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The Influence of Growth Regulators on the Productivity of Flax Plants

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ABSTRACT

Contemporary agrobiology is aimed at solving the problem of sufficiently stable agricultural crop yield, given the principles of eco-friendly nature use and mandatory monitoring of anthropogenic load on agrocenoses. Hormonal regulation of physiological functions, including the use of preparations based on phytohormones and modifiers of their activity, is one of the topical directions for tackling the problem of plant productivity. The article presents the research results of the effect of the inhibitor of antigibberellin action – chlormequat chloride – and the stimulator based on treptoleum phytohormones on the processes of morphogenesis, the formation of the photosynthetic apparatus, and the yield of flax plants. The plant height is established to decrease under the action of chlormequat chloride, and increase under the influence of treptolem. Both preparations caused an increase in the flax stem diameter. When applying growth regulators, the number of leaves and their total surface area, duration of functioning increased, which generally contributed to the improvement of the crop structure and flax plants productivity. Determination of the content of residual amounts of drugs was carried out on samples of leaves and stems of flax, while the complete absence or traces of chlormequat chloride was noted.

Keywords: oil flax, growth regulators, morphogenesis, productivity, residual content of substances.

INTRODUCTION

The anthropogenic load on ecosystems is persistently increasing especially when it comes to solving the problem of high productivity and stable harvest of agricultural crops. It occurs due to the introduction of an additional amount of mineral fertilizers, plowing of new lands or cultivation of economically profitable, but exhausting for the soil, crops. Hormonal regulation of physiological functions, integration of physiological processes in the plant, and adaptation to biotic or abiotic changes in the environment are one of the potential alternative ways to have an effect on plant productivity (Kuryata, Khodanitska, 2018).

The principal direction of solving such global problems is the study of plant growth and development under the influence of physiologically active substances (Ahmad et al., 2019). They include growth regulators, which are an integral part of the complex chemistry of crop production. The application of physiologically active substances with re-regulating properties allows having a targeted influence on individual stages of plant development, strengthening or weakening signs and properties within the limits of the reaction rate determined by the genotype (Shadchyna et al., 2006). In this respect, it is of high importance to be aware of the mechanisms of their action at the physiological, biochemical, molecular and genetic levels.

Growth regulators are, by their very nature, analogues or modifiers of the plant hormonal status (Rademacher, 2016). Modern growth regulators contain phytohormones, their analogues of microbiological origin, inhibitors, and compositions of organic acids and trace elements that are included in metabolic processes and lead to visible changes in the course of development phases, shoot growth, the formation of an assimilation surface, and the rhizosphere formation (Rohach et al., 2020). They activate the main life processes of plants – membrane processes, cell division, respiration and nutrition processes. Furthermore, they contribute to increasing the biological and economic efficiency of crop production (Koutroubas, Damalas, 2016; Zhou et al., 2020).

Because of the effectiveness of the application, growth regulators of the inhibitory type – retardants – have become widespread, these are anti-gibberellin preparations that affect the donor-acceptor relationship in the plant organism and slow down vegetative growth, redistributing the flow of photoassimilates to economically significant organs (Polyvanyi et al., 2020; Shevchuk et al., 2021). Moreover, physiologically active complexes as part of growth stimulants contribute to a more intensive course of metabolic processes, mitosis, activate enzyme systems, photosynthesis and air nutrition, improve plant resistance to diseases or fluctuations in environmental conditions (Bakry et al., 2013; Sang-Kuk et al., 2014).

It is important to note that these drugs have good ecological characteristics: they are low-toxic; have no carcinogenic and blastomogenic properties; the growth regulators don′t accumulate and decompose in the organism, after two days they are excreted from it (Polyvanyi et al., 2020). The half-life period of chlormequat chloride in the soil is about 3 to 43 days, depending on the temperature and humidity. In the soil, the preparation breaks down into choline chloride, choline, and betaine, and later carbon dioxide, water, nitrogen, and hydrochloric acid, which soil carbonates neutralize.

