Application of Synthetic Low Molecular Weight Heterocyclic Compounds Derivatives of Pyrimidine, Pyrazole and Oxazole in Agricultural Biotechnology as a New Plant Growth Regulating Substances

Research Article

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Abstract

Study of plant growth regulating activity of synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole was conducted. It was found that all tested synthetic heterocyclic compounds used at concentration 10-9M/l of distilled water revealed high stimulating auxin-like activity on vegetative growth of two cultivars of pea and maize, and stimulating cytokinin-like activity on growth of the isolated cotyledons of pumpkin. The obtained biometric indexes of 21st-day-old seedlings of pea (Pisum sativum L.) of cultivar L35/11 middle stalwart bewiskered grown on the water solution of heterocyclic compounds used at concentration 10-9M/l of distilled water were higher of the biometric indexes of 21st-day-old seedlings of pea grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10-9M/l of distilled water in average: at the 7-8% - by total length of seedlings, at the 6-46% - by total length of roots, and at the 15-70% - by total number of roots. The obtained biometric indexes of 21st-day-old seedlings of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewiskered grown on the water solution of heterocyclic compounds used at concentration 10-9M/l of distilled water were higher of the biometric indexes of 21st-day-old seedlings of pea grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10-9M/l of distilled water in average: at the 23% - by total length of seedlings, at the 57% - by total length of roots, and at the 40% - by total number of roots. The obtained biometric indexes of 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190 grown on the water solution of heterocyclic compounds used at concentration 10-9M/l of distilled water were higher of the biometric indexes of 21st-day-old seedlings of maize grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10-9M/l of distilled water in average: at the 62% - by total length of seedlings, 86% - by total length of roots, and at the 20-87% - by total number of roots. The specific bioassay on cytokinin-like activity conducted on the 16th-day-old cotyledons isolated from seeds of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea, showed that all heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole used at concentration 10-9M/l of distilled water demonstrated high stimulating cytokinin-like activity. The indexes of biomass growth of isolated cotyledons of pumpkin grown on the water solution of heterocyclic compounds used at concentration 10-9M/l of distilled water were higher of the indexes of biomass growth of isolated cotyledons of pumpkin grown either on the distilled water (control) or on the water solution of phytohormone cytokinin Kinetin used at the same concentration 10-9M/l of distilled water in average at the 6-30%. It was shown also the positive effect of some from tested synthetic heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole on activation of photosynthetic processes in the leaves of 21st-day-old pea seedlings and 14th-day-old maize seedlings due to increase of synthesis of photosynthetic pigments in the plant cells; the content of chlorophyll a was increased in average at the 4-36%; the content of chlorophyll b was increased in average at the 3-74%; the content of chlorophylls a+b was increased in average at the 5-36%; the chlorophylls a/b ratio was increased in average at the 3-44%; the content of carotenoids was increased in average at the 3-37% as compared with control, IAA and NAA, respectively; the carotenoid/chlorophyll ratio was increased in average at the 7-17% as compared with control. The application in agricultural biotechnology of synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole as new effective substitutes of phytohormones auxins and cytokinins for improving of cultivation of pea, maize, and pumpkins is proposed.

Keywords: Agricultural Biotechnology; Pisum sativum L.; Zea mays L.; Cucurbita moschata Duch. et Poir.; Auxins IAA and NAA; Cytokinin Kinetin; Plant Growth Regulating Substances; Synthetic Low Molecular Weight Heterocyclic Compounds; Pyrimidine; Pyrazole; Oxazole.

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Introduction

It is known that plant growth is the result of the different processes such as cell division, cell elongation, cell proliferation and cell differentiation resulting in formation of tissue, organ and whole plant organism; these basic processes are controlled by genetic program of plant growth and development [1-5]. The major classes of low molecular weight compounds such as phytohormones: auxins, cytokinins, gibberellins, abscisic acid, ethylene, brassinosteroids, jasmonates and salicylic acid play an a key role in the regulation of genetic program of plant growth and development during ontogenesis, improving of yield and product quality and increase of plant resistance to abiotic and biotic stress-factors (such as cold, drought, salinity, soil pollution by anthropogenic factors, and various pathogens and pests) [4, 6-17].

Plant hormones auxins (AUXs) are the major plant hormones involved in control of plant embryogenesis, promotion of seed germination, cell elongation and cell division in hypocotyls and coleoptiles, apical dominance, cambium cell division, plant tropisms, root initiation and development of root system on the plant seedlings as well as on the stem and leaf cuttings, promotion of fruit setting, prevention of leaf abscission, plant-pathogen interactions, and plant adaptation to biotic and abiotic stresses [18-29].

Plant hormone salicylic acid (SA) plays a vital role in the regulation of dormant seeds, the formation and development of plant reproductive and vegetative organs such as flowers, pollen, fruit, seed, leaves, formation and elongation of the lateral and adventitious roots, formation of glandular trichomes, fruit ripening, synthesis of vegetative storage protein (VSPs) in seeds and pigments carotenoids in fruit, leaf senescence, stomata closure, biosynthesis of plant secondary metabolites that are important compounds such as cold, drought, salinity, light, and nutrient deficiency, and plant defense response to abiotic stress factors such as viruses, bacteria, fungi, parasitic nematodes, herbivores [26, 58-62].

Plant hormone brassinosteroids (BRs) are involved in regulation of cell division, cell expansion, cell differentiation, programmed cell death, and cell homeostasis [26, 49-58]. These plant hormones reveal pleiotropic effects on varied physiological processes like photomorphogenesis and socotomorphogenesis (etiolation), promotion of elongation of hypocotyl, epicotyl, and mesocotyl in plant seedlings, seed germination, stem and root growth, gravitropism, xylem differentiation, vascular development, leaf morphogenesis, leaf bending and epinasty, photosynthesis, stomata development, leaf senescence and abscission, floral initiation, development of flowers, pollen tube growth, male fertility, development of fruits, plant adaptive properties in response to environmental stimuli, both biotic and abiotic [49-58].

Plant hormone auxins play an important role in the regulation of the basic processes of plant growth and development, including seed germination and seedling establishment, flowering, fruit ripening, stomatal aperture, respiration, leaf photosynthesis and senescence, under normal and under different abiotic stress conditions. SA takes part in plant tolerance to abiotic stress factors such as drought, salinity, heat, chilling, osmotic stress, heavy metal toxicity, and plant resistance to biotic stress factors such as pathogens and pests [26, 63-65].

Nowadays the different biotechnological and bioengineering tools based on traditional and molecular plant breeding methods, genetic engineering, cellular engineering, as well as chemical engineering methods based on application of different classes of phytohormones and plant growth regulators of synthetic or natural origin in the practice of sustainable agriculture to develop crops with genetically improved commercially important traits such as hypoxycolyte on the light, horizontal growth of stem with respect to gravity (i.e., diageotropism), stimulation of radial swelling of stem, swelling of hypocotyl and exaggerated hook curvature in etiolated (dark grown) seedlings [43-48]. Ethylene has a positive effect on fruit ripening, loss of chlorophyll, and abortion of plant parts, stems shortening, emergence and epinasty of leaves, promotes leaves abscission in autumn, and senescence at the end of a plant’s life [47, 48]. Ethylene production is strongly regulated by internal signals during plant development; this plant hormone controls plant adaptive properties in response to environmental stimuli, both biotic and abiotic [43-48].
as accelerated growth and development, increased productivity and quality, and enhanced resistance to a biotic and biotic stress-factors such as drought, salinity, cold, pathogenic and parasitic organisms, and soil pollution by anthropogenic factors [66-94].

