SciDoc Publishers
Infer, Interpret & Inspire Science

International Journal of Medical Biotechnology & Genetics (IJMBG)
ISSN: 2379-1020

New Wheat Growth Regulators Based On Thioxopyrimidine Derivatives

Research Article

Tsygankova V.A.[1*], Vasylenko N.M.[1], Andrusevich Ya.V.[1], Kopich V.M.[1], Solomyannyi R.M.[1], Pilyo S.G.[1], Bondarenko O.M.[2], Popilnichenko S.V.[2], Brovarets V.S.[1]

[1] Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds, V.P. Kukhar Institute of Bioorganic Chemistry and Petrochemistry, National Academy of Sciences of Ukraine, 1, Academician Kukhar str., 02094, Kyiv-94, Ukraine.
[2] Department of scientific-organizational work and intellectual property, V.P. Kukhar Institute of Bioorganic Chemistry and Petrochemistry, National Academy of Sciences of Ukraine, 1, Academician Kukhar str., 02094, Kyiv-94, Ukraine.

Abstract

Screening of new growth regulators of wheat (*Triticum aestivum* L.) variety Demira among synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, was carried out. The plant growth-regulating activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives was compared with the activity of plant hormone auxin IAA - (1*H*-indol-3-yl)acetic acid), or with the activity of known synthetic low molecular weight heterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin). For this purpose, wheat seeds were soaked for 48 hours with water solutions of all the studied compounds at a concentration of 10^{-6}M. Control wheat plants were soaked with distilled water. Morphometric parameters (average length of shoots (mm), average length of roots (mm), and average biomass of 10 plants (g)), biochemical parameters (content of photosynthetic pigments chlorophylls a, b, a+b and carotenoids (μg/ml)) of wheat plants were measured after 2 weeks. It has been shown that some synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives exhibit high growth regulating activity on the morphometric and biochemical parameters of wheat plants, similar or higher than the activity of IAA, Methyur, Kamethur and Ivin. The activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives is differentiated depending on their chemical structure. The most active synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, were selected and proposed to be used as new growth regulators of wheat (*Triticum aestivum* L.) variety Demira.

Keywords: Wheat; Auxin IAA; Plant Growth Regulators; Methyur; Kamethur; Ivin; Thioxopyrimidine Derivatives.

Introduction

One of the most important tasks of modern agrobiotechnology is the development of new environmentally friendly plant growth regulators to increase yields and improve the quality of crop products, as well as increase plant resistance to stress factors of abiotic and biotic origin [1, 2]. Special attention is focused on plant biostimulants, which contain compounds of synthetic and natural origin, non-toxic for animals, humans and the environment, increase the immune properties of plants to pathogenic fungi, parasitic nematodes, insects and abiotic stresses [3-5].

A new promising approach is the development of new environmentally friendly plant growth regulators based on synthetic low molecular weight heterocyclic compounds, pyrimidine and pyridine derivatives, which are used as therapeutic agents in medicine [6-12], as well as pesticides and fungicides in agriculture [13- 22]. Among the currently known plant growth regulators created on the basis of synthetic low molecular weight heterocyclic compounds are derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin) [23-28]. These plant growth regulators have regulatory effects, similar to plant hormones, on

***Corresponding Author**:
Tsygankova Victoria Anatolyivna,
Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds, V.P. Kukhar Institute of Bioorganic Chemistry and Petrochemistry, National Academy of Sciences of Ukraine, 1, Academician Kukhar str., 02094, Kyiv-94, Ukraine.
E-mail: vTsygankova@ukr.net

Received: April 01, 2024
Accepted: April 17, 2024
Published: April 30, 2024

Citation: Tsygankova V.A., Vasylenko N.M., Andrusevich Ya.V., Kopich V.M., Solomyannyi R.M., Pilyo S.G., Bondarenko O.M., Popilnichenko S.V., Brovarets V.S., New Wheat Growth Regulators Based On Thioxopyrimidine Derivatives. *Int J Med Biotechnol Genetics.* 2024;S1:02:004:23-30.

the growth and development of important grains, legumes, vegetables, industrial and horticultural crops, increasing their productivity and resistance to abiotic stress factors [23-28]. The use of these plant growth regulators allows reducing the use of pesticides and fungicides that are toxic to humans and animals [29, 30], which has a significant economic effect for agriculture and contributes to the solution of ecological problems for the environment.

In recent years, among synthetic low molecular weight heterocyclic compounds, new biologically active compounds have been discovered that can increase plant productivity by improving the growth and development of plant roots, shoots, and leaves, and enhancing the processes of photosynthesis and protein biosynthesis [31-36]. Along with this, the screening for new synthetic low molecular weight heterocyclic compounds, pyrimidine derivatives, which reveal a regulatory effect related to auxins and cytokinins or synthetic plant growth regulators Methyur, Kamethur or Ivin, is carried out [37-43].

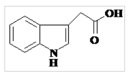
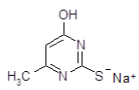
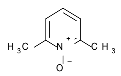
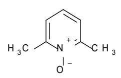
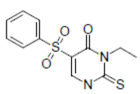
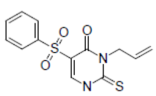
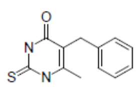
As is known, plant photosynthetic pigments play a key role in photosynthesis and photoprotection of plants and ensure their productivity [44-46]; in addition, plant pigments such as α-carotene, β-carotene, β-cryptoxanthin, lutein, zeaxanthin, lycopene are important biologically active compounds that have found practical use in medicine as therapeutic agents for the prevention and treatment of various human diseases [47, 48]. Our recent studies on various agricultural crops show that the regulatory activity of new synthetic low molecular weight heterocyclic compounds, pyrimidine derivatives on plant growth and development, as well as on the synthesis of photosynthetic pigments chlorophylls and carotenoids in plant leaves, is similar or higher than the activity of plant hormones auxins and cytokinins or synthetic plant growth regulators Methyur, Kamethur and Ivin [37-43].