Oil flax is a valuable crop that can be a good predecessor for cereals and vegetables. Flaxseed contains about 50% oil rich in unsaturated fatty acids (Aghaee, Rahmani, 2019; Dawood et al., 2019). The products of its processing are used in the food, pharmaceutical, chemical, light, and electrical industries as a raw material foundation for biofuel. For many decades, sunflower has been paramount oilseed crop in Ukraine, while rapeseed – to a lesser extent. However, their crops deplete the soil too much, which leads to the violation of mineral supply, changes in the microbiological background. Linseed oil is a considerable alternative. The short growing season and drought resistance of flax allow expanding crops and increasing the production of vegetable oils without deteriorating the condition of the land (Khodanitska et al., 2019).

The production of competitive linseed products calls for optimized growing technologies with the possibility of introducing plant development regulators. Therefore, the ultimate aim of our study was to establish the possibility of improving the productivity of linseed seeds when applyin growth regulators with different mechanisms of action, taking into consideration the residual amounts of preparations in the seeds.

MATERIAL AND METHODS

The field research was carried out using the small-area method. Oil flax plants of the Orpheus variety were once treated with a solution of chlormequat chloride (0.25%, 0.50%) and treptolem (0.03ml/l, 0.05ml/l) in the budding phase. Control plants were treated with water. The repetition is fivefold.

Chlormequat chloride (“BASF AG”, Germany) is a preparation of the group of quaternary ammonium compounds included in the list of pesticides and agrochemicals approved for the use in Ukraine. This retardant has no carcinogenic properties, it does not stockpile in the body and is excreted within two days. In the soil, the preparation breaks down into choline chloride, choline and betaine, which are native products of metabolism and do not produce a toxic consequence on the soil (Kuryata, Khodanitska, 2018). Chlormequat chloride blocks the biosynthesis of gibberellin, entering the plant mainly through the leaves and is partially absorbed by the root system from the soil. Its action is manifested in the inhibition of the cell stretching of the subapical meristem, as a result of which growth is inhibited in length, the differentiation of the growth cone slows down.

Treptolem is a growth regulator with a stimulating direction of action, a balanced composition based on 2,6-dimethylpyridine-1-oxide, succinic acid, as well as natural phytohormones of the auxin, cytokinin, gibberellin series, amino acids, carbohydrates, and nutrients obtained from biochemical processes in the cells of endophyte fungi from the root systems of higher plants. The preparation is recommended for increasing the yield and oil content of agricultural crops (Khodanitska et al., 2019).

Oil flax of the Orpheus variety, developed by the Institute of Oil Crops of the National Academy of Sciences of Ukraine, belongs to medium-ripening varieties. The growing season lasts 86–89 days. The height of the plants is 55–58 cm. The leaves are lanceolate, without petioles. The flower is of medium size, the petals are blue. The seeds are brown, the weight of 1000 seeds is 7.5–8.0 g. The oil content in the seeds is 44–48%. The average seed yield is 18.0–20.0 c/ha. The variety is resistant to lodging, shedding, drought. It is generally advocated for steppe and forest-steppe zones.

Oil flax was grown based on standard technology, according to the technological map of crop cultivation. The predecessor of flax in the crop rotation was winter wheat. The soil cover in the area of the experiments is represented by gray and light gray forest-soled soils.

The plant height, the stem diameter in the central part was determined morphometrically. The leaf area was determined by the method of traces.

Productivity and crop structure were determined at the end of the growing season. The residual amount of chlormequat chloride in linseed samples was found out using thin-layer chromatography. The basis of the method was extraction removal of the preparation with acetone and its subsequent purification using silica gel in chromatographic columns. The chromatography process was carried out in a thin cationic layer, SilufolUV-254 plates manufactured by the Kavalier company were used. Sulfuric acid at a concentration of 23% was used as a mobile solvent. The plates were exposed by dipping in 11% phosphorous-molybdic acid followed by washing in water. Later, these plates were immersed in a solution of 1% stannous chloride in 10% hydrochloric acid. The amount of chloromequat chloride was calculated by comparing the optical densities of the chromatograms of experimental samples and standard solutions, which were determined using a SF-46 spectrophotometer. Research on the residual content of treptolem was carried out by gas-liquid chromatography using the Crystal 2000M chromatograph. Steel columns (100 mm in size) filled with SE-30 sorbent (5%) were used as well. Nitrogen and hydrogen were used as the carrier gas, the flow rate was 60 ml/min. The temperature parameters of the column were 240°C, for the flame ionization detector 300°C, while for the evaporator – 260°C.

