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Allelopathic activity of plants *Hyssopus officinalis* L.

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Abstract. The need for phytoremediation prompts the introduction of plants into the culture, which will not only have several directions of use of the obtained raw materials, but also contribute to the improvement of the soil and be a good precursor for the further successful cultivation of the following agricultural crops. It is known that essential oil crops activate the development of beneficial microbiota and prevent soil fatigue. The article presents the results of research on the allelopathic activity of plant parts of medicinal hyssop (*Hyssopus officinalis* L.) of the Marquis variety, taking into account age characteristics under conditions of climate change in Southern Ukraine. The aim of the work was to reveal the influence of allelopathic activity of aqueous extracts of leaves, stems and flowers of hyssop, soil in the rhizosphere zone and plant age on the growth of watercress roots. In the research process, empirical methods were used, in particular, an experiment. As a result of research carried out with the medicinal hyssop culture of the first, second and third years of vegetation on the basis of the experimental field of the Mykolaiv National Agrarian University during 2019-2021, the optimal concentration of water extracts of the culture with a stimulating effect was found. The dependence of the allelopathic activity of water-soluble biologically active substances of aerial organs of medicinal hyssop plants is shown, and the concentration of the solution, which causes an inhibitory effect, is revealed. Thus, the highest allelopathic activity was noted on the variant using hyssop flowers of medicinal plants of the second year of vegetation in a concentration of 1:10. Aqueous solutions of the soil layer of the root system where medicinal hyssop plants grew in the third year of vegetation have an inhibitory effect on the linear growth of watercress roots. It was the largest in the leaf + stem variant at a concentration of the aqueous solution of 1:10. This suggests that it is necessary to use the culture of medicinal hyssop in crop rotation carefully taking into account its ontogenesis features. The obtained results will have practical application in enterprises of various forms of ownership that will have the desire to grow medicinal hyssop and use it in the structure of crop rotation

Keywords: medicinal hyssop; watercress; aqueous extracts; solution concentration; allelopathy; stimulation; inhibitory effect

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INTRODUCTION

Such consequences of climate change as an increase in average annual temperatures, frequent and intense droughts, as well as the active, often ill-advised implementation of advanced agricultural technologies lead to deterioration of soil properties and loss of soil fertility. Therefore, there is a need to find effective solutions to restore optimal conditions for growing agricultural crops. One of these solutions can be the use of phytoremediation, which significantly improves the physical properties of the soil, enhancing its biological activity and increasing its humus content, which positively affects the productivity and yield of plants (Aipova *et al.*, 2020).

Recently, research aimed at the use of essential oil medicinal plants as phytomeliorants that synthesize specific secondary metabolites, mainly of phenolic nature, is relevant. For example, L. Mikhalska (2018) experimentally established the possibility of cleaning soils contaminated with metals and improving their ecological condition with the help of such a plant as narrow-leaved lavender. According to A. Shahid (2021), root secretions of white mustard reduce the accumulation of common diseases in the soil, such as late blight, rhizoctoniosis, fusarium rot, etc.

The specificity of medicinal plants is that they contain a variety of biologically active substances that can be released into the environment, and their type, content and proportion can affect the growth and development of plants that are in the same agrophytocenosis. Such phytochemicals include phenolic compounds, alkaloids, flavonoids, tannins, resins and balms, essential oils, etc. But terpenoids deserve special attention – secondary metabolites that affect the taste of fruits, the color of leaves and the smell of flowers and are the main component of plant essential oils. Terpenoids produced by plants protect them from fungal diseases, insects and animals. One of the ways of terpenoids entering the soil is plant root secretions (Kornienko *et al.*, 2021). Essential oils have high volatility in atmospheric air (Grodzinsky, 1992). Phytomelioration significantly improves the agrochemical, agrophysical and biological parameters of the soil. According to scientists' experiments, the essential oil of plants belonging to the *Lamiaceae* family significantly reduces the number of phytonematodes. The most sensitive are the soil stages of the root nematode (Abd-Elgawad & Omer, 1995). In the conditions of the Mykolaiv region, medicinal hyssop, as an essential oil crop adapted to the extreme soil and climatic conditions of the south of Ukraine, can be grown for the reclamation of degraded soils, on technogenically polluted territories for local greening, on saline soils for the purpose of improving ecosystems (Dobrovolskyi *et al.*, 2021).

