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Phytohormone-like effect of pyrimidine derivatives on regulation of vegetative growth of tomato

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Abstract
Tomato (*Solanum lycopersicum* L.) is a major agricultural crop cultivated over the world. The elaboration of new effective plant growth regulators for improving growth of tomato is an important task for plant biotechnology. In the present work the comparative effect of plant hormones auxins IAA and NAA, cytokinin Kinetin, and new synthetic compounds pyrimidine derivatives on acceleration of vegetative growth of tomato was studied. The obtained biometric indices of 24th-day-old tomato seedlings grown on the water solution of pyrimidine derivatives used at the concentration 10^{-8}M were similar or higher of the biometric indices of tomato seedlings grown on the distilled water (control), or on the water solution of IAA, NAA and Kinetin used at the same concentration 10^{-8}M in average: at the 29-255 %, 22-235 %, 10-156 %, and 13-95 % - by total number of roots, and at the 23 - 255 %, 21-115 %, 19-138 %, and 9-61 % - by total length of roots, respectively. The content of photosynthetic pigments in tomato seedlings grown on the water solution of pyrimidine derivatives was increased in average: chlorophyll a - at the 17-116 %, 17-122 %, 19-22 %, and 19-52 %; chlorophyll b - at the 19-155 %, 21-161 %, 12-45 %, and 11-81 %; chlorophylls a+b - at the 16- 126 %, 13-132 %, 23-28 %, and 14-60 %; carotenoids - at the 15-86 %, 19-107 %, 20-31%, and 16-50 %, as compared with similar indices of tomato seedlings grown on the distilled water (control), or on the water solution of IAA, NAA and Kinetin, respectively. The content of total soluble proteins in tomato seedlings grown on the water solution of pyrimidine derivatives was increased in average: at the 40-241 %, 9-145 %, 15-122 %, and 17-123 %, as compared with similar indices of tomato seedlings grown on the distilled water (control), or on the water solution of IAA, NAA and Kinetin, respectively. The relationship between chemical structure and plant growth regulatory activity of pyrimidine derivatives was set. The highest growth regulatory activity revealed the compounds, derivatives of dihydroimidazo[1,2-*c*]pyrimidine. The obtained results confirmed the possibility of application of pyrimidine derivatives as new effective regulators of vegetative growth of tomato.

Keywords: tomato, auxin, cytokinin, pyrimidine derivatives, plant growth regulation

1. Introduction

Tomato (*Solanum lycopersicum* L.) is a commercially important agricultural food crop cultivated over the world [1, 2]. According to the National Nutrient Database of the US Department of Agriculture, tomato fruit contains important for human health dietary nutrients (per 100 g FW): 1 % energy, 3 % carbohydrates, 1.6 % protein, 0.7 % total fat, 3 % dietary fiber, vitamins: 4 % folates, 4 % niacin, 6 % pyridoxine, 3 % thiamin, 28 % vitamin A, 21.5 % vitamin C, 4 % vitamin E, 6.5 % vitamin K, electrolytes: 1 % sodium, 5 % potassium, minerals: 1 % calcium, 4 % iron, 3 % magnesium, 6.5 % manganese, 3 % phosphorus, 1.5 % zinc, and phyto-nutrients such as carotene-ß, carotene-α, lutein-zeaxanthin, lycopene, flavonoids as well as hydroxycinnamic acid derivatives [2, 3]. The lycopene is an abundant carotenoid in red tomatoes; it is attributed to acyclic isomer of carotene-ß, which has antioxidant and anti-cancer properties [2, 4-7]. Unlike carotene-ß, lycopene can not be metabolized in the human organism to vitamin A, but it has a dual antioxidant potential of carotene-ß. The use of tomato fruit and tomato products containing lycopene in human diet food reduces the risk of development of chronic diseases, such as cancer, cardiovascular and some age-related diseases [4, 8 - 11].

Today the natural or synthetic plant growth regulators are applied to improve the tomato growth and productivity and increase plant resistance to unfavorable biotic and abiotic stress-factors [12-34]. In recent years, the innovative technologies of plant growing based on use of low molecular weighted synthetic heterocyclic compounds, the derivatives of pyrimidine, pyrazole, and oxazole as new effective and environmentally safe substitutes of traditional plant growth regulators are used to improve growth and productivity of important agricultural crops [35-52].

As is known the main disadvantages of practical application of traditional plant growth regulators are low level of their growth regulatory activity, storage instability and high toxicity to humans, animals and environment due to their using at high concentrations [53-55]. Taking into account this fact, the new promising approach for modern agriculture is a practical application of synthetic low molecular weight heterocyclic compounds (LMWHC) as effective substitutes of traditional plant growth regulators. To the main advantages of LMWHC belong the broad specificity of their action on various agricultural crops and their high growth regulatory activity at very low concentrations, which are non-toxic to human and the environment [37-43, 45-52].

The high interest in LMWHC is due to broad spectrum of their biological activity on the human cells and, therefore, these compounds are widely used in medicinal practice for the treatment of cancer, nervous, viral, fungal, allergic, bacterial, infectious, inflammatory, and other diseases [56-73].