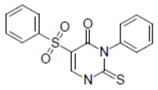
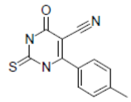
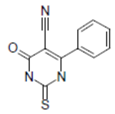
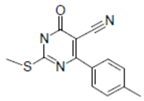
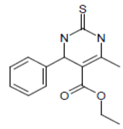
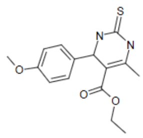
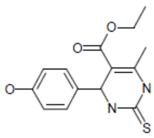
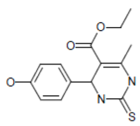
The purpose of this work is the screening of new biologically active compounds among synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, capable of exerting a regulatory effect on growth and photosynthesis of an important grain crop - wheat (*Triticum aestivum* L.) variety Demira.

Materials And Methods

Chemical structures of the studied compounds: The known synthetic low molecular weight heterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur), N-oxide-2,6-dimethylpyridine (Ivin) and new synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives (compounds № 1–11) were synthesized using methods [49-54] 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 (Table 1). Plant hormone auxin IAA (1*H*-indol-3-yl)acetic acid) was manufactured by Sigma-Aldrich, USA (Table 1).

Table 1. Chemical structures of plant hormone auxin IAA - (1*H*-indol-3-yl)acetic acid), synthetic low molecular weightheterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur), N-oxide-2,6-dimethylpyridine (Ivin) and thioxopyrimidine derivatives (compounds № 1–11).

Chemical compound	Chemical structure	Chemical name and relative molecular weight (g/mol)
IAA		1*H*-indol-3-ylacetic acid MW=175.19
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
Ivin		N-oxide-2,6-dimethylpyridine MW=125.17
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

Plant treatment and growing conditions

The seeds of wheat (*Triticum aestivum* L.) variety Demira were sterilized with 1 % $KMnO_4$ 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 15 - 20 seeds) on the perlite moistened with distilled water (control sample),or water solutions of plant hormone auxin IAA - (1*H*-indol-3-yl) acetic acid), or studied synthetic low molecular weight heterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur), N-oxide-2,6-dimethylpyridine (Ivin) and thioxopyrimidine derivatives (compounds № 1–11),which were used 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. After 48 hours, wheat seedlings were placed in a climate chamber, where they were grown at the 16/8 h light/dark conditions, at a temperature of 20-22°C, light intensity of 3000 lux, and air humidity 60-80%.

Determination of morphometric and biochemical parameters of wheat plants. Morphometric parameters of wheat plants (average length of shoots (mm), average length of roots (mm), and average biomass of 10 plants (g)) were measured after 2 weeks according to methodological recommendations [55]. The morphometric parameters determined in the wheat plants of the experimental samples compared to the similar parameters determined in the wheat plants of the control samples were expressed in (%).

Biochemical parameters of wheat plants (content of photosynthetic pigments (µg/ml)) were also measured after 2 weeks according to methodological recommendations [44-46]. To perform the extraction of photosynthetic pigments, we homogenized a sample (500 mg) 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 0,1-0,2 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 a temperature of 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 SpecordM-40 (Carl Zeiss, Germany).

The content of chlorophyll a, chlorophyll b, and carotenoids in wheat leaves was calculated in accordance with formula:

$Cchl\ a = 13.36 \times A664.2 – 5.19 \times A648.6$,
$Cchl\ b = 27.43 \times A648.6 – 8.12A \times 664.2$,
$Cchl\ (a + b) = 5.24 \times A664.2 + 22.24 \times A648.6$,
$Ccar = (1000 \times A470 – 2.13 \times Cchl\ a – 97.64 \times Cchlb)/209$,

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 (FW) of extracted from wheat 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, A1 – 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 biochemical parameters determined in the wheat plants of the experimental samples compared to the similar parameters determined in the wheat plants of the control samples were expressed in (%).

Statistical data analysis

Each experiment was performed three times. Statistical processing of the experimental data was carried out using Student's t-test with a significance level of $P \leq 0.05$; mean values ± standard deviation (± SD) [56].

Results and Discussion

Study of morphometric parameters of wheat plants. The plant growth-regulating activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives was studied. It was shown that synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives exhibit similar or higher activity to the plant hormone auxin IAA - (1*H*-indol-3-yl)acetic acid) orderivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and N-oxide-2,6-dimethylpyridine (Ivin).

Wheat plants obtained from seeds treated with water solutions of all studied synthetic compounds at a concentration of 10^{-6} M grew more intensively and had more developed roots and shoots compared to control wheat plants treated with distilled water (Fig. 1).

Morphometric parameters (average length of shoots (mm)) of the experimental wheat plants, measured after 2 weeks, exceeded the morphometric parameters of the control wheat plants.

The synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1, 4–8 showed the highest activity; the parameters of the average length of shoots increased: by 64,95% - after treatment with Ivin, by 63,92% - after treatment with Methyur, by 57,73 % - after treatment with Kamethur, by 45,36–70,61% - after treatment with most active thioxopyrimidine derivatives № 1, 4–8, respectively, compared to control plants (Fig. 2).

