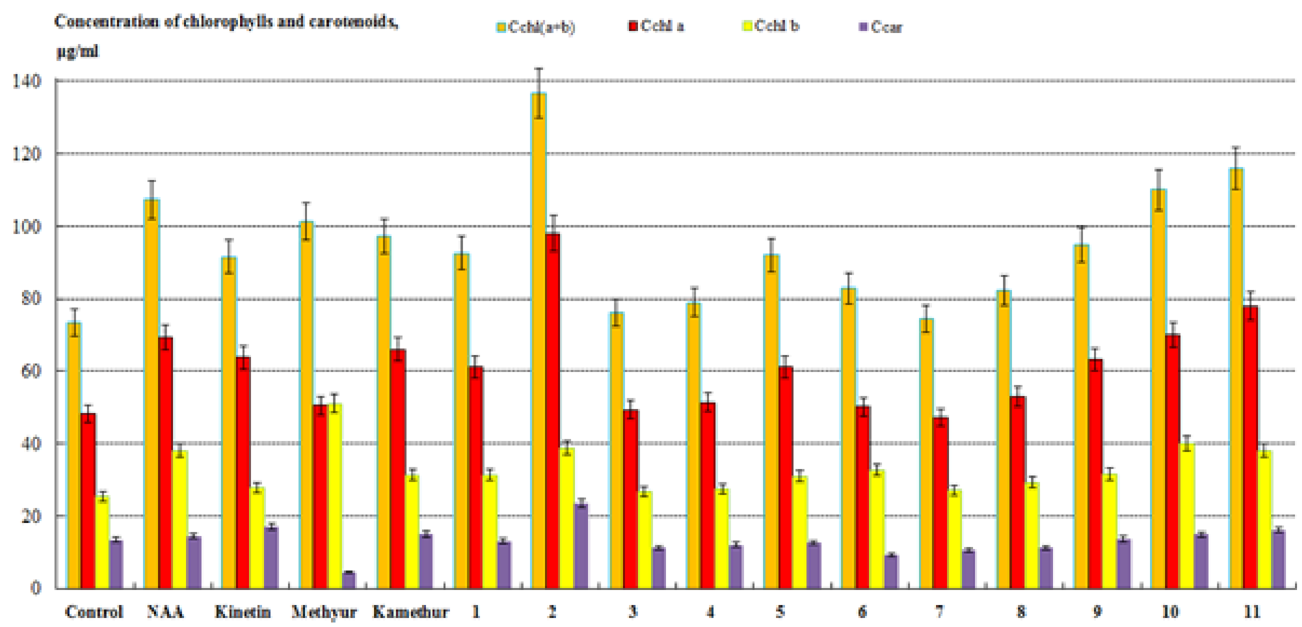


Figure 5: The content of chlorophyll a, chlorophyll b, chlorophylls a+b and carotenoids (µg/ml) in 3-week-old seedlings of winter wheat (*Triticum aestivum* L.) variety Zysk, grown under treatment with plant hormones NAA and Kinetin or synthetic compounds Methyur, Kamethur and derivatives of thioxopyrimidine (compounds № 1 - 11) at a concentration of 10^{-6}M compared to control plants.

Analyzing the relationship between the chemical structure and selectivity of the regulatory activity of synthetic compounds, thioxopyrimidine derivatives, according to morphometric and biochemical indicators of plants, it is possible to suggest that their activity, similar to plant hormones auxins and cytokinins, is associated with the presence of substituents in the chemical structures of these compounds (Table 1). The synthetic compounds, derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 showed the highest regulatory effect on the morphometric and biochemical parameters of plants, these compounds contain: 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 № 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 № 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 № 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 № 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; 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 least regulatory effect on the morphometric and biochemical parameters of plants was found in synthetic compounds, derivatives of thioxopyrimidine № 1, 4, 6 and 7, which contain: 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 № 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 № 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. Summarizing the obtained morphometric parameters of wheat plants (average length of shoots and roots (mm), average biomass of 10 plants (g)), it should be noted that new synthetic compounds, derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 showed the highest plant growth regulatory activity, which was similar or higher than that of the auxin NAA, cytokinin Kinetin and synthetic compounds Methyur and Kamethur. The obtained data indicate that the activity of these synthetic compounds, similar to the plant hormones auxin and cytokinin, is due to their hormone-like effect on the processes of division, elongation and differentiation of plant cells, which are the basis for the growth and development of root and shoot meristems during the vegetative stage [18-21].