Root exudation is an important process that determines the interaction of plants with the soil environment and is the main component of carbon distribution in the soil. Root exudation is a complex phenomenon that encompasses processes that control carbon transport to roots and exudation from roots to soil. This process optimizes root growth to facilitate efficient foraging for nutrients and possibly detection of competing neighbors. Root escudates include rhizodeposits consisting of sugars, organic acids, amino acids, etc. The peculiarity of perennial plants is that over the years in the process of cultivation, they form a dead mass that forms a specific microbiota, which not only activates the processes in the soil, but also changes its properties. With the constant cultivation of such crops, there is an accumulation of phytopathogens and toxigens, which negatively affect the realization of the biological potential of the plant cultivated after the previous one (Canarini *et al.*, 2019). An experiment by Japanese scientists showed that joint plantations of tomato (*Solanum Lycopersicum*) with plants of the *Lamiaceae* family improve the growth and development of tomato plants, due to changes in secondary metabolites and amino acids of the plant. That is, *Lamiaceae* root exudates change soil properties and have a positive effect on its microbiota (Ahmad *et al.*, 2020).

It is necessary to investigate not only the use of allelopathy of essential oil crops in agriculture, but also to establish determinants that can interfere with its positive effect on the growth and development of plants. A distinctive feature of plants of the *Lamiaceae* family, which includes hyssop, is their aromaticity, which proves the presence of terpenes and their oxygen-containing derivatives. In addition, plants contain glycosides, saponins, resins and alkaloids (Islam Mominul *et al.*, 2022). Over time, the accumulation of these chemicals can have toxic potential.

Based on the above, the goal was to study the influence of age, parts of plants and their root secretions depending on the concentration of the solution on the allelopathic activity of water-soluble biologically active substances and to establish its stimulating and inhibitory effect.

The *tasks* that contributed to the realization of the set goal were:

– to investigate the allelopathic activity of the above-ground organs of the hyssop plant and its root-containing soil layer;

– to compare the allelopathic activity of the obtained water extracts in relation to the test object;

– to determine the allelopathic activity of water extracts of aerial parts of the hyssop plant depending on the age and the root layer of the soil in relation to the test object.

LITERATURE REVIEW

In connection with the active cultivation of essential oil crops, including medicinal hyssop, it is important to study their effect on other types of plants, so scientists have started researching their allelopathic properties.

According to M. Shinwari *et al.* (2013), 70 species of Japanese plants were examined for allelopathy using the aqueous extraction method. The scientists concluded that before large-scale cultivation of any medicinal plant in an established agricultural field, the plant should be evaluated allelopathically, as chemical exposure from previous plants, residues, related plants and even autotoxicity can adversely affect the cropping system. The results of experiments by Bulgarian scientists show that water infusions of hyssop contain secondary metabolites that show allelopathic effects in the early stages of growth of other plants in laboratory conditions (Dragoeva *et al.*, 2010). Other studies demonstrate that hyssop essential oil exhibited an allelopathic effect and inhibited seed germination and seedling development of wheat and barley (Zheljazkov *et al.*, 2021). But medicinal hyssop, which was cultivated in the extreme conditions of Southern Ukraine, was almost never studied.

According to A.M. Grodzinsky (1992) regarding allelopathy, the main issue of a biological phenomenon in which an organism produces one or more biochemical substances that affect the germination, growth, survival and reproduction of other organisms from the same community is the study of genes – their concentration and chemical composition. In addition, it is necessary to study all stages of the cycle – in plant secretions and precipitation, in the rhizosphere microflora and their allelopathic influence on the phytocenosis. The scientist believed that knees have a complex chemical nature, so their presence and allelopathic activity should be determined with the help of biological samples. Since each plant can be both a producer – a donor of physiologically active substances, and a recipient – their consumer, accordingly, a plant can create both a protective biological sphere, or be allelopathically active, and adapt to the presence of genes in the environment, that is, be allelopathic tolerant. These special properties make it possible to find out the possibility of using such a plant in combined crops or its ability to inhibit the growth and development of weeds. Accumulating and releasing genes into the environment, the plant creates an allelopathic sphere around itself (Grodzinsky, 1992; Aipova *et al.*, 2020; Grodzinsky, 1991).

Plant groups accumulate knees to a certain level, which determines the activity of their growth and development. There is a dependence between the production of knees and the accumulation of plant biomass: the higher the level of knees – the deterioration of the growth of the components of the grouping. A reduction in the production of knees weakens the growth and accumulation of plant biomass (Canarini *et al.*, 2019).