Our previous researches conducted on major agricultural crops showed the possibility of application of synthesized in the Institute of Bioorganic Chemistry and Petrochemistry of NAS of Ukraine of LMWHC, derivatives of pyrimidine, pyrazole, and oxazole used for the treatment of plant seed at the germination stage under *in vivo* conditions or on the nutrient media for cultivation of isolated plant cells and tissues under *in vitro* conditions at very low, nanomolar concentrations ranging from 10^{-8}M up to 10^{-9}M as new effective substitutes of phytohormones auxins and cytokinins [74-78]. Based on our obtained data, the great theoretical and practical interest is study the possibility of application in the biotechnological practice of synthetic LMWHC, pyrimidine derivatives for regulation of growth of tomato plants during vegetative stage.

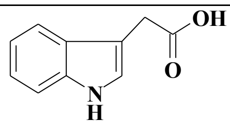
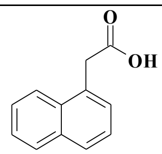
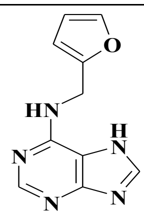
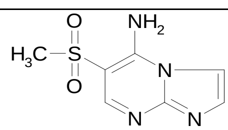
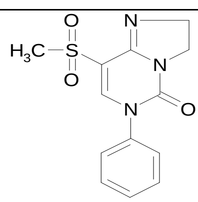
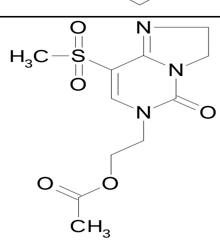
This work is aimed to study of regulatory effect of LMWHC, pyrimidine derivatives on biometric indices (i.e. number of germinated seeds (%), length of shoots (cm), total number of roots (pcs), total length of roots (mm)) and biochemical indices (content of photosynthetic pigments and content of total soluble protein) of tomato (*Solanum lycopersicum* L.) seedlings during vegetation in the laboratory conditions.

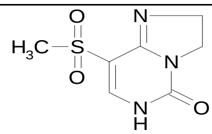
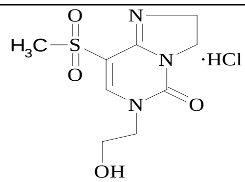
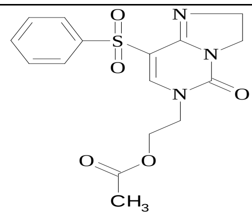
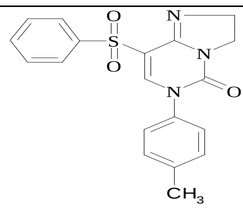
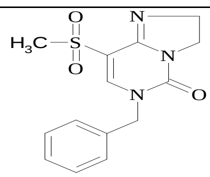
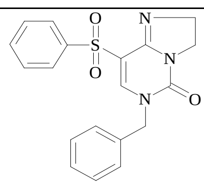
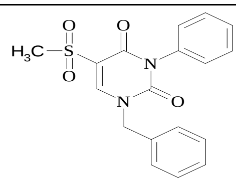
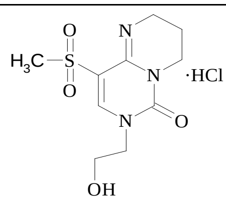
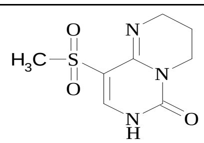
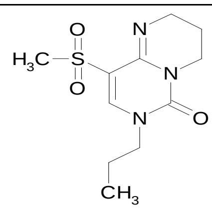
2. Material and methods

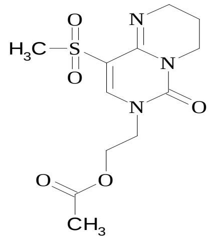
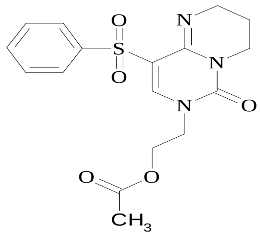
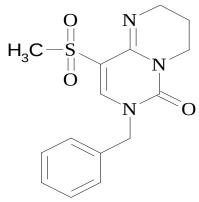
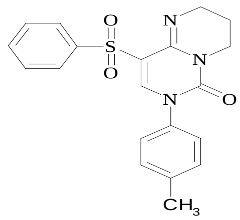
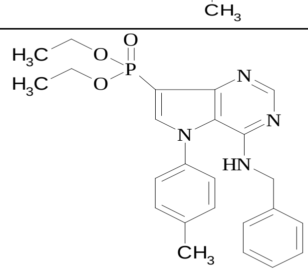
2.1 Chemical structure of tested compounds

In the laboratory conditions we studied the plant growth regulatory activity of synthetic LMWHC, pyrimidine derivatives synthesized at the Department for Chemistry of Bioactive Nitrogen-Containing Heterocyclic Compounds of Institute of Bioorganic Chemistry and Petrochemistry of NAS of Ukraine. The plant growth regulatory activity of pyrimidine derivatives - the compounds № 1-18 was compared with the activity of phytohormones auxins IAA (1*H*-Indol-3-ylacetic acid), NAA (1-Naphthylacetic acid) and cytokinin Kinetin (*N*-(2-Furylmethyl)-7*H*-purin-6-amine) (Table 1).