The obtained research results were statistically calculated. Average values and their standard errors are presented in graphs and tables.

RESULTS AND DISCUSSION

Hormonal system plays the decisive role in the regulation of plant morphogenesis and the physiological effect depends not on the concentration of individual phytohormones, but on their ratio. Ontogenetic changes in the ratio of gibberellins, cytokinins and auxins remarkably affect growth processes and features of the histogenesis of vegetative and generative plant organs.

Growth regulative preparations, affecting the morphogenesis of plants, are widely used to combat the lodging of cereal crops. Consequently, retardants block the synthesis or reception of gibberellins and, correspondingly, inhibit the excessive growth of vegetative organs. Like cereals, flax plants are also susceptible to lodging depending on the agro-meteorological conditions of cultivation, which causes deterioration of the quality of straw and seeds.

Our research results testify to the fact that the use of the anti-gibberellin growth regulator chlormequat chloride led to a decrease in the linear dimensions of flax plants, which is a representative reaction of plants to the influence of retardants (Fig. 1). Hence, when using chlormequat chloride at a concentration of 0.25%, the height of the flax stem decreased by 4.5%, at a concentration of 0.50% – by 8% compared to the control sample. The treatment of plants with treptolem caused an increase in the stem height by 4.8–5.8% higher than the control ones.

We have discovered that when applying growth-regulating compounds, stem thickening of experimental plants of all variants was observed. Remarkably, under the action of the retardant, the thickness of the flax stem increased by 18–25% compared to the control sample. This can be explained by the slowing of elongation and differentiation of cells under the influence of a growth inhibitor, which increases the thickness. Since growth stimulants lead to a general increase in plant growth, stem diameter also increased under the influence of treptolem. An increase of 14–22% was found out compared to the control plants. The studies revealed that the stem thickening occurred due to the increased development of the bark and xylem (Fig. 2).

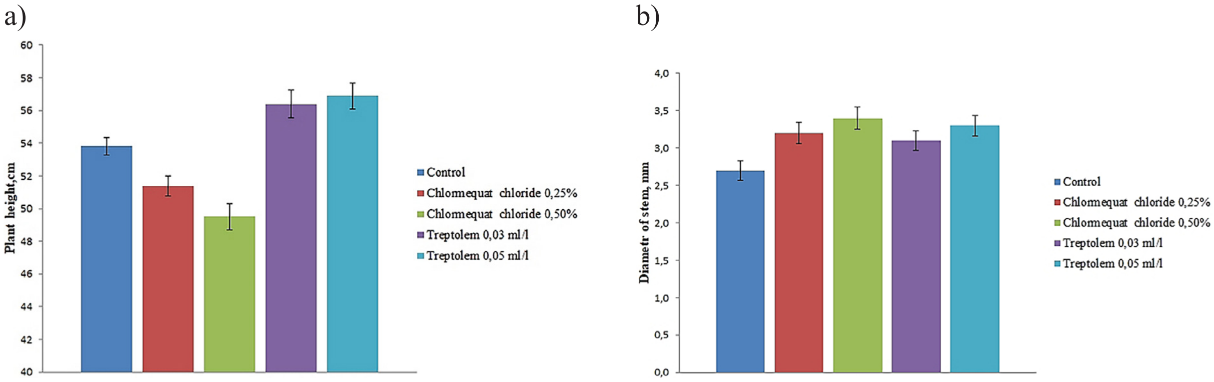

Fig. 1. The influence of growth regulators on the height and diameter of the flax stem; (a) height of the flax stem; (b) diameter of the flax stem

Contemporary phytophysiology considers the plant as a complete self-regulating system, in which photosynthetic organs, primarily leaves, act as donors of assimilates, while all other organs are acceptors. On that account, photosynthetic activity plays a crucial role in plant productivity, which is largely determined both by the area of the leaf surface and their anatomical features, and by the formation of the demand for assimilates by different acceptor zones.