Thus, the allelopathic activity of a plant is determined by such main properties as the formation, ability to accumulate and release into the environment knees, and allelopathic tolerance – resistance to secretions of other plants or one's own (Storozhyk, 2019). The method of labeled atoms confirmed the presence of root secretions (Laurent Simon *et al.*, 2019; Ćeranić *et al.*, 2020; Vivanco *et al.*, 2012).

But it should be taken into account that there are methodological difficulties in determining the allelopathic properties of a plant. Also, allelopathy is noted for its instability in natural conditions (Cheng *et al.*, 2015).

Allelopathy is a natural phenomenon that has a significant impact on the functioning of biocenoses. The phenomenon of allelopathy includes various types of chemical interactions between organisms and is carried out by the formation and release of metabolites with allelopathic activity into the environment (Polyak *et al.*, 2019; Aci *et al.*, 2022; Hussain *et al.*, 2021). The term "allelopathy" is most often used to characterize the relationships between plants, but it is also widely used to describe the relationships between microorganisms and between plants and microorganisms (Kucheryavay, 2020; Zorikova *et al.*, 2017).

By chemical composition, allelopathic substances vary from simple carbohydrates to complex polycyclic aromatic phenols, terpenes, flavonoids, polyacetylenes, fatty acids. Allelopathic substances play an important role in plant defense (Reigosa *et al.*, 2010; Khalid, 2002).

Allelopathy is associated with competition for resources and largely depends on many factors such as soil structure, moisture, temperature, plant parts, plant age, availability of nutrients, concentration of allelic components and their stability (Sira, 2021; Amb *et al.* , 2016).

MATERIALS AND METHODS

Research on model experiments of the Marquis medicinal hyssop, which is promising for cultivation in the conditions of the southern steppe of Ukraine, was conducted with plants of the first, second and third years of vegetation during 2019-2021 on the basis of the laboratories of the Mykolaiv National Agrarian University. The plant material, i.e. the aerial part of the medicinal hyssop, was selected in the phase of full flowering of plants, because this phase is the most indicative of the manifestation of allelopathic activity. Allelopathic activity in water-soluble secretions of hyssop plants (*Hyssopus officinalis* L.) was determined according to the generally accepted method of A.M. Grodzinsky (1991) using biological tests. Watercress seedlings (*Lepidium sativum* L.) of the same size and from the same crop were selected as the test crop. The choice was due to the fact that watercress has a high seed germination, so it is more sensitive to external factors. The next day after planting, the germination of the seeds of the test crop was observed. The research was conducted in laboratory conditions at a temperature of +23°C and a relative humidity of 60-70%. Water extracts of various concentrations from the leaves, stems and flowers of the plant in the flowering phase were used to detect the allelopathic properties of hyssop. The main place of manifestation of allelopathic relationships is the soil (Scavo *et al.*, 2019). Therefore, the root layer of the soil of medicinal hyssop was also studied. Soil samples for research were taken in the rhizosphere zone of hyssop plants, in clear weather. To obtain aqueous extracts, fresh plant material was crushed and infused in distilled water for one day. After infusion, the aqueous extract was filtered. Aqueous soil extract with a concentration of 1:10, 1:50, and 1:100 was used for the research. In the experiment, aqueous extracts from leaves, stems and flowers of medicinal hyssop were used in concentrations of 1:10, 1:50, and 1:100.

Watercress seeds were germinated on filter paper moistened with medicinal hyssop extracts in labeled Petri dishes in a dark thermostat at a temperature of 25°C in the amount of 100 pieces for each variant of the experiment, which were carried out in 3 repetitions. Control test objects were germinated by moistening with distilled water. The distance between adjacent seeds was approximately the same.

To determine the effect of water extracts of different concentrations on the test object, the length of *Lepidium sativum* L. roots was measured with a ruler to the nearest 1 mm. The increase was calculated as a percentage of the increase in the length of the roots of the control seedlings, which were placed in distilled water, using the methods of mathematical statistics (Rozhkov *et al.*, 2016).