The recent innovation strategy used in an agricultural biotechnology is the elaboration of new effective and ecologically safe plant growth regulating substances on the base of synthetic low molecular weight five and six-membered heterocyclic compounds derivatives of pyridine, pyrimidine, pyrazole, oxazole, and isoflavones as an effective substitutes of phytohormones and traditional growth regulators to improve growth of economically important agricultural crops and increase their productivity [95-110]. This innovation strategy is the most progressive approach to achieve successful development of modern agricultural biotechnology.

Pea (Pisum sativum L.) is an important agricultural crop cultivated over the world [111]. Cultivation of pea has beneficial impact on environment. Symbiosis of pea with nitrogen-fixing bacteria has positive influence on fixation of atmospheric nitrogen resulting in increased soil fertility; pea root system prevents erosion of the soil [112]. The rotation of peas with other crops results in decrease of pest outbreaks and prevents crop invasion by pests. Pea seed enriched with nutrients such as starch, protein, vitamins B and E, essential fatty acids omega-3 (alpha-linolenic acid, ALA) and omega-6 (linolenic acid, LA), carotenoids, polyphenolic antioxidants, minerals, soluble and insoluble dietary fiber, is used as source for human food and animal feed [113-115]. A garden pea (green pea) contains coumestrol and Bowman-Birk protease inhibitor (BBI) having protective effect against stomach cancer [116]. Pea seed contains a variety of bioactive substances including peptide fraction of total proteins having angiotensin I-converting enzyme inhibitor activity and antioxidant activity that play an important role for prevention of hypertension and ischemic heart disease; albumin fraction of total proteins having anti inflammatory effect on gastrointestinal tract; saponins exhibiting hypcholesterolemic and anticancer activity; galactose oligosaccharides exerting beneficial prebiotic effects in the large intestine; lectins, phytates, and phenolic compounds having important therapeutical properties including modulation of detoxifying enzymes, stimulation of the immune system, regulation of lipid and hormone metabolism, antioxidant, anti diabetic, antimutagen, and antiangiogenic effects, reduction of tumor initiation and induction of apoptosis [114-118]. Pea seed starch having lower glycemic index due to intermediate amylose content positively effects on decrease of sucrose level in the blood due to which it can be used for prevention and treatment of diabetes [115]. The vitamins and minerals containing in pea seed play an important role for prevention of diseases, caused by deficiencies of Se or folate [114, 115]. Pea seed coat and the cell walls of the cotyledon are enriched with dietary fiber having therapeutic effect on gastrointestinal function, as well as polyphenolics and flavonoids proanthocyanidins (PAs) having antioxidant and anticarcinogenic activity [114, 115, 119].

Maize (Zea mays L.) is ancient cereal crop traditionally used as source for dietary food and pharmaceutical industry due to high content of nutrients such as lipids, proteins, carbohydrates, vitamins, dietary fiber and biological active compounds in the seed and seed oil, and as raw material for the biofuel industry and animal feed [120-127].

Pumpkin (Cucurbita pepo L.) is widely cultivated crop used as source for dietary food, animal forage and drugs due to high content of biological active compounds in the fruit and seed oil such as carotenoids, flavonoid polyphenolic antioxidants, including lutein and xanthin, tocopherols, sterols, essential fatty acids omega-3 and omega-6, and vitamin A having anti diabetic, anti fungal, antibacterial, antioxidant, anticancer, anti hypertensive and anti-inflammatory activity [128-133].

The problem of increasing of pea, maize and pumpkin productivity, improving of quality of crop production and increase of crop resistance to abiotic and biotic stress-factors is quite relevant. Today the intensive technologies based on application of various classes phytohormones and plant growth regulators of natural and synthetic origin for improvement of growth and development of pea, maize and pumpkin are used in the practice of agricultural biotechnology [134-150]. The great theoretical and practical interest is the elaboration of new ecologically safe plant growth regulators created on the base of low molecular weight five and six-membered heterocyclic compounds having similar to phytohormones activity for improving of pea, maize and pumpkin growth and increase their productivity.

In our previous researches we showed that created at the Institute of Bioorganic Chemistry and Petrochemistry of National Academy of Sciences of Ukraine new synthetic low molecular weigh five and six-membered heterocyclic compounds derivatives of pyridine, pyrimidine, pyrazole, oxazole, and isoflavones revealed high stimulating, similar to phytohormones auxin and cytokinin activity on the growth and development of important agricultural crops such as flax, maize, haricot bean, pumpkins, soybean, wheat, and lettuce on both whole organism of plants in vivo and on the isolated plant tissues and organs in vitro conditions [151-154].

The aim of this work was study of growth regulating activity of new synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole according to their stimulating effect on vegetative growth of pea and maize seedlings, and according to their cytokinin-like activity studied on the isolated cotyledons of pumpkin.

Materials and Methods

Chemicals

Plant growth regulating activity of synthetic low molecular weight five and six-membered heterocyclic compounds derivatives of pyrimidine (compounds № I-III), pyrazole (compounds № IV-VI), and phosphorylated derivatives of oxazole (compounds № VII and VIII) and pyrimidine (compounds № IX) was studied. The chemical low molecular weight five and six-membered heterocyclic compounds were synthesized at the Department for chemistry of bioactive nitrogen-containing heterocyclic compounds of Institute of Bioorganic Chemistry and Petrochemistry of NAS of Ukraine. The activity of chemical heterocyclic compounds was compared with the activity of phytohormones auxins IAA (compound № X) and NAA (compound № XI), and cytokinin Kinetin (compound № XII).

The chemical name, structure and relative molecular weight of phytohormones and synthetic heterocyclic compounds used for bioassays are shown on the Figure 1.
I. Compound 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidin-5-one, Molecular weight = 291.33 g/mol

II. Compound 7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydroprymidido[1,6-d]pyrimidin-6-one hydrochloride, Molecular weight = 309.77 g/mol

III. Compound 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride, Molecular weight = 295.74 g/mol

IV. Compound 7-(1,3-Benzothiazol-2-yl)-3H4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-one, Molecular weight = 279.27 g/mol

V. Compound 2-{4-Oxo-7-phenyl-3H4H,7H-pyrazolo[3,4-d][1,2,3]triazin-3-yl]acetic acid, Molecular weight = 271.24 g/mol

VI. Compound 6-{4-Oxo-3H4H,7H-pyrazolo[3,4-d][1,2,3]triazin-7-yl}-1,2-dihydroisoquinolin-1-one, Molecular weight = 280.24 g/mol

VII. Compound Diethylster {5-{(2-Hydroxyethyl)-methylamino}-2-phenyl-1,3-oxazol-4-yl} phosphonic acid, Molecular weight = 354.34 g/mol

VIII. Compound Diethyl ester {5-(3-Hydroxypropy-1-yl)-2-phenyl-1,3-oxazol-4-yl} phosphonic acid, Molecular weight = 380.37 g/mol

IX. Compound 4-Benzylamino-5-p-tolyl-5H-pyrrrolo-[3,2-d]pyrimidin-7-ylphosphonic acid diethyl ester, Molecular weight = 450.48 g/mol

X. IAA (1H-Indol-3-ylacetic acid), Molecular weight = 175.19 g/mol

XI. NAA (1-Naphthylacetic acid), Molecular weight = 186.21 g/mol

XII. Kinetin (N-(2-Furylmethyl)-7H-purin-6-amine), Molecular weight = 215.22 g/mol

Study of growth regulating activity of synthetic heterocyclic compounds on pea and maize seedlings

In the laboratory conditions we studied growth regulating activity of phytohormones auxins IAA and NAA, and synthetic heterocyclic compounds derivatives of pyrimidine, pyrazole, and phosphorylated derivatives of oxazole and pyrimidine according to their impact on germination of seeds and vegetative growth of seedlings of two cultivars of pea (Pisum sativum L.) - of cultivar L35/11 middle stalwart bewhiskered and cultivar L303/04 semi-dwarf bewhiskered, as well as maize (Zea mays L.) hybrid Palmyra FAO 190. With this aim seeds of these crops were surface sterilized successively in 1% KMnO4 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 each heterocyclic compound used at concentration 10-7M/1 of distilled water or water solution of auxins IAA or NAA used at the same concentration 10-7M/1 of distilled water (experiment). 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 21 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 indexes of seedlings (i.e. number of germinated seeds (%), seedlings height (cm), root number (pcs), root length (mm)) was carried out at the 21st day after their sprouting according to the guideline [155].