Table 1: The chemical structure, name and relative molecular weight of tested compounds

№	Chemical structure of tested compound	Chemical name and relative molecular weight of tested compound
IAA		(1*H*-Indol-3-ylacetic acid); MW 175.19
NAA		(1-Naphthylacetic acid); MW 186.21
Kine-tin		(*N*-(2-Furylmethyl)-7*H*-purin-6-amine); MW 215.22
1		6-(Methanesulfonyl)imidazo[1,2-*a*]pyrimidin-5-ylamine; MW 212.23
2		8-(Methanesulfonyl)-6-phenyl-2,6-dihydroimidazo[1,2-*c*] pyrimidin-5(3*H*)-one; MW 291.33
3		2-[8-(Methanesulfonyl)-5-oxo-2,3-dihydroimidazo[1,2-*c*] pyrimidin-6(5*H*)-yl] ethyl acetate; MW 301.32

4		8-(Methanesulfonyl)-2,6-dihydroimidazo[1,2-*c*]pyrimidin-5(3*H*)-one; MW 215.23
5		6-(2-Hydroxyethyl)-8-(methanesulfonyl)-2,6-dihydroimidazo [1,2-*c*]pyrimidin-5(3*H*)-one hydrochloride; MW 295.75
6		2-[8-(Benzenesulfonyl)-5-oxo-2,3-dihydroimidazo[1,2-*c*] pyrimidin-6(5*H*)-yl]ethyl acetate; MW 363.39
7		8-(Benzenesulfonyl)-6-(4-methylphenyl)-2,6-dihydroimidazo[1,2-*c*]pyrimidin-5(3*H*)-one; MW 367.43
8		6-Benzyl-8-(methanesulfonyl)-2,6-dihydroimidazo[1,2-c] pyrimidin-5(3H)-one; MW 305.36
9		8-(Benzenesulfonyl)-6-benzyl-2,6-dihydroimidazo[1,2-*c*] pyrimidin-5(3*H*)-one; MW 383.47
10		1-Benzyl-5-(methanesulfonyl)-3-phenyl-1*H*-pyrimidine-2,4-dione;MW 356.4
11		7-(2-Hydroxyethyl)-9-(methanesulfonyl)-2,3,4,7-tetrahydro-6*H*-pyrimido[1,6-*a*]pyrimidin-6-one; MW 309.77
12		9-(Methanesulfonyl)-2,3,4,7-tetrahydro-6*H*-pyrimido[1,6-*a*]pyrimidin-6-one; MW 229.26
13		9-(Methanesulfonyl)-7-propyl-2,3,4,7-tetrahydro-6*H*-pyrimido [1,6-*a*]pyrimidin-6-one; MW 271.34

14		2-[9-(Methanesulfonyl)-6-oxo-3,4-dihydro-2*H*-pyrimido [1,6-*a*]pyrimidin-7(6*H*)-yl]ethyl acetate; MW 315.35
15		2-[9-(benzenesulfonyl)-6-oxo-3,4-dihydro-2*H*-pyrimido [1,6-*a*]pyrimidin-7(6*H*)-yl]ethyl acetate; MW 377.42
16		7-Benzyl-9-(methanesulfonyl)-2,3,4,7-tetrahydro-6*H*-pyrimido [1,6-*a*]pyrimidin-6-one; MW 319.39
17		9-(Benzenesulfonyl)-7-(4-methylphenyl)-2,3,4,7-tetrahydro-6*H*-pyrimido[1,6-*a*]pyrimidin-6-one; MW 381.46
18		Diethyl [4-(benzylamino)-5-(4-methylphenyl)-5*H*-pyrrolo[3,2-*d*]pyrimidin-7-yl]phosphonate; MW 450.48

2.2 Plant treatment and growing conditions

Seeds of tomato (*Solanum lycopersicum* L.) of cultivar Fakel were surface sterilized in 1 % $KMnO_4$ solution for 3 min and 96 % ethanol solution for 1 min, and then washed three times with sterile distilled water. After this procedure seeds were placed in the cuvettes (each containing 25-30 seeds) on the perlite moistened with distilled water (control), or with water solution of either synthetic LMWHC, pyrimidine derivatives, or phytohormones cytokinin Kinetin, or auxins IAA and NAA used at the concentration 10^{-8}M. After this procedure the control and experimental seeds were placed in the thermostat for their germination in the darkness at the temperature 23 °C during 48 hours. Sprouted seedlings were placed in the plant growth chamber in which seedlings were grown for 24 days at the 16/8 h light/dark conditions, at the temperature 24 °C, light intensity 3000 lux and air humidity 60-80 %. Comparative analysis of biometric indices of seedlings (i.e. number of germinated seeds (%), length of shoots (cm), total number of roots (pcs), total length of roots (mm)) was carried out at the 24th day after their sprouting according to the guideline [79].