Auxin IAA and synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives № 2, 3, 9–11 showed lower activity; the parameters of the average length of shoots increased: by 32,99% - after treatment with auxin IAA, by 10,31–44,33% - after treatment with thioxopyrimidine derivatives № 2, 3, 9–11, respectively, compared to control plants (Fig. 2).

Morphometric parameters (average length of roots (mm)) of the experimental wheat plants, measured after 2 weeks, exceeded the morphometric parameters of the control wheat plants.

Auxin IAA and synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1, 4–8, 11 showed the highest activity; the parameters of the average length of roots increased: by 87,93% - after treatment with auxin IAA, by 86,21 % - after treatment with Ivin, by 84,62 % - after treatment with Methyur, by 75,86 % - after treatment with Kamethur, by 74,13–150 % - after treatment with most active thioxopyrimidine derivatives № 1, 4–8, 11, respectively, compared to control plants (Fig. 3).

Synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives № 2, 3, 9, 10, showed lower activity; the parameters of the average length of roots increased: by 24,14–68,97% - after treatment with thioxopyrimidine derivatives № 2, 3, 9, 10, respectively, compared to control plants (Fig. 3).

Morphometric parameters (average biomass of 10 plants (g)) of the experimental wheat plants, measured after 2 weeks, exceeded the morphometric parameters of the control wheat plants.

The synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1–9, 11 showed the highest activity; the parameters of the average biomass of 10 plants increased: by 86,67 % - after treatment with Ivin, by 58,33 % - after treatment with Methyur, by 67,5 % - after treatment with Kamethur, by 64,17–125,83 % - after treatment with most active thioxopyrimidine derivatives № 1–9, 11, respectively, compared to control plants (Fig. 4).

Auxin IAA and synthetic heterocyclic compound, thioxopyrimidine derivative № 10 showed lower activity; the parameters of the average biomass of 10 plants increased: by 34,17 % - after treatment with auxin IAA, by 51,67 % - after treatment with thioxopyrimidine derivative № 10, respectively, compared to control plants (Fig. 4).

Summarizing the obtained data, it should be noted that synthetic

Figure 1. The effect of auxin IAA and synthetic low molecular weight heterocyclic compounds Methyur, Kamethur, Ivin and thioxopyrimidine derivatives № 1 – 11 at a concentration of 10^{-6}M on the growth of shoots and roots of 2-week-old wheat (*Triticum aestivum* L.) variety Demira compared to control plants.

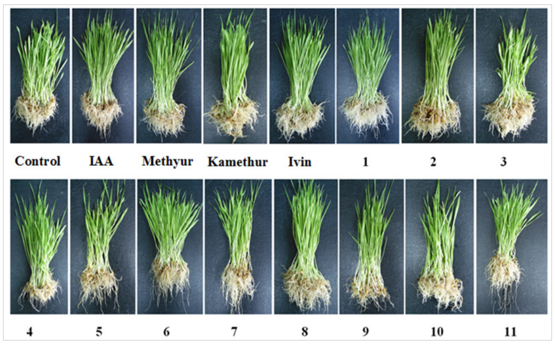


Figure 2. The effect of auxin IAA and synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1 – 11 at a concentration of 10^{-6}M on the average length of shoots (mm) of 2-week-old wheat (*Triticum aestivum* L.) variety Demira compared to control plants.

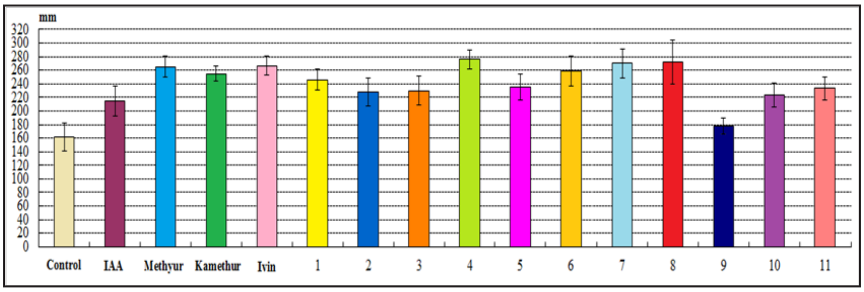


Figure 3. The effect of auxin IAA and synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1 – 11 at a concentration of 10^{-6}M on the average length of roots (mm) of 2-week-old wheat (*Triticum aestivum* L.) variety Demira compared to control plants.

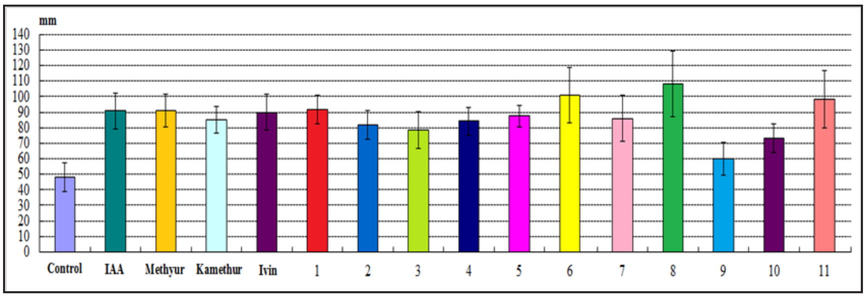
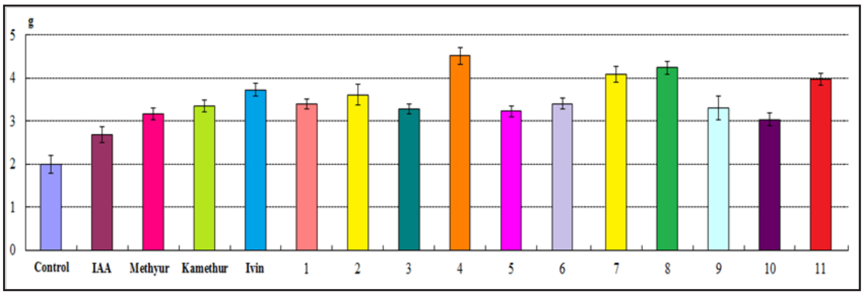