The results obtained also indicate the hormone-like activity of synthetic compounds Methyur, Kamethur and the most active derivatives of thioxopyrimidine № 2, 5, 8, 9, 10 and 11, on increasing the content of chlorophylls and carotenoids in 3-week-old wheat seedlings. Apparently, the hormone-like activity of these synthetic compounds on the processes of photosynthesis in wheat seedlings is associated with their regulatory effect, similar to cytokinins, on enhancing the biosynthesis and preventing the degradation of chlorophylls and carotenoids in plant leaves, which play an important role in plant productivity [21,70,71].

The results of our previously published work [72], which investigated the regulatory effect of synthetic compounds Methyur, Kamethur and thioxopyrimidine derivatives № 1-11 (Table 1), on the growth and photosynthesis of wheat (*Triticum aestivum* L.) variety Svitlana in the vegetative phase, correlate with our current findings. In this work, the regulatory effect of the synthetic compounds Methyur, Kamethur and thioxopyrimidine derivatives № 1-11 at a concentration of 10^{-6}M was compared with the regulatory effect of auxin IAA (1*H*-indol-3-yl) acetic acid), used at a similar concentration. The results obtained showed that the highest auxin-like and cytokinin-like activity in terms of morphometric parameters and the content of photosynthetic pigments in wheat (*Triticum aestivum* L.) variety Svitlana grown for 2 weeks was demonstrated by synthetic compounds Methyur, Kamethur and thioxopyrimidine derivatives № 2, 3, 5, 6, 7, 8, 9 and 11. Their plant growth regulatory activity was similar or higher than that of auxin IAA. Synthetic compounds of thioxopyrimidine derivatives, such as compounds № 1, 4, and 10, demonstrated lower auxin-like and cytokinin-like activity in terms of morphometric parameters and the content of photosynthetic pigments in wheat (*Triticum aestivum* L.) variety Svitlana.

Comparing the results of the work [72] with the data of the present work, it should be noted that synthetic compounds Methyur, Kamethur and thioxopyrimidine derivatives № 2, 3, 5, 8, 9 and 11 showed the highest auxin-like and cytokinin-like growth-regulating activity on both wheat varieties - Svitlana and Zysk and compounds № 1 and 4 showed less growth-regulating activity on both wheat varieties - Svitlana and Zysk. At the same time, synthetic compounds of thioxopyrimidine derivatives № 6, 7, and 10 showed selective growth-regulating activity depending on the wheat variety. These results indicate the variety-specificity of the growth-regulating activity of synthetic compounds of thioxopyrimidine derivatives № 6, 7 and 10 on wheat plants.

Conclusion

A comparative study of the plant growth regulatory activity of synthetic low-molecular nitrogen-containing heterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and new derivatives of thioxopyrimidine № 1-11 (Table 1) was conducted. The most active synthetic compounds such as Methyur, Kamethur and derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11, which show the highest auxin-like and cytokinin-like activity on the growth and photosynthesis of wheat plants, were selected. Based on the results obtained, it can be concluded that the use in agricultural practice of synthetic compounds Methyur, Kamethur and selected derivatives of thioxopyrimidine № 2, 3, 5, 8, 9, 10 and 11 will contribute to improving growth during the vegetation phase, increasing photosynthesis and yield of the important grain crop wheat (*Triticum aestivum* L.) variety Zysk.

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