The biometric indices determined in the tomato seedlings treated with pyrimidine derivatives was expressed in % according to similar indices determined in the control tomato seedlings or tomato seedlings treated with phytohormones.

2.3 Determination of photosynthetic pigments content in tomato seedlings

The total content of chlorophyll a, chlorophyll b, and carotenoids was determined in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel grown either on the distilled water (control), or on the water solution of synthetic LMWHC, pyrimidine derivatives, or water solution of phytohormones cytokinin Kinetin, or auxins IAA and NAA used at the concentration 10^{-8}M.

The sample (500 mg) of leaves from control and experimental 24th-day-old seedlings of tomato was homogenized 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) to perform extraction of pigments. The 1 ml of homogenate was centrifuged at 8000 g in a refrigerated centrifuge K24D (MLW, Engelsdorf, Germany) during 5 min and at the temperature 4 °C. The obtained precipitate was washed three times with 1 ml 96 % etanol and centrifuged at above mentioned conditions. After this procedure the optical density of chlorophyll a, chlorophyll b and carotenoids in the obtained extract was measured using spectrophotometer Specord M-40 (Carl Zeiss, Germany). The total content of chlorophyll a, chlorophyll b, and carotenoids was calculated in accordance with formula [80]:

$$C_{chl\ a} = 13.36\times A664.2 - 5.19\times A648.6,$$
$$C_{chl\ b} = 27.43\times A648.6 - 8.12A\times 664.2,$$
$$C_{chl\ (a+b)} = 5.24\times A664.2 + 22.24\times A648.6,$$
$$C_{car} = (1000\times A470 - 2.13\times C_{chl\ a} - 97.64\times C_{chlb})/209,$$

Where, C_{chl} – concentration of chlorophylls (mg/ml), C_{car} – concentration of carotenoids (mg/ml), $C_{chl\ a}$– concentration of chlorophyll a (mg/ml), $C_{chl\ b}$– concentration of chlorophyll b (mg/ml), A – absorbance value at a proper wavelength in nm.

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

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

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

The index of content of chlorophyll a, chlorophyll b, and carotenoids determined in the leaves of tomato seedlings treated with pyrimidine derivatives was expressed in % according to similar index determined in the leaves of control tomato seedlings or tomato seedlings treated with phytohormones.

2.4 Determination of total soluble protein content in tomato seedlings

The determination of total soluble protein content (g of proteins per 100 g of FW of plant material) in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel grown either on the distilled water (control), or on the water solution of synthetic LMWHC, pyrimidine derivatives, or on the water solution of phytohormones cytokinin Kinetin, or auxins IAA and NAA used at the concentration 10^{-8}M was carried out using Bradford method [81]. To prepare plant extracts the sample (100 mg) of leaves of control and experimental 24th-day-old seedlings of tomato was homogenized in the porcelain mortar in a 0,1 M sodium phosphate buffer (pH 6,0 – 8,0) at the ratio of 1:5 (weight: volume) at the temperature 4 °C during 1 h. The obtained homogenates were centrifuged at 8000 g in a refrigerated centrifuge K24D (MLW, Engelsdorf, Germany) at the temperature 4 °C during 15 min. Then 1,5 ml of distilled water and 1,5 ml of reagent Coomassie Brilliant Blue G 250 (Bio-Rad, 500-0006) were added to 50 ml of obtained supernatant, and mixture was stirred during 10 min. The optical density of total soluble protein was measured using spectrophotometer Specord M-40 at a wavelength 595 nm. The total soluble protein content (mg/ml) in the sample was determined using the calibration graph constructed on the base of measured OD of the samples containing 1,5 ml solution of bovine serum albumin (BSA) used as a standard and 1,5 ml of reagent the Coomassie Blue G 250 (Bio-Rad, 500-0006). The index of total soluble protein content determined in the leaves of tomato seedlings treated with pyrimidine derivatives was expressed in % according to similar index determined in the leaves of control tomato seedlings or tomato seedlings treated with phytohormones.

2.5 Statistical Analysis

Each experiment was performed in triplicate. Statistical analysis of the data was performed using dispersive Student's-t test with the level of significance at $p\leq 0,05$, the values are mean ± Standard Deviation [82].

3. Results and Discussion

3.1 Impact of pyrimidine derivatives on seed germination and growth of tomato seedlings

As is known the major plant hormones auxins and cytokinins are involved in control of plant embryogenesis, seed germination, de-etiolation, cell cycle control, cell elongation and differentiation, protein synthesis, growth and development of plant root and shoot, development of flower and fruit, prevention of leaf abscission and delaying of leaf senescence [83-88].

In the laboratory conditions we studied the auxin-like and cytokinin-like activity of synthetic LMWHC, pyrimidine derivatives used at concentration 10^{-8}M on germination of seeds and growth of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel. The growth regulatory activity of pyrimidine derivatives was compared with activity of phytohormones cytokinin Kinetin, and auxins IAA and NAA used at the same concentration 10^{-8}M.