Figure 4. The effect of auxin IAA and synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1 – 11 at a concentration of 10^{-6}M on the average biomass of 10 plants (g) of 2-week-old wheat (*Triticum aestivum* L.) variety Demira compared to control plants.



low molecular weight heterocyclic compounds,derivatives of N-oxide-2,6-dimethylpyridine (Ivin), sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur), and thioxopyrimidine derivatives № 1, 4–8, 11 showed the highest plant growth-regulating activity. The activity of these synthetic low molecular weight heterocyclic compounds, applied at a concentration of 10^{-6}M, was similar to or exceeded the activity of auxin IAA, applied at a similar concentration. It is obvious that the growth-regulating activity of synthetic low molecular weight heterocyclic compounds, similar to auxin IAA, is explained by their auxin-like and cytokinin-like effects on plant cell proliferation, elongation, and differentiation, which are the main processes of the formation and development of shoots and roots [57-59].

Study of biochemical parameters of wheat plants. The effect of synthetic low molecular weight heterocyclic compoundson the content of photosynthetic pigments in the leaves of wheat plantswas also studied. It was found that the biochemical parameters (content of chlorophyll a, chlorophyll b, chlorophylls a+b, and carotenoids (µg/ml)) in the leaves ofthe experimental wheat plants, measured after 2 weeks, exceeded the biochemical parameters of the control wheat plants.

The synthetic low molecular weight heterocyclic compounds Methyur, Kamethur and thioxopyrimidine derivatives № 1, 2, 4, 5, 6, 7, 10 and 11 showed the highest activity. The biochemical parameters (content of chlorophyll a, chlorophyll b, chlorophylls a+b, and carotenoids (µg/ml)) increased: chlorophyll a - by 82 % - after treatment with Methyur, by 95,15 % - after treatment with Kamethur, by 44,72–88,83 % - after treatment with thioxopyrimidine derivatives № 1, 2, 4, 5, 6, 7, 10 and 11; chlorophyll b - by 74,98 % - after treatment with Methyur, by 88,56% - after treatment with Kamethur, by 53,66–101,36% - after treatment with thioxopyrimidine derivatives № 1, 2, 4, 5, 6, 7, 10 and 11; chlorophylls a+b -by 79,65 % - after treatment with Methyur, by 92,97 % - after treatment with Kamethur, by 47,897–93,02% - after treatment with thioxopyrimidine derivatives № 1, 2, 4, 5, 6, 7, 10 and 11; carotenoids - by 62,35 % - after treatment with Methyur, by 71,55 % - after treatment with Kamethur, by 24,86–66,68% - after treatment with thioxopyrimidine derivatives № 1, 2, 4, 5, 6, 7, 10 and 11, respectively, compared to control plants (Fig. 5).

Auxin IAA, synthetic low molecular weight heterocyclic compounds Ivin and thioxopyrimidine derivatives № 3 and 9 showed lower activity. The biochemical parameters (content of chlorophyll a, chlorophyll b, chlorophylls a+b, and carotenoids (µg/ml)) increased: chlorophyll a - by 53,18 % - after treatment with auxin IAA, by 47,15 % - after treatment with Ivin, by 2,96–25,32 % - after treatment with thioxopyrimidine derivatives №3 and 9; chlorophyll b – by 50,06% - after treatment with auxin IAA, by 33,1% - after treatment with Ivin, by 15,42–39,55% - after treatment with thioxopyrimidine derivatives №3 and 9; chlorophylls a+b - by 52,13 % - after treatment with auxin IAA, by 42,45 % - after treatment with Ivin, by 17,18–30,08 % - after treatment with thioxopyrimidine derivatives №3 and 9; carotenoids - by 43,27% - after treatment with auxin IAA, by 55,58% - after treatment with Ivin, by 68,57–69,343 % - after treatment with thioxopyrimidine derivatives №3 and 9, respectively, compared to control plants (Fig. 5).

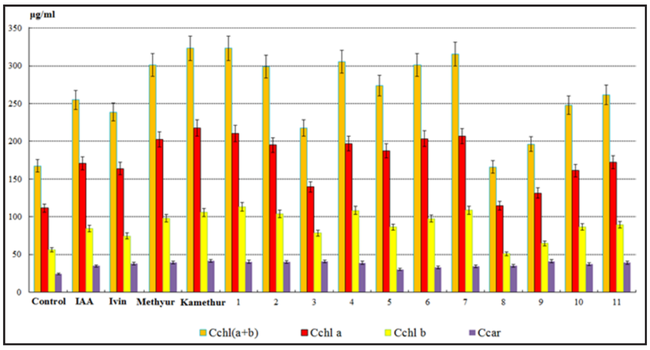
The synthetic heterocyclic compound, thioxopyrimidine derivative № 8 showed a stimulating activity only on the content of carotenoids (µg/ml) in the leaves of wheat plants, which increased by 43,69 % compared to control plants, while the content of chlorophylls a, b, a+b (µg/ml) were not statistically significantly different from the control plants (Fig. 5).