To improve the analysis of allelopathic data, the RI, response index, or inhibition index was determined, which characterizes the vector and relative magnitude of the effect of allelopathic substances on the growth rate of watercress seedlings, according to Williamson as follows:

– if B>K, then RI=1–(K/B)

– if B<K, then RI=(B/K)–1

At the same time, B is the morphometric index of the embryo in the experiment, K is the morphometric index of the embryo in the control.

The stimulatory effect occurs when the value of RI>0, the inhibitory effect occurs when the value of RI<0 (Williamson & Richardson, 1988).

RESULTS AND DISCUSSION

In the process of growth and development, plants accumulate genes that are released into the environment, forming an allelopathic sphere around them. The allelopathic activity of a plant occurs within its surrounding space – the phytogenic field. Allelochemical substances can be primary and secondary metabolites of plants, produced during their development and dependent on environmental conditions. There is an allelopathic interaction in plant communities (Dragoeva *et al.*, 2010; Hussain *et al.*, 2021). But allelopathic activity depends both on the soil and climatic conditions of cultivation, and on the characteristics of the plant species (Grodzinsky, 1991).

According to N. Zaimenko *et al.* (2021), under the influence of microflora and microfauna in the soil, there is a transformation of allelopathically active substances, which in turn change the composition and number of soil microbiota. Under the influence of allelopathic substances, physical and chemical processes in the soil change, which affect the growth and development of plants. Thus, each plant receives chemical signals that regulate its growth and development. M. Reigosa *et al.* (2010) believe that allelopathy in agroecosystems leads to a wide range of interactions between crops. As a rule, such an interaction leads to the problem of soil disease or can cause autotoxicity, which will adversely affect the yield of the agricultural crop. But scientists also do not rule out that allelochemical substances can be used in practice, for example, to fight against weeds and pests. The study determined the activity of knees in the allelopathic field of hyssop of the medicinal grade Marquis, which makes it possible to analyze and determine its effect on the soil during unchanged cultivation and use of this plant as a precursor.

The obtained results prove that the age of medicinal hyssop affects the allelopathic activity of the plant in relation to the germination of watercress seeds. Both the stimulatory and inhibitory effects of aqueous hyssop solutions on the germination of the seeds of the test object were revealed.

During 2019-2021, there was an accumulation of genes in the rhizosphere of hyssop of the medicinal variety Marquis, which have both a stimulating and an inhibiting effect on the germination of watercress seeds (Table 1).

Table 1. *The effect of root secretions of hyssop plants of different growing seasons in the flowering phase on the growth of watercress roots (1:100 dilution)*

Vegetation year	Filtrate dilution			
	M±m	Cv, %	Allelopathic activity, %	Allelopathic activity index (RI)
Control	3.36±0.13	39.42	-	-
First	5.37±0.15	27.33	+59.82	+0.38
Second	5.26±0.16	30.45	+56.55	+0.36
Third	2.99±0.11	37.45	-11.02	- 0.11

Source: *author's development*

According to Table 1, it can be seen that in the plants of the first year of vegetation, the allelopathic activity of the soil in the rhizosphere zone of medicinal hyssop is more active in the flowering phase, which was expressed in the stimulating development of the test object and amounted to 59.82% relative to the control, in the second year – 56.55% in accordance. The experiment proves that already in the second year of growing medicinal hyssop, it is possible to observe a decrease in the positive effect of allelopathically active soil substances on the growth of watercress roots by 3.3%. This is also confirmed by the value of the allelopathic activity index (Fig. 1).

Figure 1 shows that the index of allelopathic activity of the soil, which expresses the inhibitory effect in the rhizosphere zone of medicinal hyssop, increases depending on the age of the plants. This indicator was the highest when using medicinal hyssop plants of the third year of life. An inhibition of the growth of the roots of the test object by 11.02% was observed, which was also confirmed by the index of allelopathic activity, which was a negative number (-0.11). That is, in the third year of growing hyssop of the medicinal variety Marquis, water infusion of the soil of the rhizosphere zone of this plant containing knees, inhibits the growth and development of watercress roots.

This is also confirmed by the results obtained by S.I. Sorokinoi & N.I. Hnatyuk (2017) in studies of the dynamics of allelopathic activity of water-soluble secretions from the soil and aerial parts of medicinal hyssop plants.