The obtained results showed that all tested synthetic LMWHC, pyrimidine derivatives revealed high auxin-like and cytokinin-like stimulating activity on growth of the 24th-day-old seedlings of tomato (Fig. 1).

Fig 1: Effect of pyrimidine derivatives (compounds №№ 1-18) and phytohormones (Kinetin, IAA, NAA) on growth of roots and shoots on the 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel. C – Control (distilled water)

The comparative statistical analysis showed that synthetic LMWHC, pyrimidine derivatives used at the concentration 10^{-8}M revealed high auxin-like and cytokinin-like effect on increasing of length of shoots (cm), total number of roots (pcs), and total length of roots (mm) on the 24th-day-old seedlings of tomato (Fig. 2). At the same time the number of germinated seeds (%) did not differ significantly from the similar indices of control seedlings and seedlings grown on the water solution of phytohormones cytokinin Kinetin, or auxins IAA and NAA used at the same concentration 10^{-8}M.

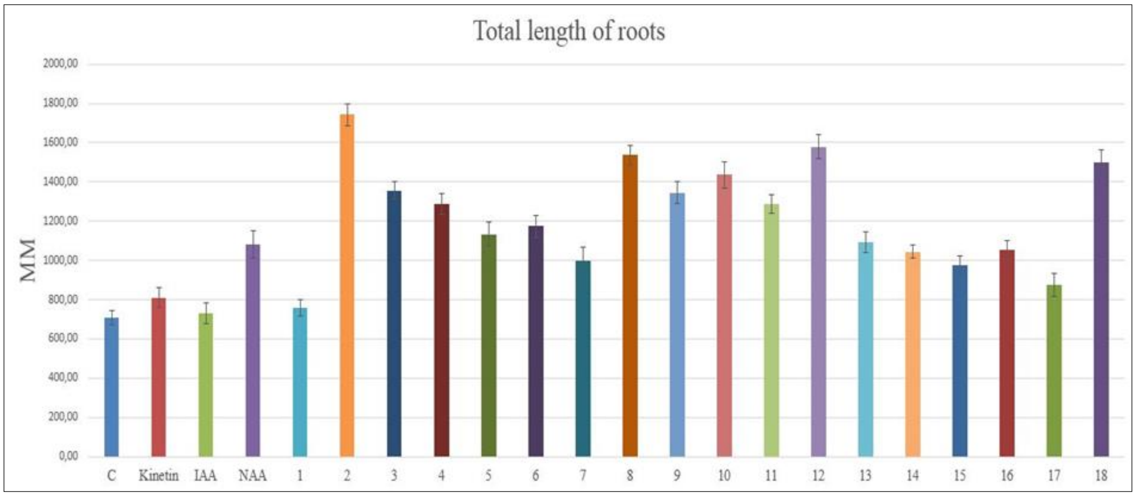


Fig 2A

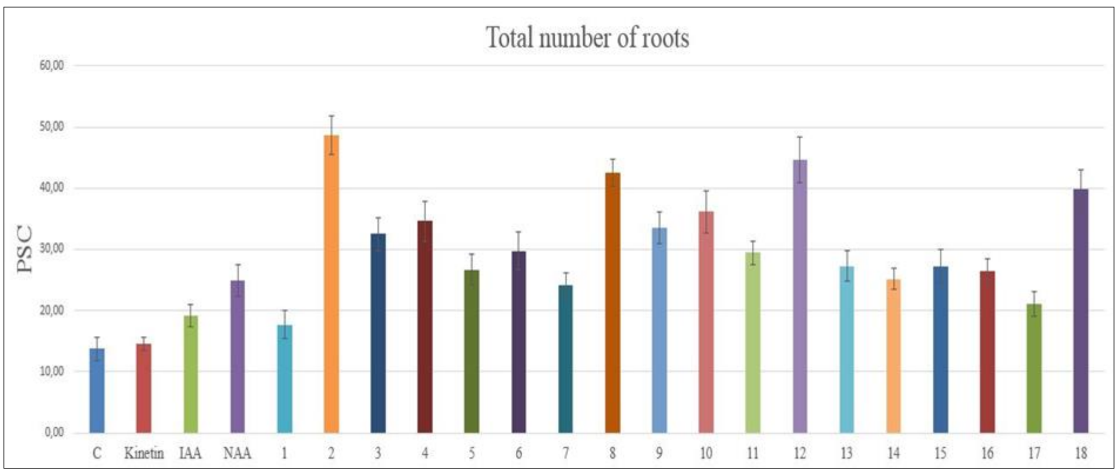


Fig 2B: Effect of pyrimidine derivatives (compounds №№ 1-18) and phytohormones (Kinetin, IAA, NAA) on biometric indices of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel: A – total length of roots, mm; B – total number of roots, psc.