Thus, the obtained results confirmed that synthetic low molecular weight heterocyclic compounds, derivatives of sodium and potassium salts of 6-methyl-2-mercapto-4-hydroxypyrimidine (Methyur, Kamethur) and thioxopyrimidine derivatives №1, 2, 4, 5, 6, 7, 10 and 11revealed the highest stimulating activity on the content of photosynthetic pigments (chlorophyll a, chlorophyll b, chlorophylls a+b, and carotenoids (µg/ml)) in the leaves of wheat plants.The activity of these synthetic low molecular weight heterocyclic compounds, applied at a concentration of 10^{-6}M, was similar to or exceeded the activity of auxin IAA, applied at a similar concentration.

This fact can be explained by the assumption that the increase in the content of photosynthetic pigments in the leaves of wheat plants is associated with the cytokinin-like effect of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives on increasing the synthesis and slowing down the degradation of chlorophyll a, b and carotenoids in plant cells, which play a key role in photosynthesis and plant productivity [44-46, 59-62].

Summarizing the obtained morphometric and biochemical parameters of wheat plants and analyzing the relationship between the chemical structure and biological activity of most active synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives №1, 4, 5, 6, 7 and 11, it can be assumed that their high plant growth-regulating activity and regulatory effect on the process of photosynthesis in plant leaves is associated with the presence of substituents in their chemical structure (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 № 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 № 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 № 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-

Figure 5. The effect of auxin IAA and synthetic low molecular weight heterocyclic compounds Ivin, Methyur, Kamethur and thioxopyrimidine derivatives № 1 – 11 at a concentration of 10^{-6}M on the content of chlorophylls a, b, a+b and carotenoids (µg/ml) in the leaves of 2-week-old wheat (*Triticum aestivum* L.) variety Demira compared to control plants.



1,2,3,4-tetrahydropyrimidine ring.

The decrease in the plant growth-regulating activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives № 2, 3, 8, 9 and 10 and their regulatory effect on the process of photosynthesis in plant leaves can be explained by the presence of substituents in the chemical structures of these compounds (Table 1): 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 № 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.

Based on the obtained results, it can be assumed that the plant growth-regulatory activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, occurs due to their impact on increasing or decreasing the activity of key enzymes of biosynthesis, metabolism and transport of endogenous auxins and cytokinins in plant cells, as well as due to their participation in auxin and cytokinin signaling pathways [63-72].

Conclusion

The growth-regulating effect of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives on the morphometric and biochemical parameters of wheat plants was studied.The activity of the synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives applied at a concentration of 10^{-6}M, was similar or exceeded the activity of auxin IAA, applied at a similar concentration. The obtained morphometric parameters (average length of shoots (mm), average length of roots (mm), and average biomass of 10 plants (g)) and biochemical parameters (content of photosynthetic pigments chlorophylls a, b, a+b and carotenoids (μg/ml)) of experimental wheat plants treated with synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, exceeded the biochemical parameters of the control wheat plants. It was concluded that the biological activity of synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives, depends on their chemical structure. The selected most biologically active synthetic low molecular weight heterocyclic compounds, thioxopyrimidine derivatives №1, 4, 5, 6, 7 and 11are proposed to be used as new growth regulators of wheat (*Triticum aestivum* L.) variety Demira.

References

[1]. Basra A.S. (Ed). Plant Growth Regulators in Agriculture and Horticulture: Their Role and Commercial Uses. Haworth Press, Inc., New York, London, Oxford. 2000; 264.

[2]. Rademacher W. Plant growth regulators: backgrounds and uses in plant production. Journal of plant growth regulation. 2015 Dec; 34: 845-72.

[3]. Geelen D, Xu L, Stevens C. The Chemical Biology of Plant Biostimulants. Wiley, Hoboken, NJ, USA, 2020; 328.

[4]. Tsygankova VA, Andrusevich YV, Blyuss KB, Shysha EN, Yemets AI, Biliavska LA, et al. Using microbial biostimulants to deliver RNA interference in plants as an effective tool for biocontrol of pathogenic fungi, parasitic nematodes and insects. In Research Advances in Plant Biotechnology 2020; 205-319.

[5]. Tsygankova VA, Spivak SI, Shysha EN, Pastukhova NL, Biliavska LA, Iutynska GA, et al. The role of polycomponent biostimulants in increasing plant resistance to the biotic and a biotic stress factors. In: Agricultural Research Updates: 46. Editor(s): Prathamesh Gorawala and Srushti Mandhatri. Nova Science Publishers, Inc., NY, USA, 2023; 307.

[6]. Amr AG, Mohamed AM, Mohamed SF, Abdel-Hafez NA, Hammam Ael-F. Anticancer activities of some newly synthesized pyridine, pyrane, and pyrimidine derivatives. Bioorg Med Chem. 2006 Aug 15;14(16):5481-8. PubMed PMID: 16713269.

[7]. Ho Y.-W, Suen M. C. Thioxopyrimidine in Heterocyclic Synthesis I: Synthesis of Some Novel 6- (Heteroatom-substituted) - (thio) pyrimidine Derivatives. Journal of Chemistry. 2013: 15

[8]. Mohamed EA, Ismail NS, Hagras M, Refaat H. Medicinal attributes of pyridine scaffold as anticancer targeting agents. Future Journal of Pharmaceutical Sciences. 2021 Dec; 7:1-7.

[9]. Tolba MS, Kamal El-Dean AM, Ahmed M, Hassanien R. Synthesis, reactions, and biological study of some new thienopyrimidine derivatives as antimicrobial and anti-inflammatory agents. Journal of the Chinese Chemical Society. 2019 May;66(5):548-57..