Figure 1. Chemical Structures of Phytohormones and Synthetic Heterocyclic Compounds used for Bioassays.
The chlorophyll content per 1 g of fresh weight (FW) of plant tissue extracted was calculated by the following formula (separately for chlorophyll a and chlorophyll b):

\[ C_{\text{chl}} = \frac{(C \times V)}{(1000 \times a_1)} \]

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

The calculation of total content of chlorophyll a, chlorophyll b, and carotenoids was performed using the following formula [158]:

\[
C_{\text{chl}a} = 13.36 \times A_{664.2} - 5.19 \times A_{648.6}, \\
C_{\text{chl}b} = 27.43 \times A_{648.6} - 8.12 \times A_{664.2}, \\
C_{\text{chl}a+b} = 5.24 \times A_{664.2} + 22.24 \times A_{648.6}, \\
C_{\text{car}} = \left(1000 \times A_{470} - 2.13 \times C_{\text{chl}a} - 97.64 \times C_{\text{chl}b}\right)/209, \\
\]

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

\[ \text{Statistical Analysis} \]

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 ± SD [159].

\[ \text{Results} \]

Stimulating effect of chemical heterocyclic compounds derivatives of pyrimidine on vegetative growth of pea (\textit{Pisum sativum L.}) of cultivar L35/11 middle stalwart bewhiskered

In the laboratory conditions we studied growth regulating activity of synthetic heterocyclic compounds derivatives of pyrimidine used at concentration 10^{-9}M/1 of distilled water on seed germination and vegetative growth of pea (\textit{Pisum sativum L.}) of cultivar L35/11 middle stalwart bewhiskered (Figure 2).

The growth regulating activity of synthetic heterocyclic compounds was compared with the activity of phytohormones auxins IAA and NAA used at the same concentration 10^{-9}M/1 of distilled water. The obtained results showed that all tested heterocyclic compounds revealed high stimulating effect on growth of the 21st-day-old seedlings of pea (Figure 2).

It was found that all synthetic heterocyclic compounds considerably stimulated growth and development of roots on the 21st-day-old pea seedlings, and their stimulating effect was similar or higher than the effect of phytohormones auxins IAA and NAA (Figure 3).

The comparative analysis of biometric indexes of 21st-day-old seedlings of pea (i.e. number of germinated seeds (%), length of seedlings (cm), total number of roots (pcs), total length of roots (mm)) showed that the biometric indexes of pea seedlings grown on the water solution of chemical heterocyclic compounds derivatives of pyrimidine used at concentration 10^{-9}M/1 of distilled water were as generally similar or higher than the biometric indexes of 21st-day-old pea seedlings grown on the water solution of phytohormones auxins IAA and NAA used at the same concentration 10^{-9}M/1 of distilled water as compared to lower biometric indexes of 21st-day-old pea seedlings grown on the distilled water (control) (Figure 4).

Particularly, it was found that the highest growth regulating activity revealed the compound № III – 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride; the biometric indexes of 21st-day-old pea seedlings grown on the water solution of this compound used at concentration 10^{-9}M/1 of distilled water were as generally higher than the biometric indexes of 21st-day-old pea seedlings grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10^{-9}M/1 of distilled water as follows: according with length of seedlings – at the 7% as compared with control; according with total length of roots – at the 46%, 15%, and 15% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 70%, 54% and 48% as compared with control, IAA and NAA, respectively (Figure 4).
Figure 2. Impact of synthetic heterocyclic compounds derivatives of pyrimidine and phytohormones auxins IAA and NAA on vegetative growth of the 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L35/11 middle stalwart be-whiskered. C – Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidin-5-one, Compound № II -7-(2-Hydroxyethyl)-9-methanesulfon-fy1-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride, Compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride.

Figure 3. Impact of synthetic heterocyclic compounds derivatives of pyrimidine and phytohormones auxins IAA and NAA on growth of roots on the 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L35/11 middle stalwart be-whiskered. C – Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidin-5-one, Compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride, Compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride.

Figure 4. Impact of synthetic heterocyclic compounds derivatives of pyrimidine and phytohormones auxins IAA and NAA on biometric indexes of the 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L35/11 middle stalwart bewhiskered. Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidin-5-one, Compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride, Compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride. А – Number of germinated seeds (%), B – length of seedlings (cm), C - total length of roots (mm), D - total number of roots (pcs).
The high growth regulating activity revealed also the compound № II - 7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-c]pyrimidin-6-one hydrochloride; the biometric indexes of 21-day-old pea seedlings grown on the water solution of this compound used at concentration 10⁻⁹ M/l of distilled water were as generally higher than the biometric indexes of 21-day-old pea seedlings grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10⁻⁹ M/l of distilled water as follows: according with length of seedlings – at the 8% as compared with control; according with total length of roots – at the 35%, 6%, and 0% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 46%, 32% and 27% as compared with control, IAA and NAA (Figure 4).

Based on the obtained results it is possible to assume that the growth stimulating activity of synthetic heterocyclic compounds-derivatives of pyrimidine, which is similar to activity of phytohormones auxins, may be explained by their inducing effect on the plant cell division, cell elongation, cell proliferation, cell differentiation, and the increase of cell metabolism, resulting in an improving of growth and development of pea (Pisum sativum L.) of cultivar L35/11 middle stalwart bewhiskered.

**Impact of synthetic heterocyclic compounds derivatives of pyrimidine on the total content of pigments in the leaves of pea (Pisum sativum L.) of cultivar L35/11 middle stalwart bewhiskered**

It is known that photosynthesis is a key process that ensures the productivity of plants, so the study of quantitative and qualitative content of photosynthetic pigments and their ratio in the plant cells is a very important aspect to clarify the impact of plant growth regulating compounds on the productivity of plants [158, 160-162]. The important indicator of the balanced photosynthetic process is the ratio of chlorophylls a/b, since the chlorophyll a is bound to both photosynthetic reaction centers and light-harvesting complexes (LHCs) or antennas, while chlorophyll b and carotenoids are bound exclusively to light-harvesting complexes (LHCs) of a photosystem [158, 160-162]. Thus, changes in the chlorophylls a/b ratio may indicate the degree of formation of plant photosystem.

Carotenoids belong to major plant pigments that play an important role in photosynthetic processes in the plant cells and a positive role in human health [163-165]. It is known that there is significant correlation in carotenoid/chlorophyll ratio indices across various plant species growing in different natural environments; but usually this correlation is disrupted in senescing leaves during the seasonal changes [161].

In this work we conducted comparative study of impact of synthetic heterocyclic compounds derivatives of pyrimidine, and phytohormones auxins IAA and NAA used at concentration 10⁻⁹ M/l of distilled water on the total content of chlorophylls (including chlorophyll a and chlorophyll b), as well as carotenoids in the leaves of 21-day-old seedlings of pea (Pisum sativum L.) of cultivar L35/11 middle stalwart bewhiskered. The obtained results showed the increase of total content of pigments in the leaves of 21-day-old pea seedlings grown on the water solution of some synthetic heterocyclic compounds used at concentration 10⁻⁹ M/l of distilled water (Figure 5).

The increase of synthesis of chlorophyll a was found in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride used at concentration 10⁻⁹ M/l of distilled water; the content of chlorophyll b was increased at the 19%, 36% and 22% as compared with control, IAA and NAA, respectively (Figure 5).