Among all tested synthetic LMWHC, pyrimidine derivatives the highest regulatory activity on growth of tomato seedlings during 24 days revealed the compounds №№ 2, 7, 8, and 12, derivatives of dihydroimidazo[1,2-*c*]pyrimidine. The biometric indices of 24th-day-old seedlings of tomato grown on the water solution of these compounds used at concentration 10^{-8}M were higher than the biometric indices of tomato seedlings grown either on the distilled water (control), or on the water solution of cytokinin Kinetin, or auxins IAA and NAA used at the same concentration 10^{-8}M in average: according with length of seedlings – at the 7 – 11 %, 5 – 9 %, 6 – 10 % as compared with control, Kinetin, and IAA, respectively; according with total length of roots – at the 41 – 255 %, 23 – 115 %, 36 – 138 %, 42 – 61 % as compared with control, Kinetin, IAA and NAA, respectively; according with total number of roots – at the 76 – 255 %, 67 – 235 %, 26 – 154 %, 70 – 95 % as compared with control, Kinetin, IAA and NAA, respectively (Fig. 2). Among these compounds the highest growth regulatory activity revealed the compound № 2, the lower growth regulatory activity revealed the compounds № 7, 8 and 12.

The lower growth regulatory activity revealed the compounds №№ 1, 3, 4, 5, 6, 9, 10, 11, 13, 14, 15, 16, 17 and 18; the biometric indices of 24th-day-old seedlings of tomato grown on the water solution of these compounds used at concentration 10^{-8}M were higher than the biometric indices of tomato seedlings grown either on the distilled water (control), or on the water solution of cytokinin Kinetin, or auxins IAA and NAA used at the same concentration 10^{-8}M in average: according with length of seedlings – at the 6 – 8 %, 4 – 5 %, 5 – 6 % as compared with control, Kinetin, and IAA, respectively; according with total length of roots – at the 7 – 111 %, 8 – 85 %, 10 – 104 %, 5 – 38 % as compared with control, Kinetin, IAA and NAA, respectively; according with total number of roots – at the 29 - 191 %, 22 – 175 %, 31 – 108 %, 6 – 59 % as compared with control, Kinetin, IAA and NAA, respectively (Fig. 2).

Thus, the conducted researches proved that all tested synthetic

LMWHC, pyrimidine derivatives revealed high growth regulatory activity, which was similar or higher than activity of phytohormones cytokinin Kinetin, and auxins IAA and NAA. Obviously, that the high growth regulatory activity of pyrimidine derivatives may be explained by their auxin- and cytokinin-like stimulating effects on plant cell elongation, proliferation and differentiation, that are the basic processes of plant growth and development [83 – 88].

The study of relationship between chemical structure and plant growth regulatory activity of pyrimidine derivatives showed that growth regulatory activity of synthetic LMWHC, pyrimidine derivatives was differentiated depending on their chemical structure. The highest growth regulatory activity on growth of seedlings of tomato during 24 days revealed the compounds №№ 2, 7, 8, 12 which belong to derivatives of dihydroimidazo[1,2-*c*]pyrimidine. Moreover, the growth regulatory activity of these compounds that have the same methylsulfonyl group in 8 position, but different substituents in the 6 position of dihydroimidazo[1,2-*c*]pyrimidine was also differentiated. Obviously, the highest growth regulatory activity of compound № 2 is explained by that the presence of phenyl substituent in the 6 position as compared with lower activity of the compounds: compound № 12, which does not contain any one substituent in 6 position, the compound № 7 containing 4-methylphenyl substituent in the 6 position, and compound № 8 containing benzyl substituent in the 6 position of dihydroimidazo [1, 2-*c*]pyrimidine. The high growth regulatory activity revealed also phosphorylated derivative of pyrimidine, the compound № 18 containing the benzylamino substituent in 4 position and 4-methylphenyl substituent in 5 position of pyrimidine fragment.

The other tested synthetic LMWHC, pyrimidine derivatives revealed lower growth regulatory activity, which was also differentiated depending on substituents in their chemical structure, but at the same time the activity of these compounds was higher of the activity of phytohormones cytokinin Kinetin, and auxins IAA, and NAA. Particularly, the activity of compounds № 3 and 6, which have 2-acetoxyethyl substituent in 2 position, was similar; the absence of substituent in 6-position of compound № 4 reduced activity of this compound; the presence of hydrophilic substituent in 6-position of compound № 5 did not increase the activity of this compound; the presence of benzenesulfonyl group at the 8 position decreased the activity of compound № 9; the compounds № 14 and 15 containing the same substitute - 2-acetoxyethyl in 2 position and different substitutes - methylsulfonyl substituent (compound № 14) and benzenesulfonyl substituent (compound № 15) in 9 position showed similar growth regulatory activity; the compound № 17 containing the 4-methylphenyl substituent in 7 position and benzenesulfonyl substituent in 9 position of pyrimidine fragment revealed the lowest growth regulatory activity.

3.2 Impact of pyrimidine derivatives on content of photosynthetic pigments in tomato seedlings

As is known the major photosynthetic pigments such as chlorophylls and carotenoids play a key role in photosynthesis and photoprotection in plants, and provide plant productivity [89-93]. In addition, the therapeutic effect of the major plant pigments carotenoids in the treatment of various human diseases has also been shown [89, 90, 94].