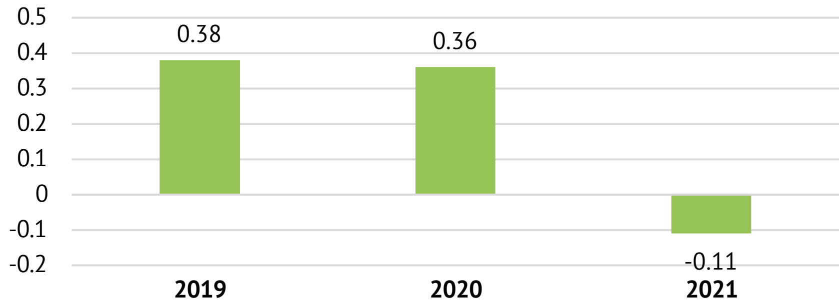

***Figure 1**. Changes in the allelopathic activity index of the root-containing soil layer over the years of research*
***Source**: author's development*

According to the results of the scientists' research, it was found that the effect of knees on the development of the test object was both inhibitory and stimulating. In addition, it was found out that the soil in the rhizosphere zone of the plant and the zone between the rows accumulates knees throughout the growing season, but the highest content of knees of inhibitory action is observed in the flowering phase.

Medicinal hyssop is absent in the natural range of Southern Ukraine, so the obtained results of the experiment can be explained by the fact that it is an introduced culture for the southern regions (Kucheryaviy, 2020; Reigosa *et al.*, 2010).

In addition, plants of the *Lamiáceae* family, which includes medicinal hyssop, differ in their ability to exhibit allelopathic activity. For example, the results of the study of water extracts of the leaves and rhizospheric sol of *Marubium vulgare* L., or *Common Shandra* showed that they significantly ($p<0.05$) inhibited the germination and growth of *Sinapis arvensis* (weed) and *Lactuca sativa* (cultivated) seedlings, and their allelopathic activity was dependent on the concentration - with an increase in the concentration of the extracts, the allelopathic effects were more pronounced. Allelopathic activity may be due to the presence of allelochemical compounds, including tannins, phenolic acids, and flavonoids, which prevented seed germination or caused seed death through chromosomal aberrations in dividing cells. In addition, terpenoids and phenolic substances are inhibitory substances in allelopathy. Phenolic compounds are rapidly adsorbed and/or oxidized by the soil and are most strongly correlated with inhibition of plant growth. In addition, it has been reported that toxicity may result from synergistic effects rather than either alone. In fact, allelochemical compounds that determine the success of seed germination can inhibit germination by altering membrane permeability, respiration, plant water balance, enzyme activity, etc. (Dallali *et al.*, 2017).

It is known that the essential oil of hyssop is mainly accumulated in the leaves and flowers and not a large amount in the stems of the plant (Wolski *et al.*, 2006). Hyssop essential oil contains secondary metabolites, the release of which can affect the growth and development of other plants (ZawiĞlak, 2013). Therefore, the study analyzed the effect of aqueous extracts of different concentrations from the above-ground organs of hyssop of the medicinal grade Marquis on the selected test object.

The results of the analysis of the root length of the test object and the allelopathic activity of the water-soluble biologically active substances of the aerial organs of *Hyssopus officinalis* L. of the Marquis variety are shown in Tables 2 and 3.

Table 2. *The root length of the test object depending on the age of the plants and the concentration of the solution, mm*

Part of plant	Vegetation year	Concentration of the solution		
		1:100	1:50	1:10
Control	H_2O	3.36±0.13	3.36±0.13	3.36±0.13
Leaf	First	3.64±0.17	3.40±0.17	3.49±0.16
	Second	4.44±0.19	4.54±0.17	4.95±0.14
	Third	2.60±0.07	2.51±0.08	1.02±0.05
Stem	First	3.84±0.18	3.79±0.15	3.90±0.18
	Second	4.34±0.15	4.83±0.16	4.46±0.15
	Third	2.73±0.09	2.59±0.09	1.46±0.07
Flower	First	4.04±0.14	4.42±0.16	4.15±0.15
	Second	4.73±0.16	4.56±0.16	5.36±0.15
	Third	2.96±0.11	2.81±0.10	1.85±0.06
Leaf +stem	First	4.07±0.15	4.37±0.13	3.45±0.13
	Second	4.73±0.18	4.83±0.19	3.80±0.12
	Third	1.39±0.05	1.12±0.05	0.68±0.03

Source: *author's development*

An aqueous solution of hyssop flowers of the first year of vegetation with a concentration of 1:50 accelerated the growth of the root system of the test object by 1.31 times compared to the control. Aqueous leaf-stem mixture reduced linear growth of watercress roots compared to aqueous flower solution. During the study and analysis of the allelopathic effect of the age of plants and their aerial organs on the growth of watercress roots, it was established that the aqueous solution of hyssop flowers of the second year of vegetation at a concentration of 1:10 had the greatest effect. Active growth of the roots of the test object took place. On average, the length of watercress roots was 5.36 mm, which is 2.0 mm more than the control variant. When the concentration of the aqueous solution of hyssop flowers was reduced to 1:50-1:100, the length of the roots of the test object decreased to 4.56-4.73 mm, respectively.