Our research results clearly demonstrate that the use of growth regulators with different mechanisms of action caused changes in the formation of the leaf surface of linseed plants (Figs. 3, 4).

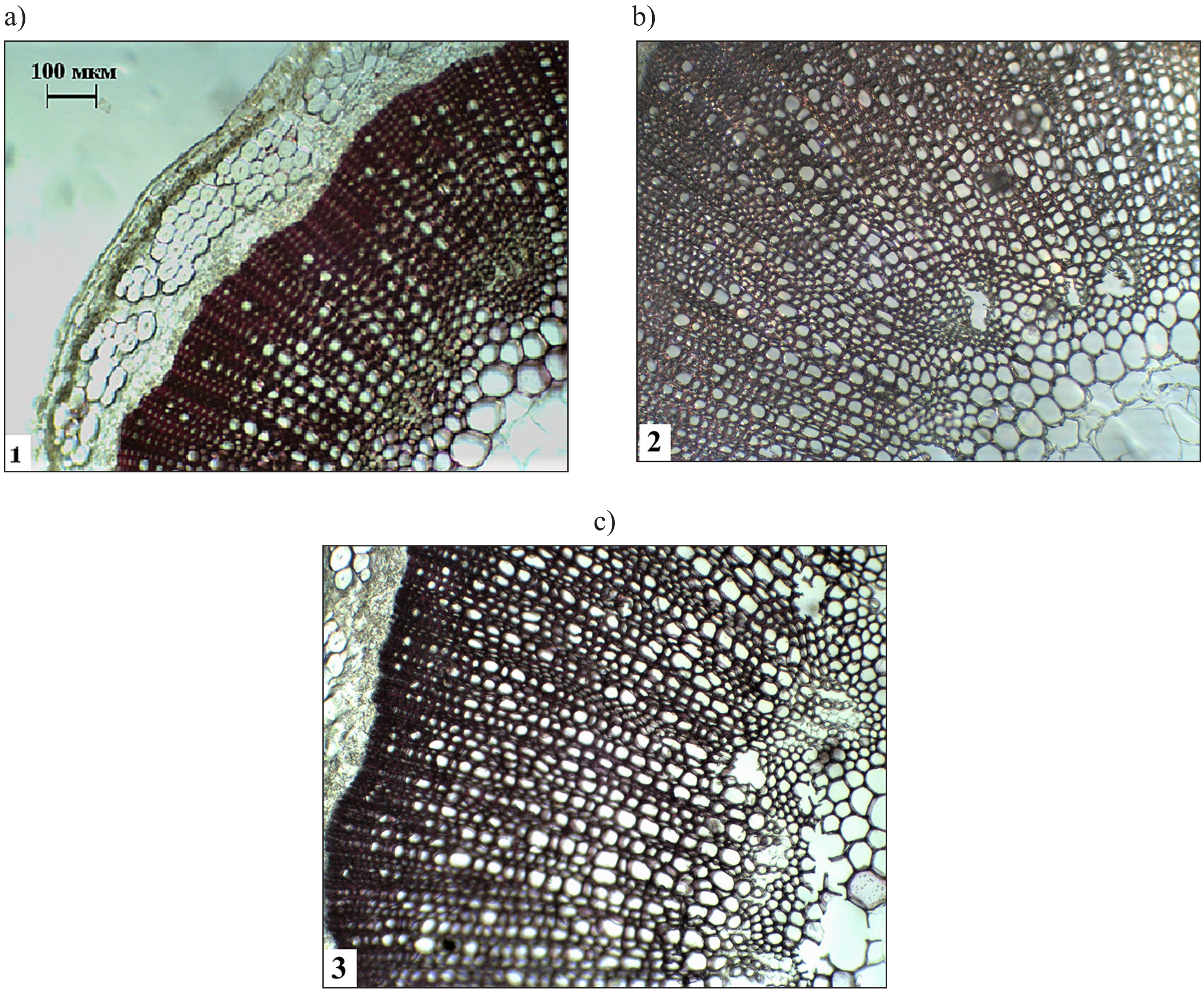

Fig. 2. Transverse section of a flax stem under the action of growth regulators: (1) control; (2) chlormequat chloride (0.50%); (3) treptolem (0.05 ml/l)

Consequently, under the action of chlormequat chloride and treptolem, the number of leaves on the plant increased already from the first records after their treatment with the preparations. It is found out that under the influence of the anti-gibberellin preparation, the total area of the leaf surface was unreliably different from the control one. This shows a decrease in the area of one leaf under the action of the preparation, which is a typical reaction of plants to gibberellin deficiency. Under the action of the treptolem growth stimulator with cytokinin and auxin activity, the plant not only formed a larger number of leaves, but also increased their total surface area, since the growth rate of the leaves is positively correlated with the content of these phytohormones.