[10]. Lagardère P, Fersing C, Masurier N, Lisowski V. Thienopyrimidine: A Promising Scaffold to Access Anti-Infective Agents. Pharmaceuticals (Basel). 2021 Dec 27; 15(1):35. PubMed PMID: 35056092.

[11]. Mahapatra A, Prasad T, Sharma T. Pyrimidine: a review on anticancer activity with key emphasis on SAR. Future journal of pharmaceutical Sciences. 2021 Jun 19;7(1):123.

[12]. Sayed MT, Hassan RA, Halim PA, El-Ansary AK. Recent updates on thienopyrimidine derivatives as anticancer agents. Medicinal Chemistry Research. 2023 Apr;32(4):659-81..

[13]. Kawarada A, Nakayama M, OtaYa, Takeuchi S. Use of pyridine derivatives as plant growth regulators and plant growth regulating agents. Patent DE2349745A1, 25 Apr 1974.

[14]. Minn K, Dietrich H, Dittgen J, Feucht D, Häuser-Hahn I, Rosinger C.H. Pyrimidine Derivatives and Their Use for Controlling Undesired Plant Growth. Patent USOO8445408B2, 21 May 2013.

[15]. Cansev A, Gülen H, Zengin MK, Ergin S, Cansev M. Use of pyrimidines in stimulation of plant growth and development and enhancement of stress tolerance. 2014 Aug 28.

[16]. Mansfield DJ, Rieck H, Greul J, Coqueron PY, Desbordes P, Genix P, et al. Pyridine derivatives as fungicidal compounds. Patent US7754741B2, 2010 Jul 13.

[17]. Boussemghoune MA, Whittingham WG, Winn CL, Glithro H, Aspinall MB. Pyrimidine derivatives and their use as herbicides, Patent US20120053053 A1, 1 March 2012.

[18]. Ota C, Kumata S, Kawaguchi S, inventors; Nihon Nohyaku Co Ltd, assignee. Novel herbicides, usage thereof, novel thienopyrimidine derivatives, intermediates of the same, and process for production thereof. United States patent application US 10/529,474. 2007 Jan 11.

[19]. Wang DW, Li Q, Wen K, Ismail I, Liu DD, Niu CW, et al. Synthesis and Herbicidal Activity of Pyrido[2,3-d]pyrimidine-2,4-dione-Benzoxazinone Hybrids as Protoporphyrinogen Oxidase Inhibitors. J Agric Food Chem. 2017 Jul 5;65(26):5278-5286. PubMed PMID: 28616976.

[20]. El-Dean AMK, Abd-Ella AA, Hassanien R, El-Sayed MEA, Zaki RM, Abdel-Raheem SAA. Chemical design and toxicity evaluation of new pyrimidothienotetrahydroisoquinolines as potential insecticidal agents. Toxicol Rep. 2018 Dec 18;6:100-104. PubMed PMID: 30622903.

[21]. Wang DW, Zhang H, Yu SY, Zhang RB, Liang L, Wang X, et al. Discovery of a Potent Thieno[2,3-d]pyrimidine-2,4-dione-Based Protoporphyrinogen IX Oxidase Inhibitor through an In Silico Structure-Guided Optimization Approach. J Agric Food Chem. 2021 Dec 1;69(47):14115-14125. PubMed PMID: 34797973.

[22]. Li JH, Wang Y, Wu YP, Li RH, Liang S, Zhang J, et al. Synthesis, herbicidal activity study and molecular docking of novel pyrimidine thiourea. Pestic Biochem Physiol. 2021 Feb;172:104766. PubMed PMID: 33518053.

[23]. Tsygankova VA, Voloshchuk IV, Kopich VM, Pilyo SG, Klyuchko SV, Brovarets VS. Studying the effect of plant growth regulators Ivin, Methyur and Kamethur on growth and productivity of sunflower. Journal of Advances in Agriculture. 2023.14:17–24.

[24]. Tsygankova VA, Voloshchuk IV, Pilyo SH, Klyuchko SV, Brovarets VS. Enhancing Sorghum Productivity with Methyur, Kamethur, and Ivin Plant Growth Regulators. InBiology and Life Sciences Forum. 2023 Oct 26;(27):1-36.

[25]. Tsygankova VA, Voloshchuk IV, Andrusevich YaV, Kopich VM, Oliynyk OO, Stefanovska TR, et al. Use of synthetic plant growth regulators in ag-