In our experiments the comparative analysis of regulatory activity of synthetic LMWHC, pyrimidine derivatives, and phytohormones cytokinin Kinetin, and auxins IAA and NAA on content in the tomato seedlings of the major photosynthetic pigments such as chlorophylls and carotenoids was conducted.

The obtained results showed the high stimulating effect of some from tested synthetic LMWHC, pyrimidine derivatives used at the concentration 10^{-8}M on increasing of content of total photosynthetic pigments (chlorophyll a, chlorophyll b, and carotenoids) in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel as compared with content of photosynthetic pigments in the leaves of tomato seedlings grown either on the distilled water (control), or on the water solution of cytokinin Kinetin, or auxins IAA and NAA used at similar concentration 10^{-8}M (Fig. 3).

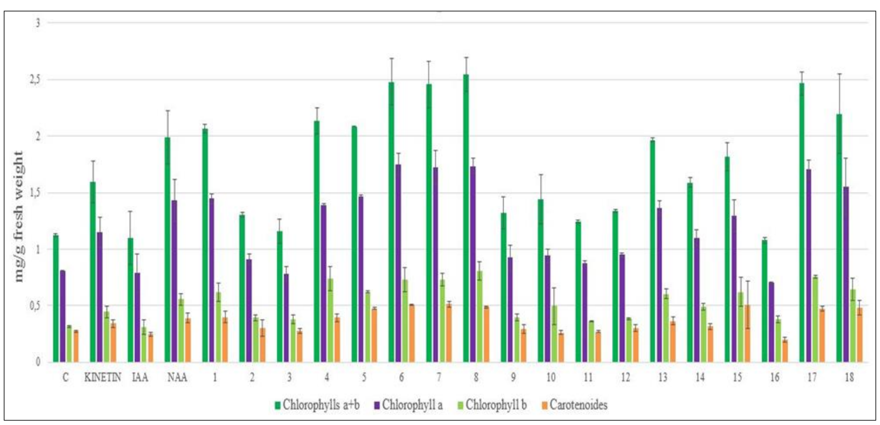


Fig 3: Effect of pyrimidine derivatives (compounds №№ 1-18) and phytohormones (Kinetin, IAA, NAA) on content of chlorophyll a, chlorophyll b and carotenoids in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel

Among all tested synthetic LMWHC, pyrimidine derivatives the highest regulatory activity revealed the compounds №№ 6, 7, 8 and 17; the content of chlorophyll a in the leaves of 24th-day-old seedlings of tomato was increased in average: at the 111 - 115 %, 117 - 122 %, 19 – 22 %, 49 – 52 %; the content of chlorophyll b was increased in average: at the 130 - 139 %, 135 – 161 %, 31 – 45 %, and 63 – 81 %; the content of chlorophylls a+b was increased in average: at the 54 - 60 %, 124 -132 %, 23 - 28 %, and 118 - 126 %; the content of carotenoids was increased in average: at the 71 – 86 %, 91 – 106 %, 20 – 31 %, and 38 – 50 % as compared with similar indices of tomato seedlings grown either on the distilled water (control), or water solution of IAA, NAA, and Kinetin, respectively (Fig. 3).

The high regulatory activity revealed also the compounds №№ 1, 4, 5, 13, 14, 15, and 18; the content of chlorophyll a in the leaves of 24th-day-old seedlings of tomato was increased in average: at the 36 – 81 %, 40 – 86 %, 2-19 %, and 26 – 28 %; the content of chlorophyll b was increased in average: at the 55 – 134 %, 58 – 139 %, 8 – 33 %, and 35 – 66 %; the content of chlorophylls a+b was increased in average: 12-34 %, 45-95 %, 5-7 %, and 41-89 %; the content of carotenoids was increased in average: at the 15 – 84 %, 17 – 105 %, 2- 29 %, and 17 – 61 % as compared with similar indices of tomato seedlings grown either on the distilled water (control), or water solution of IAA, NAA, and Kinetin, respectively (Fig. 3).

The lowest activity revealed the compounds № 2, 3, 9, 10, 11, 12, and 16; the content of chlorophyll a in the leaves of 24th-day-old seedlings of tomato was increased in average: at the 8 – 18 %, and 12 – 21 %; the content of chlorophyll b was increased in average: at the 19 – 57 %, 17 – 60 %; the content of carotenoids was increased in average: at the 7 – 10 %, 19 – 22 % as compared with similar indices of tomato seedlings grown either on the distilled water (control), or water solution of IAA respectively; the content of chlorophylls a+b was increased in average: at the 12-34 %, 45-95 %, 5-7 %, and 41-89 % as compared with similar indices of tomato seedlings grown either on the distilled water (control), or water solution of IAA, NAA, and Kinetin, respectively (Fig. 3).

Thus the obtained results proved the positive effect of synthetic LMWHC, pyrimidine derivatives on increasing of content of photosynthetic pigments chlorophylls and carotenoids in the leaves of 24th-day-old seedlings of tomato playing a key role in photosynthesis and providing plant productivity [89-93]. Obviously, that fact is connected with cytokinin-like effect of pyrimidine derivatives on increasing of synthesis of photosynthetic pigments such as chlorophylls and carotenoids and on delaying chlorophyll breakdown in plant cells [85, 88].