Similar changes were observed in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № II - 7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-c]pyrimidin-6-one hydrochloride, as compared with control, IAA and NAA, respectively (Figure 5).
The cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one; the content of chlorophyll a was increased at the 12%, 29% and 16% as compared with control, IAA and NAA, respectively (Figure 5).

A slight decline in synthesis of chlorophyll a was found in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № II -7-(2-Hydroxyethyl)-9-methanesulfon-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride; the content of chlorophyll a was decreased at the 6 % as compared with control, but at the same time its content was higher at the 8 % as compared with IAA and similar to NAA, respectively (Figure 5).

Our studies showed also the increase of synthesis of chlorophyll b in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № III -6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one hydrochloride at concentration 10^{-9} M/l of distilled water; the content of chlorophyll b was increased at the 17%, 35% and 21% as compared with control, IAA and NAA, respectively (Figure 5).

The similar increase of synthesis of chlorophyll b was observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one; the content of chlorophyll b was increased at the 6%, 21% and 9% as compared with control, IAA and NAA, respectively (Figure 5).

The increase of the content of chlorophyll b was shown also in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride; the content of chlorophyll b was increased at the 13% as compared with IAA (Figure 5).

It was found also the positive effect of compounds № I, № II and № III on increase of the content of total chlorophylls a+b in the cells of leaves of 21st-day-old pea seedlings (Figure 5).

The highest content of chlorophylls a+b was found in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one hydrochloride - at the 19%, 36% and 22% as compared with control, IAA and NAA, respectively (Figure 5).

The high content of chlorophylls a+b was observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one at the 11%, 27% and 15% as compared with control, IAA and NAA, respectively (Figure 5).

The content of chlorophylls a+b was increased also in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride at the 9% as compared with IAA (Figure 5).

It was found that the chlorophylls a/b ratio in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I used at concentration 10^{-9} M/l of distilled water was increased at the 8%, 7% and 7% as compared with control, IAA and NAA, respectively (Figure 5).

The similar increase of chlorophylls a/b ratio at the 2% as compared with control was observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № III used at concentration 10^{-9} M/l of distilled water (Figure 5).

The investigation of quantitative content of carotenoids showed the increase of content of carotenoids in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one hydrochloride at the 28%, 37% and 24% as compared with control, IAA and NAA, respectively (Figure 5).

The increase of content of carotenoids was also observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-a]pyrimidin-5-one; the content of carotenoids in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № I was increased at the 12%, 21% and 9% as compared with control, IAA and NAA, respectively (Figure 5).

Similar changes were observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride; the content of carotenoids in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № II was increased at the 6%, 14% and 3% as compared with control, IAA and NAA, respectively (Figure 5).

The important aspect of our research was study impact of synthetic heterocyclic substances on correlation in carotenoid/chlorophyll ratio in the plant cells; the minor changes in the carotenoid/chlorophyll ratio was observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of hetero cyclic compounds № II and № III used at concentration 10^{-9} M/l of distilled water; the carotenoid/chlorophyll ratio was increased at the 10% and 8%, respectively, as compared to control.

The similar changes in the balance of endogenous photosynthetic pigments was observed in the leaves of 21st-day-old pea seedlings grown on the water solution of auxins IAA and NAA used at concentration 10^{-9} M/l of distilled water; the carotenoid/chlorophyll ratio indices was increased at the 5% and 5%, respectively, as compared to control.

The conducted researches confirmed impact of all tested synthetic heterocyclic compounds derivatives of pyrimidine and phytohormones auxins IAA and NAA on change of the balance of endogenous photosynthetic pigments in the leaves of 21st-day-old seedlings of pea (Pisum sativum L.) of cultivar L35/11 middle stawl-wart bewhiskered.
Study of cytokinin-like activity of synthetic heterocyclic compounds derivatives of pyrimidine on the isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea

The cytokinin-like growth regulating activity of synthetic heterocyclic compounds derivatives of pyrimidine was studied using the most known bioassay on growth of biomass of cotyledons (i.e. food-storage organs) isolated from seeds of pumpkin (Cucurbita pepo L.) [156, 157]. In our work we used as an experimental material the isolated cotyledons from seeds of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea, which is an important agricultural crop.

It was shown that all tested compounds manifested the expressive cytokinin-like activity; the obtained indexes of growth of biomass of the isolated cotyledons of pumpkin incubated during 16 days on the water solution of some from tested synthetic heterocyclic compounds used at concentration 10⁻⁹M/l of distilled water were similar or higher than the indexes of growth of biomass of isolated cotyledons of pumpkin incubated during 16 days on the water solution of phytohormone cytokinin Kinetin used at the same concentration 10⁻⁹M/l of distilled water as compared with control (Figure 6).

Among the synthetic heterocyclic compounds the highest growth regulating activity revealed the compound № III-6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-dihydro-3H-imidazo[1,2-c]pyrimidine-5-one hydrochloride; the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the water solution of compound № III used at concentration 10⁻⁹M/l of distilled water were higher at the 13% than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the distilled water (control) (Figure 6).

The lower growth regulating activity demonstrated compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-a]pyrimidin-6-one hydrochloride; the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the water solution of compound № II used at concentration 10⁻⁹M/l of distilled water were higher at the 18% than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the distilled water (control) (Figure 6).

Thus, the obtained results confirmed high cytokinin-like growth regulating activity of synthetic heterocyclic compounds derivatives of pyrimidine, which was similar or higher of activity of phytohormone Kinetin. Obviously that growth regulating activity of synthetic heterocyclic compounds may be explained by their specific cytokinin-like inducing effect on cell division and cell elongation, as well as activation of biosynthetic processes in the cells of isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea resulting in an increase of their growth and biomass.

Stimulating effect of synthetic heterocyclic compounds derivatives of pyrazole on vegetative growth of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered

In the laboratory conditions we studied growth regulating activity of synthetic heterocyclic compounds derivatives of pyrazole used at concentration 10⁻⁹M/l of distilled water on seed germination and vegetative growth of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered (Figure 7). The growth regulat-
Figure 7. Impact of synthetic heterocyclic compounds derivatives of pyrazole and phytohormones auxins IAA and NAA on vegetative growth of the 21st-day-old seedlings of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered.

C – Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound №IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-one, Compound №V - 2-[4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-3-y]l]acetic acid, Compound №VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-7-y]-1,2-dihydroisoquinolin-1-one.

The obtained results showed that all tested heterocyclic compounds revealed high stimulating effect on growth of the 21st-day-old seedlings of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered (Figure 7).

It was found also that all synthetic heterocyclic compounds considerably stimulated growth and development of roots on the 21st-day-old pea seedlings, and their stimulating effect was similar or higher than the effect of phytohormones auxins IAA and NAA (Figure 8).

The comparative analysis of biometric indexes of 21st-day-old seedlings of pea (i.e. number of germinated seeds (%), length of seedlings (cm), total number of roots (pcs), total length of roots (mm)) showed that the biometric indexes of pea seedlings grown on the water solution of chemical heterocyclic compounds derivatives of pyrazole used at concentration 10^-9M/l of distilled water were as generally similar or higher than the biometric indexes of 21st-day-old pea seedlings grown on the water solution of phytohormones auxins IAA and NAA used at the same concentration 10^-9M/l of distilled water as compared to lower biometric indexes of 21st-day-old pea seedlings grown on the distilled water (control) (Figure 9).

Particularly it was found that the highest growth regulating activity revealed the compound №IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-one; the biometric indexes of 21st-day-old pea seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 21st-day-old pea seedlings grown on the distilled water (control) as follows: according with length of seedlings – at the 23% as compared with control; according with total length of roots – at the 76% as compared with control; according with total number of roots – at the 16% as compared with control.