riculture and biotechnology. Polish Journal of Science. 2023.1(68): 12–17.
[26]. Tsygankova VA, Andreev AM, Andrusevich YaV, Kopich VM, Pilyo SG, Klyuchko SV, et al. Synergistic effect of synthetic plant growth regulators and microfertilizers on the growth of canola (*Brassica napu* sL). Danish Scientific Journal (DSJ). 2023. 1(77): 8-12.
[27]. Tsygankova VA, Andreev AM, Andrusevich Ya V, Pilyo SG, Klyuchko SV. Brovarets VS Use Of Synthetic Plant Growth Regulators In Combination With Fertilizers to Improve Wheat Growth. Int J Med Biotechnol Genetics. S. 2023 Apr 27;1:9-14.
[28]. Pidlisnyuk V, Mamirova A, Newton RA, Stefanovska T, Zhukov O, Tsygankova VA et al. The role of plant growth regulators in Miscanthus× giganteus utilisation on soils contaminated with trace elements. Agronomy. 2022;12(12):2999.
[29]. Brent KJ, Hollomon DW. Fungicide resistance in crop pathogens: how can it be managed?. Bristol, UK:BS8 1TD, 2007; 604.
[30]. Mahmood I, Imadi SR, Shazadi K, Gul A, Hakeem KR. Effects of pesticides on environment. Plant, soil and microbes. Volume 1: Implications in Crop Science / Eds. Hakeem K.R. et al. Springer International Publishing, Switzerland. 2016:253-69.
[31]. Tsygankova VA, Bayer OO, Andrusevich Ya V, Galkin AP, Brovarets VS, Yemets AI, Blume Ya B. Screening of five and six-membered nitrogen-containing heterocyclic compounds as new effective stimulants of *Linum usitatissimum* L. organogenesis *in vitro*. Int J Med Biotechnol Genetics S. 2016 Apr 22;2(001):1-9.
[32]. Tsygankova V, Ya A, Shtompel O, Romaniuk O, Yaikova M, Hurenko A, et al. Application of synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole and oxazole in agricultural biotechnology as a new plant growth regulating substances. Int J Med Biotechnol Genetics. 2017 Mar 22;2(002):10-32.
[33]. Tsygankova V, Andrusevich Ya, Kopich V, Shtompel O, Pilyo S, Kornienko AM, et al. Use of Oxazole and Oxazolopyrimidine to Improve Oilseed Rape Growth. Scholars Bulletin. 2018;4(3):301-12.
[34]. Tsygankova VA, Andrusevich YaV, Shtompel OI, Solomyanny RM, Hurenko AO, Frasinyuk MS, Mrug GP, Shablykin OV, Pilyo SG, Kornienko AM, Brovarets VS. Study of auxin-like and cytokinin-like activities of derivatives of pyrimidine, pyrazole, isoflavones, pyridine, oxazolopyrimidine and oxazole on haricot bean and pumpkin plants. Int J Chem Tech Res. 2018;11(10):174-90.
[35]. Mohilnikova IV, Tsygankova VA, Gurenko AO, Brovarets VS, Bilko NM, Yemets AI. Influence of pyrazole derivatives on plant growth and development *in vivo* and *in vitro*. Reports of the National Academy of Sciences of Ukraine. 2021; 6:108 - 119.
[36]. Tsygankova VA, Andrusevich YV, Shtompel OI, Solomyanny RM, Hurenko AO, Frasinyuk MS, et al. New Auxin and Cytokinin Related Compounds Based on Synthetic Low Molecular Weight Heterocycles. InAuxins, Cytokinins and Gibberellins Signaling in Plants 2022 Aug 19:353-377. Cham: Springer International Publishing.
[37]. Mohilnikova IV, Tsygankova VA, Solomyannyi RM, Brovarets VS, Bilko NM, Yemets AI. Screening of growth-simulating activity of synthetic compounds-pyrimidine derivatives. Reports of the National Academy of Sciences of Ukraine. 2020;10: 62-70.
[38]. Tsygankova VA, Voloshchuk IV, AndrusevichYaV, Kopich VM, Pilyo SG, Klyuchko SV, et al. Pyrimidine derivatives as analogues of plant hormones for intensification of wheat growth during the vegetation period. Journal of Advances in Biology. 2022. 15: 1–10.
[39]. Tsygankova VA, Andrusevich YaV, Kopich VM, Voloshchuk IV, Pilyo SG, Klyuchko SV, et al. Application of pyrimidine and pyridine derivatives for regulation of chickpea (*Cicer arietinum* L.) growth. Int J Innovative Sci Res Technol (IJISRT). 2023b. 2023;8(6):19-28.
[40]. Tsygankova VA, Kopich VM, Voloshchuk IV, Pilyo SG, Klyuchko SV, Brovarets VS. New growth regulators of barley based on pyrimidine and pyridine derivatives. Sciences of Europe. 2023; 124: 13 – 23.
[41]. Tsygankova VA. Andrusevich Ya. V, Kopich VM, Voloshchuk IV, Bondarenko OM, Pilyo SG, et al. Effect Of Pyrimidine And Pyridine De-rivatives On The Growth And Photosynthesis Of Pea Microgreens. Int J Med Biotechnol Genetics. S. 2023 Sep 7;1:15-22.
[42]. Tsygankova VA, Andrusevich YaV, Vasylenko NM, Pilyo SG, Klyuchko SV, Brovarets VS. Screening of Auxin-like Substances among Synthetic Compounds, Derivatives of Pyridine and Pyrimidine. Journal of Plant Science and Phytopathology. 2023 Dec 12;7(3):151-6.
[43]. Tsygankova V, Kopich V, Vasylenko N, Andrusevich YaV, Pilyo S, Brovarets V. Phytohormone-like effect of pyrimidine derivatives on the vegetative growth of haricot bean (*Phaseolus vulgaris* L.). Polish Journal of Science. 2024; 1(71): 6–13.
[44]. Lichtenthaler HK. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. Methods in enzymology 1987 Jan 1; (148):350-382.