Falling of the lower leaves during the growing season is characteristic of flax plants. Therefore, not only the size of the leaf surface, but also the rate of leaf death affects the yield of flax plants. The obtained experimental results indicate that the use of retardant and growth stimulator extended the life span of the leaves (Fig. 3).

Phytohormones and modifiers of their action influence the character of donor-acceptor relations in plants, as a result of which some changes in the structure of vegetative organs occur, restructuring of the assimilation apparatus, increase in the productivity of photosynthesis, redistribution of flows of plastic substances to generative organs, which therefore increases the yield of agricultural crops. Our research results reveal that the influence of growth regulators on the productivity of flax was manifested in changes in the crop structure (Table 1).

The use of chlormequat chloride blocks the synthesis of gibberellins and the partial removal of the effect of apical dominance, as a result of which there is an increase in the stem branching and the laying of more fruits. Thus, after treatment with this prepration, an increase in the number of pods on the plant by 11–17% was observed,

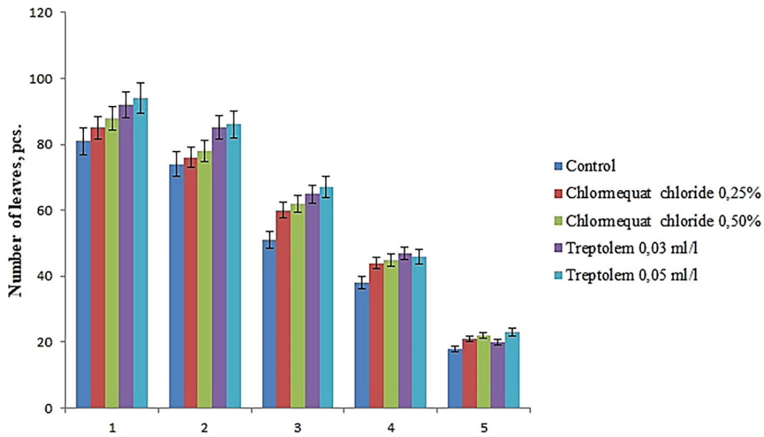

Fig. 3. The effect of growth regulators on the number of flax leaves; 1–5 – 10th, 20th, 30th, 40th, 50th day after treatment

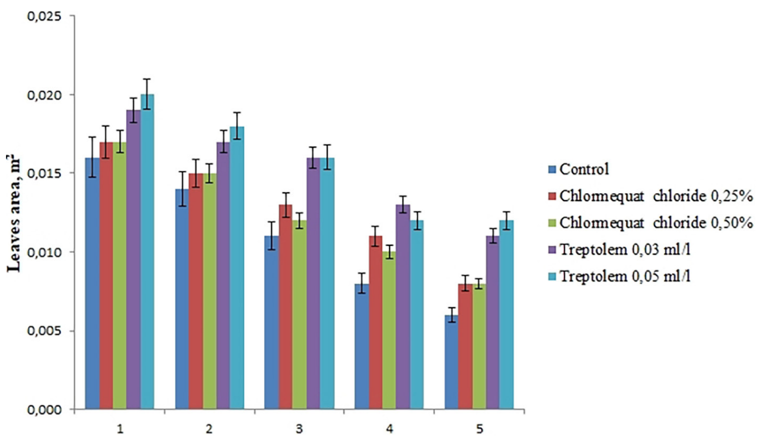

Fig. 4. The influence of growth regulators on the area of leaves of flax plants; 1–5 – 10th, 20th, 30th, 40th, 50th day after treatment