The lower growth regulating activity revealed the compound №V - 2-[4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-3-y]l]acetic acid; the biometric indexes of 21st-day-old pea seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 21st-day-old pea seedlings grown on the distilled water (control) as follows: according with length of seedlings – at the 18% as compared with control; according with total length of roots – at the 15% as compared with control; according with total number of roots – at the 16% as compared with control.

Based on the obtained results it is possible to assume that high growth stimulating activity of synthetic heterocyclic compounds derivatives of pyrazole, which is similar to activity of phytohormones auxins, may be explained by their inducing effect on the plant cell division, cell elongation, cell proliferation, cell differentiation, and the increase of cell metabolism, resulting in an improving of growth and development of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered.
of distilled water on the total content of chlorophylls (including chlorophyll a and chlorophyll b), as well as carotenoids in the leaves of 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L303/04 semi-dwarf bewhiskered. The activity of synthetic heterocyclic compounds was compared with the activity of phytohormones auxins IAA and NAA that were used at the same concentration $10^{-9}$M/l of distilled water.

The obtained results showed that some from tested heterocyclic compounds revealed high stimulating effect on increase of synthesis of pigments in the leaves of 21st-day-old pea seedlings grown on the water solution of some synthetic heterocyclic compounds (Figure 10).

In contrast, the decrease of content of chlorophyll a at the 18%, 21% and 28% as compared with control, IAA and NAA, respectively, was observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound №VI - 6-$[4$-Oxo-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$7$-yl]-1,2-dihydroisoquinolin-1-one used at concentration $10^{-9}$M/l of distilled water (Figure 10).

It was found also the increase of synthesis of chlorophyll b in the 29%, 23% and 12% as compared with control, IAA and NAA, respectively (Figure 10). Similar changes were observed in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound №V - 2-$[4$-Oxo-$7$-phenyl-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$3$-yl]-1,2-dihydroisoquinolin-1-one used at concentration $10^{-9}$M/l of distilled water (Figure 10).

Figure 8. Impact of synthetic heterocyclic compounds derivatives of pyrazole and phytohormones auxins IAA and NAA on growth of roots on the 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L303/04 semi-dwarf bewhiskered. Control (distilled water), IAA – Compound 1-$H$-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № IV - 7-$[1,3$-Benzothiazol-2-yl]-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$4$-one, Compound № V - 2-$[4$-Oxo-$7$-phenyl-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$3$-yl]acetic acid, Compound № VI - 6-$[4$-Oxo-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$7$-yl]-1,2-dihydroisoquinolin-1-one.

Figure 9. Impact of synthetic heterocyclic compounds derivatives of pyrazole and phytohormones auxins IAA and NAA on biometric indexes of the 21st-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L303/04 semi-dwarf bewhiskered. Control (distilled water), IAA – Compound 1-$H$-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № IV - 7-$[1,3$-Benzothiazol-2-yl]-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$4$-one, Compound № V - 2-$[4$-Oxo-$7$-phenyl-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$3$-yl]acetic acid, Compound № VI - 6-$[4$-Oxo-$3$-$H$$]$$4$-$H$$,7$$-$$H$-pyrazolo$[3,4$-$d$$]$$[1,2,3$$]$triazin-$7$-yl]-1,2-dihydroisoquinolin-1-one. A – Number of germinated seeds (%), B – length of seedlings (cm), C - total length of roots (mm), D - total number of roots (pcs).
the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-4-one at concentration 10^{-9}M/l of distilled water; the content of chlorophyll b was increased at the 16% and 9% as compared with control and IAA, respectively (Figure 10).

The similar increase of synthesis of chlorophyll b was observed in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № V - 2-[4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]acetic acid; the content of chlorophyll b was increased at the 9% and 3% as compared with control and IAA, respectively (Figure 10).

At the same time the decrease of content of chlorophyll b at control and IAA, respectively (Figure 10). chlorophyll b was increased at the 9% and 3% as compared with control and IAA, respectively (Figure 10).

The increase of content of chlorophyll a+b in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-4-one. The content chlorophylls a+b was increased in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]-1,2-dihydroisoquinolin-1-one used at concentration 10^{-9}M/l of distilled water (Figure 10).

The increase of content of chlorophyll a+b in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-4-one was increased in the cells of leaves of 21st-day-old pea seedlings grown on the water solution of compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]-1,2-dihydroisoquinolin-1-one used at concentration 10^{-9}M/l of distilled water (Figure 10).

Despite of decrease of content of chlorophyll a+b in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]-1,2-dihydroisoquinolin-1-one used at concentration 10^{-9}M/l of distilled water, the chlorophylls a/b ratio was increased in the cells of these plants at the 5%, 7% and 6% as compared with control, IAA and NAA, respectively (Figure 10).

Study of quantitative content of carotenoids showed that the content of carotenoids in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-4-one used at concentration 10^{-9}M/l of distilled water was increased at the 33%, 26% and 10% as compared with control, IAA and NAA, respectively (Figure 10).

It was also demonstrated that the content of carotenoids in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]-1,2-dihydroisoquinolin-1-one used at concentration 10^{-9}M/l of distilled water was increased at the 8% as compared with control (Figure 10).

In contrast, the decrease of content of carotenoids at the 5%, 9% and 21% as compared with control, IAA and NAA, respectively, was observed in the cells of leaves of 21-day-old pea seedlings grown on the water solution of compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-7-yl]-1,2-dihydroisoquinolin-1-one used at concentration 10^{-9}M/l of distilled water (Figure 10).

**Figure 10. Impact of synthetic heterocyclic compounds derivatives of pyrazole and phytohormones auxins IAA and NAA on the content of chlorophyll a, chlorophyll b, and carotenoids in the leaves of the 21-day-old seedlings of pea (*Pisum sativum* L.) of cultivar L303/04 semi-dwarf bewhiskered. Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-4-one, Compound № V - 2-[4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-3-yl]acetic acid, Compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-α][1,2,3]triazin-7-yl]-1,2-dihydroisoquinolin-1-one.**

![Figure 10](image-url)
Obviously the decrease of total content of chlorophyll a, chlorophyll b, and carotenoids in the cells of leaves of 21\(^{st}\)-day-old pea seedlings grown on the water solution of compound VI - 6-{4-Oxo-3H,4H,7H-pyrazolo[3,4-\(d\)][1,2,3]triazin-7-yl}-1,2-dihydroisoquinolin-1-one may be explained its specific auxin-like stimulating effect on acceleration of growth and development of vegetative organs and root system of 21\(^{st}\)-day-old pea seedlings at while reducing the total content of pigments per unit area of plant biomass.

The minor changes in the carotenoid/chlorophyll ratio in the cells of leaves of 21\(^{st}\)-day-old pea seedlings grown on the water solution of heterocyclic compounds № IV and № VI used at concentration 10\(^{-9}\) M/l of distilled water; the carotenoid/chlorophyll ratio was increased at the 5% and 14%, respectively, as compared to control.

It was observed also the minor changes in the carotenoid/chlorophyll ratio in the cells of leaves of 21\(^{st}\)-day-old pea seedlings grown on the water solution of heterocyclic compound № V used at concentration 10\(^{-9}\) M/l of distilled water; the carotenoid/chlorophyll ratio was increased at the 6% as compared to NAA.

The similar changes in the balance of endogenous photosynthetic pigments were observed in the leaves of 21\(^{st}\)-day-old pea seedlings grown on the water solution of auxin NAA used at concentration 10\(^{-9}\) M/l of distilled water; the carotenoid/chlorophyll ratio was increased at the 5% as compared to control.