[45]. Lichtenthaler HK, Buschmann C. Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy. Current protocols in food analytical chemistry. 2001 Aug;1(1): 4-3.
[46]. Lodish H, Berk A, Zipursky SL, Matsudaira P, Baltimore D, Darnell J. Molecular Cell Biology. Section 16.3, Photosynthetic Stages and Light-Absorbing Pigments. 4th Edtn, New York: W.H. Freeman and Company, 2000.
[47]. Tapiero H, Townsend DM, Tew KD. The role of carotenoids in the prevention of human pathologies. Biomedicine & Pharmacotherapy. 2004 Mar 1;58(2):100-10.
[48]. Bhatt T, Patel K. Carotenoids: potent to prevent diseases review. Natural Products and Bioprospecting. 2020 Jun;10:109-17.
[49]. Tsygankova VA, Andrysevich YaV, Shtompel OI, Kopich VM, Kluchko SV, Brovaretz VS. Using Pyrimidine Derivatives-Sodium Salt of Metiur and Potassium Salt of Metiur, to Intensify the Growth of Corn. Patent of Ukraine. 2018 Dec 12;130921:12.
[50]. Ramiz MM, El-Sayed WA, Hagag E, Abdel-Rahman AA. Synthesis and antiviral activity of new substituted pyrimidine glycosides. Journal of Heterocyclic Chemistry. 2011 Sep;48(5):1028-38.
[51]. Taher AT, Abou-Seri SM. Synthesis and bioactivity evaluation of new 6-aryl-5-cyano thiouracils as potential antimicrobial and anticancer agents. Molecules. 2012 Aug 17;17(8):9868-86. PubMed PMID: 22902882.
[52]. Megally Abdo NY. Synthesis and antitumor evaluation of novel dihydropyrimidine, thiazolo[3,2-a]pyrimidine and pyrano[2,3-d]pyrimidine derivatives. Acta Chim Slov. 2015;62(1):168-80. PubMed PMID: 25830973.
[53]. Alvim HG, de Lima TB, de Oliveira HC, Gozzo FC, de Macedo JL, Abdelnur PV, et al. Ionic liquid effect over the biginelli reaction under homogeneous and heterogeneous catalysis. Acs Catalysis. 2013 Jul 5;3(7):1420-30.
[54]. Silva GC, Correa JR, Rodrigues MO, Alvim HG, Guido BC, Gatto CC, et al. The Biginelli reaction under batch and continuous flow conditions: catalysis, mechanism and antitumoral activity. RSC advances. 2015;5(60):48506-15.
[55]. Voytsehovska OV, Kapustyan AV, Kosik OI. Plant Physiology: Praktykum, Parshikova TV. (Ed.), Lutsk: Teren, 2010; 420.
[56]. Bang H, Zhou XK, van Epps HL, Mazumdar M. Statistical Methods in Molecular Biology. Series: Methods in molecular biology, New York: Humana press, 2010; 13(620): 636.
[57]. Schaller GE, Bishopp A, Kieber JJ. The yin-yang of hormones: cytokinin and auxin interactions in plant development. Plant Cell. 2015 Jan;27(1):44-63. PubMed PMID: 25604447.
[58]. Sosnowski J, Truba M, Vasileva V. The impact of auxin and cytokinin on the growth and development of selected crops. Agriculture. 2023 Mar 21;13(3):724.
[59]. Wu W, Du K, Kang X, Wei H. The diverse roles of cytokinins in regulating leaf development. Hortic Res. 2021 Jun 1;8(1):118. PubMed PMID: 34059666.
[60]. Hönig M, Plíhalová L, Husičková A, Nisler J, Doležal K. Role of Cytokinins in Senescence, Antioxidant Defence and Photosynthesis. Int J Mol Sci. 2018 Dec 14;19(12):4045. PubMed PMID: 30558142.
[61]. Zhang YM, Guo P, Xia X, Guo H, Li Z. Multiple Layers of Regulation on Leaf Senescence: New Advances and Perspectives. Front Plant Sci. 2021 Dec 6;12:788996. PubMed PMID: 34938309.
[62]. Huang P, Li Z, Guo H. New Advances in the Regulation of Leaf Senescence by Classical and Peptide Hormones. Front Plant Sci. 2022 Jun 28;13:923136. PubMed PMID: 35837465.
[63]. Ljung K. Auxin metabolism and homeostasis during plant development. Development. 2013 Mar;140(5):943-50. PubMed PMID: 23404103.
[64]. Sakakibara H. Cytokinins: activity, biosynthesis, and translocation. Annu Rev Plant Biol. 2006;57:431-49. PubMed PMID: 16669769.
[65]. Mok DW, Mok MC. Cytokinin metabolism and action. Annu Rev Plant Physiol Plant Mol Biol. 2001 Jun;52:89-118. PubMed PMID: 11337393.
[66]. Lavy M, Estelle M. Mechanisms of auxin signaling. Development. 2016 Sep 15;143(18):3226-9. PubMed PMID: 27624827.
[67]. Fukui K, Hayashi KI. Manipulation and Sensing of Auxin Metabolism, Transport and Signaling. Plant Cell Physiol. 2018 Aug 1;59(8):1500-1510. PubMed PMID: 29668988.
[68]. Leyser O. Auxin Signaling. Plant Physiol. 2018 Jan;176(1):465-479. PubMed PMID: 28818861.
[69]. Ma Q, Grones P, Robert S. Auxin signaling: a big question to be addressed by small molecules. J Exp Bot. 2018 Jan 4;69(2):313-328. PubMed PMID: 29237069.
[70]. Kieber JJ, Schaller GE. Cytokinin signaling in plant development. Development. 2018 Feb 15;145(4): 149344.
[71]. Blázquez MA, Nelson DC, Weijers D. Evolution of Plant Hormone Response Pathways. Annu Rev Plant Biol. 2020 Apr 29;71:327-353. PubMed PMID: 32017604.
[72]. Fàbregas N, Fernie AR. The interface of central metabolism with hormone signaling in plants. Curr Biol. 2021 Dec 6;31(23):1535-1548. PubMed PMID: 34875246.