3.3 Impact of pyrimidine derivatives on content of total soluble protein in tomato seedlings

The comparative analysis of regulatory activity of synthetic LMWHC, pyrimidine derivatives, and phytohormones cytokinin Kinetin, and auxins IAA and NAA on content of total soluble protein in tomato seedlings, a key indicator of plant productivity was conducted [95].

The obtained results showed the high stimulating activity of some tested synthetic LMWHC, pyrimidine derivatives on increase of content of total soluble protein in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel grown either on the water solution of pyrimidine derivatives used at the concentration 10^{-8}M as compared with content of total soluble protein in the leaves of tomato seedlings grown either on the distilled water (control), or on the water solution of cytokinin Kinetin, or auxins IAA and NAA used at the same concentration 10^{-8}M (Fig. 4).

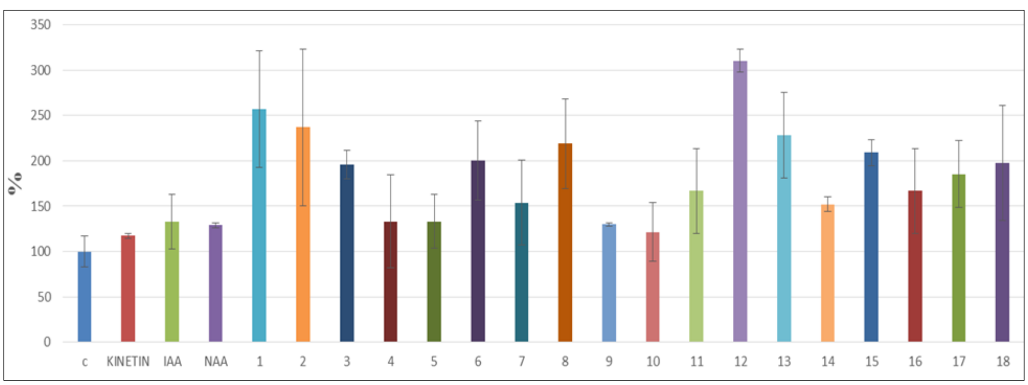


Fig 4: Effect of pyrimidine derivatives (compounds №№ 1-18) and phytohormones (Kinetin, IAA, NAA) on content of total soluble protein (%) in the leaves of 24th-day-old seedlings of tomato (*Solanum lycopersicum* L.) of cultivar Fakel

It was found that among all tested synthetic LMWHC, pyrimidine derivatives the highest regulatory activity revealed the compounds № № 1, 2, 3, 6, 8, 12, 13, 15, 17 and 18; the content of total soluble protein in the leaves of 24th-day-old seedlings of tomato grown on the water solution of these compounds was increased in average: at the 117-241 %, 56-145 %, 41-122 %, and 42-123 % as compared with similar indices of tomato seedlings grown on the distilled water (control), or on the water solution of Kinetin, IAA, and NAA, respectively (Fig. 4).

The lower regulatory activity among all tested synthetic LMWHC, pyrimidine derivatives revealed the compounds № 4, 5, 7, 9, 11, 14, and 16; the content of total soluble protein in the leaves of 24th-day-old seedlings of tomato grown on the water solution of these compounds was increased in average: at the 40-92 %, 9-38 %, 15-25 %, and 17-26 % as compared with similar indices of tomato seedlings grown on the distilled water (control), or on the water solution of Kinetin, IAA, and NAA, respectively (Fig. 4).

Obtained results proved that synthetic LMWHC, pyrimidine derivatives enhance the synthesis in plant cells of major proteins playing an important role in metabolic processes during plant growth and development.

4. Conclusion

The conducted in the laboratory conditions comparative analysis of the growth regulatory activity of synthetic LMWHC, pyrimidine derivatives showed that tested compounds used at concentration 10^{-8}M revealed high regulatory activity on vegetative growth of tomato (*Solanum lycopersicum* L.) plants of cultivar Fakel during 24 days. It was found that activity of tested synthetic LMWHC, pyrimidine derivatives was similar or higher of activity of phytohormones cytokinin Kinetin, and auxins IAA and NAA used at the same concentration 10^{-8}M. The highest regulatory activity on growth of seedlings of tomato during 24 days revealed the compounds №№ 2, 7, 8, and 12 that belong to derivatives of dihydroimidazo[1,2-*c*]pyrimidine. Most of the synthetic LMWHC, pyrimidine derivatives revealed also high stimulating effect on increasing of a key indicators of plant productivity: content of photosynthetic pigments, mainly chlorophyll a, chlorophyll b, and carotenoids, and content of total soluble protein in the leaves of 24th-day-old seedlings of tomato. The obtained data confirmed the possibility of application of synthetic LMWHC, pyrimidine derivatives in biotechnological practice as new effective regulators of vegetative growth of tomato of cultivar Fakel.

5. Conflict of interest

Authors stated that there is no conflict of interest.

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