The conducted researches confirmed the impact of some from tested synthetic heterocyclic compounds derivatives of pyrazole and phytohormone auxin NAA on change of the balance of endogenous photosynthetic pigments in the leaves of 21\(^{st}\)-day-old seedlings of pea (Pisum sativum L.) of cultivar L303/04 semi-dwarf bewhiskered.

Study of cytokinin-like activity of synthetic heterocyclic compounds derivatives of pyrazole on the isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea

Study of cytokinin-like growth regulating activity of synthetic heterocyclic compounds derivatives of pyrazole conducted on the isolated cotyledons from seeds of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea showed that all tested compounds revealed high cytokinin-like activity. The obtained indexes of growth of biomass of the isolated cotyledons of pumpkin incubated during 16 days on the water solution of some from tested synthetic heterocyclic compounds used at concentration 10\(^{-9}\) M/l of distilled water were similar or higher than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown either on the distilled water (control) or on the water solution of cytokinin Kinetin used at the same concentration 10\(^{-9}\) M/l of distilled water, respectively (Figure 11).

The high growth regulating activity demonstrated also compound № IV - 7-{1,3-Benzothiazol-2-yl}-3H,4H,7H-pyrazolo[3,4-\(d\)][1,2,3]triazin-4-yl; the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the water solution of compound № IV used at concentration 10\(^{-9}\) M/l of distilled water were higher at the 23% and 6% than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown either on the distilled water (control) or on the water solution of cytokinin Kinetin used at the same concentration 10\(^{-9}\) M/l of distilled water, respectively (Figure 11).

The lower growth regulating activity demonstrated compound № VI - 6-{4-Oxo-3H,4H,7H-pyrazolo[3,4-\(d\)][1,2,3]triazin-7-yl}-1,2-dihydroisoquinolin-1-one; the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the water solution of compound № VI used at concentration 10\(^{-9}\) M/l of distilled water were higher at the 12% than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the distilled water (control) (Figure 11).

Thus, the obtained results confirmed high cytokinin-like growth regulating activity of synthetic heterocyclic compounds derivatives of pyrimidine, which was similar or higher of activity of phytohormone Kinetin. Obviously that growth regulating activity of synthetic heterocyclic compounds may be explained by their specific cytokinin-like inducing effect on cell division and cell elongation, as well as activation of biosynthetic processes in the cells of isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea resulting in an increasing of their growth and biomass.

Stimulating effect of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on vegetative growth of maize (Zea mays L.) hybrid Palmyra FAO 190

In the laboratory conditions we studied also growth regulating activity of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine used at concentration 10\(^{-9}\) M/l of distilled water according to their impact on germination of seeds and vegetative growth of seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190 (Figure 12).

The growth regulating activity of synthetic heterocyclic compounds was compared with the activity of phytohormones auxins IAA and NAA used at the same concentration 10\(^{-9}\) M/l of distilled water.

The obtained results showed that all tested heterocyclic compounds revealed high stimulating effect on growth of the 14\(^{th}\)-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190 (Figure 12).

It was found also that all synthetic heterocyclic compounds considerably stimulated growth and development of roots on the 14\(^{th}\)-day-old seedlings, and their stimulating effect was simi-
Figure 11. Impact of synthetic heterocyclic compounds derivatives of pyrazole and phytohormone cytokinin Kinetin on growth of biomass of isolated cotyledons from seeds of muscat pumpkin (*Cucurbita moschata* Duch. et Poir.) of cultivar Gilea during the 16 days. Control (distilled water), Compound №IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-one, Compound №V -2-{4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-3-yl}acetic acid, Compound №VI - 6-{4-Oxo-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-7-yl}-1,2-dihydroisoquinolin-1-one.

Figure 12. Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine, as well as phytohormones auxins IAA and NAA on vegetative growth of the 14th-day-old seedlings of maize (*Zea mays* L.) hybrid Palmyra FAO 190. C – Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound VII - Diethyl ester [5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl]phosphonic acid, Compound VIII - Diethyl ester [5-(3-Hydroxypiperidin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid, Compound IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-ylphosphonic acid diethyl ester.

Figure 13. Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine, as well as phytohormones auxins IAA and NAA on growth of roots on the 14th-day-old seedlings of maize (*Zea mays* L.) hybrid Palmyra FAO 190. C – Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound VII - Diethyl ester [5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl]phosphonic acid, Compound VIII - Diethyl ester [5-(3-Hydroxypiperidin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid, Compound IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-ylphosphonic acid diethyl ester.
lar or higher than the effect of phytohormones auxins IAA and NAA (Figure 13).

The comparative analysis of biometric indexes of 14th-day-old seedlings of maize (i.e. number of germinated seeds (%), length of seedlings (cm), total number of roots (pcs), total length of roots (mm)) showed that the biometric indexes of 14th-day-old maize seedlings grown on the water solution of chemical heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine used at concentration 10^-9M/l of distilled water were as generally similar or higher than the biometric indexes of 14th-day-old maize seedlings grown on the water solution of phytohormones auxins IAA and NAA used at the same concentration 10^-9M/l of distilled water as compared to lower biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) (Figure 14).

Particularly it was found that the highest growth regulating activity revealed the compound № VII - Diethyl ester {5-[{(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl} phosphonic acid; the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10^-9M/l of distilled water as follows: according with total length of roots – at the 37%, 34% and 13% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 47%, 39% and 7% as compared with control, IAA and NAA, respectively (Figure 14).

The high growth regulating activity revealed also the compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl phosphonic acid diethyl ester, the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) as follows: according with total length of roots – at the 27%, 25% and 5% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 87%, 77% and 36% as compared with control, IAA and NAA, respectively (Figure 14).

Based on the obtained results it is possible to assume that high growth stimulating activity of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine, which is similar to activity of phytohormones auxins, may be explained by their inducing effect on the plant cell division, cell elongation, cell proliferation, cell differentiation, and the increase of cell metabolism, resulting in an improving of growth and development of maize (Zea mays L.) hybrid Palmyra FAO 190.

Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on the total content of pigments in the leaves of maize (Zea mays L.) hybrid Palmyra FAO 190

In our work we also studied impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine used at concentration 10^-9M/l of distilled water on the total content of chlorophylls (including chlorophyll a and chlorophyll b), as well as carotenoids in the leaves of 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190. The activity of synthetic heterocyclic compounds was compared with the activity cording with length of seedlings – at the 23% as compared with control; according with total length of roots – at the 18% and 16% as compared with control and IAA, respectively; according with total number of roots – at the 52%, 44% and 11% as compared with control, IAA and NAA, respectively (Figure 14).

The high growth regulating activity revealed also the compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl phosphonic acid diethyl ester, the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) as follows: according with total length of roots – at the 27%, 25% and 5% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 87%, 77% and 36% as compared with control, IAA and NAA, respectively (Figure 14).

Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on the total content of pigments in the leaves of maize (Zea mays L.) hybrid Palmyra FAO 190

In our work we also studied impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine used at concentration 10^-9M/l of distilled water on the total content of chlorophylls (including chlorophyll a and chlorophyll b), as well as carotenoids in the leaves of 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190. The activity of synthetic heterocyclic compounds was compared with the activity

Figure 14. Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine and phytohormones auxins IAA and NAA on biometric indexes of the 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190. Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound VII - Diethyl ester {5-[{(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl} phosphonic acid; the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) as follows: according with total length of roots – at the 37%, 34% and 13% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 47%, 39% and 7% as compared with control, IAA and NAA, respectively (Figure 14).

The high growth regulating activity revealed the compound № VIII - Diethyl ester {5-[{(3-Hydroxypropiridin-1-yl)-2-phenyl-1,3-oxazol-4-yl} phosphonic acid diethyl ester; the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) as follows: according with total length of roots – at the 27%, 25% and 5% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 87%, 77% and 36% as compared with control, IAA and NAA, respectively (Figure 14).