Table 1. The influence of growth regulators on the structure of the flax crop

Research variant	Number of fruits per plant, pcs.	Number of seeds per fruit, pcs.	Weight of 1000 seeds, g	Productivity, c/ha
Control	34.24±1.84	8.1±0.22	7.82±0.03	19.75±0.28
Chlormequat chloride 0.25%	38.08±1.94	8.9±0.18	8.08±0.05	21.10±0.31
Chlormequat chloride 0.50%	40.05±2.10	9.0±0.16*	8.15±0.03*	21.57±0.25*
Treptolem 0.03 ml/l	35.28±1.75	8.3±0.21	8.06±0.04	20.45±0.30
Treptolem 0.05 ml/l	36.12±1.82	8.5±0.19	8.02±0.03	20.87±0.32

Note: * – the difference is significant at $P \leq 0.05$.

depending on the concentration. The largest number of seeds in fruits was recorded in the version with chlormequat chloride 0.50%. Under the influence of treptolem, the number of fruits on the plant and seeds in the fruits changed unreliably. Consequently, against the background of active linear growth of plants, an increase in the number of boxes by only 3–5%, and the number of seeds in a box by 2–4%, compared to the control sample, was established. In general, the productivity of linseed under the action of chlormequat chloride increased on average by 6–9% compared to the control sample. We established that the highest yield of the crop was when applying the retardant at a concentration of 0.50%, where the increase was 1.82 c/ha more.

Treatment of flax crops with treptolem led to an increase in yield by 3–6% compared to the control variant. Due to the content of hormones of cytokinin and auxin nature, treptolem is included in physiological processes in the plant and affects growth enhancement. Despite the fact that the use of chlormequat chloride was the most effective for increasing the yield, the obtained results on the optimization of the production process with the help of treptolem are also valuable in a practical sense. Thus, it is feasible to obtain cottonized, cotton-like fiber from the straw of linseed fiber, for the production of mixed linseed-cotton fabrics, medical cotton wool, etc. Since the growth of flax plants increases under the influence of treptolem, the length of the stem increases, the use of the preparation leads to a double positive effect – an increase in the yield while simultaneously improving the fiber quality.

The development of regulations for the use of growth regulators is based on compliance with present-day toxicological and hygienic standards and is designed to ensure maximum crop growth with minimal negative impact on the natural environment. The use of synthetic and complex plant growth regulators should be accompanied by strict monitoring of the residual content of preparations in finished products. A toxicological risk study is a necessary condition taking into account the requirements of environmental safety when using plant growth regulators.

The content of residual amounts of drugs in products is an important indicator from the standpoint of ecological and toxicological standards of seed quality control. Our research results inform that the residual amount of chlormequat chloride in a sample of flax seeds of the Orpheus variety was 0.042 mg/kg, and in the majority of test samples traces of the drug were noted, or its absence, that is, the probable content was below the sensitivity of the chromatographic method of analysis. According to the standard of permissible doses of pesticides in agricultural products (8.8.1.2.3.4.-000–2001), the residual amount of chlormequat chloride in seeds can not exceed 0.100 mg/kg. The maximum residual content of treptolem in flax seeds was 0.007 mg/kg with the normalization for seeds no more than 0.030 mg/kg. Therefore, we can claim that we comply with the ecological norms for the use of preparations for growing flax.

CONCLUSIONS

To sum it up, the application of ecologically safe growth regulators on agricultural crops allows improving productivity without considerable chemical intervention in agrocenoses. The presented studies allow expanding the range of action of environmentally safe anti-gibberellin drugs and growth stimulants in agriculture, in particular, to improve the development of flax plants.

Treatment of linseed crops with growth-regulating preparations that change the hormonal status of plants affected the processes of linear growth of the shoot. Under the action of the chlormequat chloride retardant, the height and diameter of the flax stalk increased. Active growth of flax plants treated with a treptolem development stimulator brought about stem elongation and thickening. Under the influence of both growth regulators, the number of leaves on the flax plant and their total surface area increased. The observed changes in the morphogenesis of flax plants caused an increase in the productivity of the crop owing to the improvement of the crop structure. The residual content of preparations in the seeds did not exceed the maximum permissible concentrations established by the law.

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