Based on the obtained results it is possible to assume that high growth stimulating activity of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine, which is similar to activity of phytohormones auxins, may be explained by their inducing effect on the plant cell division, cell elongation, cell proliferation, cell differentiation, and the increase of cell metabolism, resulting in an improving of growth and development of maize (Zea mays L.) hybrid Palmyra FAO 190.

Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on the total content of pigments in the leaves of maize (Zea mays L.) hybrid Palmyra FAO 190

In our work we also studied impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine used at concentration 10^-9M/l of distilled water on the total content of chlorophylls (including chlorophyll a and chlorophyll b), as well as carotenoids in the leaves of 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190. The activity of synthetic heterocyclic compounds was compared with the activity

Figure 14. Impact of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine and phytohormones auxins IAA and NAA on biometric indexes of the 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190. Control (distilled water), IAA – Compound 1H-Indol-3-ylacetic acid, NAA – Compound 1-Naphthylacetic acid, Compound VII - Diethyl ester {5-[{(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl} phosphonic acid; the biometric indexes of 14th-day-old maize seedlings grown on the water solution of this compound used at concentration 10^-9M/l of distilled water were as generally higher than the biometric indexes of 14th-day-old maize seedlings grown on the distilled water (control) as follows: according with total length of roots – at the 37%, 34% and 13% as compared with control, IAA and NAA, respectively; according with total number of roots – at the 47%, 39% and 7% as compared with control, IAA and NAA, respectively (Figure 14).
of phytohormones auxins IAA and NAA that were used at the same concentration 10^{-9}M/l of distilled water.

The obtained results showed that some from tested heterocyclic compounds revealed stimulating effect on synthesis of pigments in the leaves of 14th-day-old maize seedlings grown on the water solution of the synthetic heterocyclic compounds (Figure 15).

The increase of synthesis of chlorophyll a was observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl)phosphonic acid diethyl ester used at concentration 10^{-9}M/l of distilled water; the content of chlorophyll a was increased at the 8%, 8% and 10% as compared with control, IAA and NAA, respectively (Figure 15).

In contrast, the decrease of synthesis of chlorophyll a was observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VII - Diethyl ester {5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl}phosphonic acid used at concentration 10^{-9}M/l of distilled water; the content of chlorophyll a was decreased at the 3% as compared with control (Figure 15).

Similar decrease of synthesis of chlorophyll a was observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VIII - Diethyl ester [5-(3-Hydroxypiperidin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid; the content of chlorophyll a was decreased at the 5% as compared with control (Figure 15).

At the same time the increase of synthesis of chlorophyll b was found in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VII - Diethyl ester {5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl}phosphonic acid used at concentration 10^{-9}M/l of distilled water; the content of chlorophyll b was increased at the 74% and 39% as compared with control and IAA, respectively (Figure 15).

The increase of synthesis of chlorophyll b was also observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VIII - Diethyl ester [5-(3-Hydroxypiperidin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid; the content of chlorophyll b was increased at the 45% and 15% as compared with control and IAA, respectively (Figure 15).

The increase of content of chlorophyll b at the 38% and 10% as compared with control and IAA, respectively, was shown also in the cells of leaves of 14th-day-old pea seedlings grown on the water solution of compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl)phosphonic acid diethyl ester used at concentration 10^{-9}M/l of distilled water (Figure 15).

It was observed the increase of content of chlorophylls a+b at the 11%, 9% and 5% as compared with control, IAA and NAA, respectively, in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl)phosphonic acid diethyl ester (Figure 15).

The increase of content of chlorophylls a+b at the 4% and 2% as compared with control and IAA, respectively, was found in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VII - Diethyl ester {5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl}phosphonic acid used at concentration 10^{-9}M/l of distilled water (Figure 15).

At the same time the decrease of chlorophylls a/b ratio at the 44% and 30% as compared with control and IAA, respectively, was observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № VII - Diethyl ester {5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl}phosphonic acid used at concentration 10^{-9}M/l of distilled water (Figure 15).

The decrease of chlorophylls a/b ratio at the 34% and 17% as compared with control and IAA, respectively, was observed also in the cells of leaves of 14th-day-old maize seedlings grown on...
the water solution of compound № VIII - Diethyl ester [5-(3-Hydroxypropyridin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid (Figure 15).

Similar changes were observed in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrrolo-[3,2-d]pyrimidin-7-yl]phosphonic acid diethyl ester; the chlorophylls a/b ratio was decreased at the 21% as compared with control (Figure 15).

Thus the obtained data confirmed positive effects of some synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on the synthesis of photosystem - chlorophylls a and b that play a key role in the photosynthetic processes in the leaves of 14th-day-old maize seedlings. At the same time, the results showed the effect of these compounds on the decline of chlorophyll a/b ratio. This fact indicates the selectivity of action of these compounds towards the intensification of biosynthesis of chlorophyll b, which is known to take an important part in plant adaptation to environmental stress factors [162].

Study of quantitative content of carotenoids showed that the content of carotenoids in the cells of leaves of 14th-day-old maize seedlings grown on the water solution of compounds № VII - Diethyl ester [5-[(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-yl]phosphonic acid and № VIII - Diethyl ester [5-(3-Hydroxypropyridin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid used at concentration 10^{-9}M/l of distilled water was decreased at the 10% and 14% as compared with control, respectively, while there was no any significant changes in the content of carotenoids in the cells of leaves of 21th-day-old maize seedlings grown on the water solution of compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl]phosphonic acid diethyl ester used at concentration 10^{-9}M/l of distilled water (Figure 15).

The changes in the carotenoid/chlorophyll ratio were observed in the leaves of 14th-day-old maize seedlings grown on the water solution of compounds № VII, № VIII and № IX used at the concentration 10^{-9}M/l of distilled water; the carotenoid/chlorophyll ratio was decreased at the 16%, 17% and 7%, respectively, as compared to control.

The similar changes in the balance of endogenous photosynthetic pigments was observed in the leaves of 14th-day-old maize seedlings grown on the water solution of auxins IAA and NAA used at concentration 10^{-9}M/l of distilled water; the carotenoid/chlorophyll ratio was decreased at the 11% and 19%, respectively, as compared to control.

This fact testifies about the change of the balance of endogenous photosynthetic pigments towards the increase of biosynthesis of chlorophylls and decrease of biosynthesis of carotenoids in the 14th-day-old seedlings of maize (Zea mays L.) hybrid Palmyra FAO 190 occurred under impact of tested heterocyclic compounds and phytohormones auxins IAA and NAA.

Study of cytokinin-like activity of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine on the isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea

The cytokinin-like growth regulating activity of synthetic heterocyclic compounds phosphorylated derivatives of oxazole and pyrimidine was conducted on the isolated cotyledons from seeds of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea. It was shown that all tested compounds demonstrated high cytokinin-like activity.

The obtained indexes of growth of biomass of the isolated cotyledons of pumpkin incubated during 16 days on the water solution of synthetic heterocyclic compounds used at concentration 10^{-9}M/l of distilled water were similar or higher than the indexes of growth of biomass of isolated cotyledons of pumpkin incubated during 16 days on the water solution of phytohormone cytokinin Kinetin used at the same concentration 10^{-9}M/l of distilled water as compared with control (Figure 16).

The obtained results showed that the highest growth regulating activity revealed the compound № IX - 4-Benzylamino-5-p-tolyl-5H-pyrrolo-[3,2-d]pyrimidin-7-yl]phosphonic acid diethyl ester.
The high growth regulating activity demonstrated compound № VIII - Diethyl ester [5-(3-Hydroxypiperidin-1-yl)-2-phenyl-1,3-oxazol-4-yl]phosphonic acid; the indexes of growth of biomass of the isolated cotyledons of pumpkin grown on the water solution of compound № VIII used at concentration 10⁻⁹ M/l of distilled water were higher at the 30% and 13% than the indexes of growth of biomass of the isolated cotyledons of pumpkin grown either on the distilled water (control) or on the water solution of cytokinin Kinetin used at the same concentration 10⁻⁹ M/l of distilled water, respectively (Figure 16).

Thus, the obtained results confirmed high cytokinin-like growth regulating activity of synthetic heterocyclic compounds phosphorolyated derivatives of oxazole and pyrimidine, which was similar or higher than activity of phytohormone Kinetin. Obviously that growth regulating activity of synthetic heterocyclic compounds may be explained by their specific cytokinin-like inducing effect on cell division and cell elongation, as well as activation of biosynthetic processes in the cells of isolated cotyledons of muscat pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea resulting in an increasing of their growth and biomass.

Discussion

To provide successful development of sustainable agriculture the new intensive technologies based on application of different classes of phytohormones, plant growth regulators of synthetic origin, and biostimulants are used for regulation of genetic program of plant growth and development, improve of quality of crop production and increase of crop resistance to stress-factors of environment [6-65, 86-94].

The elaboration of new effective plant growth regulating substances of natural or chemical origin on the base of different classes of synthetic and natural compounds having plant growth regulating activity similar to activity of phytohormones is a very important task for agricultural biotechnology. To study plant growth regulating activity of new bioactive compounds, the specific bioassays on phytohormone-like activity based on the effect of tested compounds on plant cell division, cell proliferation, cell elongation and cell differentiation in vivo and in vitro conditions are used [156, 157, 166-175]. Study of relationship between chemical structure and biological activity of different classes of synthetic plant growth regulating substances showed that conformational, electronic, and stereochemical features, as well as different substituents in the chemical structure play a major role in determining the growth regulating activity of these substances [170, 171, 176].

Today the new classes of plant growth regulating substances derivatives of low molecular weight five and six-membered heterocyclic compounds are synthesized in the Institute of Bioorganic Chemistry and Petrochemistry of National Academy of Sciences of Ukraine. Study of the biological activity of these low molecular weight heterocyclic compounds conducted on human and animal cells suggest that this compounds exhibit anticancer, antiviral, antibacterial, antifungal and anti-inflammatory activity [177-181]. Our previous researches devoted to study of plant growth regulating activity of heterocyclic compounds derivatives of pyridine, pyrimidine, pyrazole, and isoflavones showed high auxin-like and cytokinin-like stimulating effect on shoot organogenesis in the culture of isolated tissues of flax and on growth of isolated organs of haricot bean and pumpkin in vitro conditions, as well as on germination of seed and vegetative growth of maize, soybean, wheat, flux and lettuce plants in vitro conditions [151-154].

Based on the literature data and results of our previous researches the our present work was aimed to study of growth regulating activity of synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole according with their stimulating auxin-like effect on seed germination and vegetative growth of economically important agricultural crops such as pea and maize, as well as according with their cytokinin-like effect on growth of biomass of isolated cotyledons of another important agricultural plant - pumpkin.

The obtained results testify that all tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole used at very low nanomolar concentration 10⁻⁹ M/l of distilled water manifested high auxin-like stimulating effect on the vegetative growth of two cultivars of pea (Pisum sativum L.) - of cultivar L35/11 middle stalwart bewhiskered and cultivar L303/04 semi-dwarf bewhiskered, and maize (Zea mays L.) hybrid Palmyra FAO 190.

The activity of tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole used at concentration 10⁻⁹ M/l of distilled water was similar or higher than the activity of phytohormones auxins IAA and NAA, and cytokinin Kinetin used at the same concentration 10⁻⁹ M/l of distilled water. The obtained biometric indexes of pea and maize seedlings grown on the water solution of heterocyclic compounds used at concentration 10⁻⁹ M/l of distilled water were in average similar or higher of the biometric indexes of pea and maize seedlings grown either on the distilled water (control) or on the water solution of auxins IAA and NAA used at the same concentration 10⁻⁹ M/l of distilled water.

Among the tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole the highest growth regulating activity showed compounds: the compound № II -7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydro-2H-pyrimido[1,6-d]pyrimidin-6-one hydrochloride, the compound № III - 6-(2-Hydroxyethyl)-8-methanesulfonyl-2,6-
The lower growth regulating activity revealed heterocyclic compounds: the compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-d]pyrimidine-5-one, the compound № IV - 7-(1,3-Benzothiazol-2-yl)-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-one, the compound № VI - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-7-yl]-1,2-dihydroisoquinolin-1-one.

It was found also positive stimulating effect of some from tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole on synthesis of total chlorophylls and carotenoids in the leaves of pea and maize seedlings. The indexes of content of chlorophyll a, chlorophyll b, and carotenoids in the leaves of plants grown on water solution of heterocyclic compounds used at concentration 10^-9 M/l of distilled water were in average similar or higher than activity of phytohormones auxins IAA and NAA used at the same concentration 10^-9 M/l of distilled water.

The higher growth regulating activity showed heterocyclic compounds: the compound № I - 8-Methanesulfonyl-6-phenyl-2,6-dihydro-3H-imidazo[1,2-d]pyrimidine-5-one, the compound № III - 6-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-d]pyrazin-5-one hydrochloride, the compound № V - 2-{4-Oxo-7-phenyl-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-4-yl}acetic acid diethyl ester.

The lower cytokinin-like activity showed heterocyclic compounds: the compound № II - 7-(2-Hydroxyethyl)-9-methanesulfonyl-2,3,4,7-tetrahydropyrimido[1,6-d]pyrazin-6-one hydrochloride, the compound № IV - 6-[4-Oxo-3H,4H,7H-pyrazolo[3,4-d][1,2,3]triazin-7-yl]-1,2-dihydroisoquinolin-1-one, and the compound № VII - Diethyl ester [5-(2-Hydroxyethyl)-methyl-amino]-2-phenyl-1,3-oxazol-4-ylphosphonic acid diethyl ester.

Taking into account of obtained results it is possible to assume that the high auxin-like and cytokinin-like growth regulating activity of synthetic heterocyclic compounds may be explained by similarity of some fragments of their chemical structure to natural phytohormones auxins and cytokinins or their natural precursors, or their synthetic structural analogues, as well as their specific auxin-like and cytokinin-like inducing effect on cell division, cell elongation, cell differentiation, cell metabolism, and photosynthetic processes, resulting in accelerating of whole plant organism growth and growth of isolated plant organs [8, 18-32, 182-184].

Conclusion

Study of plant growth regulating activity of synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole used at concentration 10^-9 M/l of distilled water showed stimulating auxin-like activity of all tested compounds on vegetative growth of two cultivars of pea (Pisum sativum L.) - of cultivar L303/04 semi-dwarf bewhiskered, and maize (Zea mays L.) hybrid Palmyra FAO 190, as well as stimulating cytokinin-like activity of all tested compounds on growth of the isolated cotyledons of pumpkin (Cucurbita moschata Duch. et Poir.) of cultivar Gilea. The activity of tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole used at concentration 10^-9 M/l of distilled water was similar or higher than activity of phytohormones auxins IAA and NAA, and cytokinin Kinetin used at the same concentration 10^-9 M/l of distilled water. Study of regulating effect of synthetic heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole on photosynthesis in the leaves of pea and maize seedlings showed the positive effect of some from the tested compounds on increase of synthesis of chlorophyll a, chlorophyll b, and carotenoids in the plant cells. Based on the obtained results the application in agricultural biotechnology of the most effective from the tested synthetic low molecular weight heterocyclic compounds derivatives of pyrimidine, pyrazole, and oxazole as a new effective substitutes of phytohormones auxins and cytokinins to improve growth and development of pea, maize, and pumpkin is proposed.
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