Aqueous solutions of all variants of plant concentrations in the third year of vegetation slowed down the linear growth of watercress roots and inhibited their growth. This variant showed an inhibitory effect in all years of research (Table 3).

Table 3. *Allelopathic activity of medicinal hyssop plant organs depending on age and solution concentration, %*

Part of plant	Vegetation year	Concentration of the solution		
		1:100	1:50	1:10
Control	H_2O	-	-	-
Leaf	First	8.33	1.19	3.87
	Second	32.14	35.12	47.32
	Third	-22.62	-25.3	-69.64
Stem	First	14.29	12.8	16.07
	Second	29.17	43.85	32.74
	Third	-18.75	-22.92	-56.55
Flower	First	20.25	31.55	23.51
	Second	40.77	35.71	59.52
	Third	-11.9	-16.37	-44.9
Leaf +stem	First	21.13	30.06	2.68
	Second	40.77	43.75	13.1
	Third	-58.63	-66.67	-79.76

Source: *author's development*

Aqueous solution of flowers of plants of the first year of vegetation at a concentration of 1:10-1:50 showed the highest allelopathic activity – 23.51-31.55%, respectively. When the concentration of the solution was reduced to 1:100, the stimulating effect on the linear growth of watercress roots also decreased.

Aqueous solutions from all above-ground organs of plants of the second year of vegetation had a varying but positive effect on allelopathic activity. It was found to be the lowest in an aqueous solution of a mixture of leaves and stems at a concentration of 1:10-3.1%, and the highest – 59.52% when using an aqueous solution of flowers at a concentration of 1:50.

It is characteristic to note that when using flowers in a concentration of 1:100 and 1:50, a positive effect is noted, but the allelopathic activity of plants of the third year of vegetation is significantly inferior to plants of the first and, especially, of the second year of vegetation.

This is confirmed by the experiments of A.P. Dragoeva *et al.* (2010), in which aqueous infusions of hyssop show an allelopathic effect on the early growth stages of *T. aestivum* and *C. sativus*. The effect of inhibition of root growth was stronger in *T. aestivum* than in *C. sativus*, which confirms the presence of secondary metabolites that exhibit allelopathic effects in leaves, stems, and flowers of hyssop plants. L.A. Kotyuk & D.B. Rakhmetov (2014), investigating the allelopathic effect of plant residues of 13 introduced species of the family *Lamiaceae Lindl.*, including hyssop, found that aqueous extracts from *H. officinalis* plants slowed down seed germination in *Z. mays* and caused the highest phytotoxic effect against *T. aestivum*, i.e. inhibited growth processes. The allelopathic potential of lavender plants, which also belong to the *Lamiáceae* family, as well as medicinal hyssop, were investigated. In order to determine the allelopathic potential of lavender plants, the seeds of the studied plants: corn, beans, wheat and lentils were placed in aqueous extracts of seeds and leaves in concentrations of 5%, 10%, and 15%. The percentage of germination, the length of roots and plumes, the total antioxidant activity and the amount of hormones in the seeds were monitored. Depending on the increasing concentrations of lavender extracts used in the tests, the inhibitory and phytotoxic effect on seed germination and growth of the tested plants increased (Ayşe Kuru, 2016).

Scientists of the Ferdowsi University of Mashhad Crop Research Center and Mashhad Botanical Garden (S. Sadeqifard *et al.*, 2022) collected different parts of plants – flowers, stems, leaves, roots (123 samples) belonging to 31 families of medicinal plants. The influence of the studied plants on the basal and hypocotyl growth of lettuce seeds, comparison with the control in different plant families was studied separately. In each plant family, the comparison was made at two levels of probability ($p \leq 0.05$; $p \leq 0.01$). A high percentage of inhibition (83-95%) of the growth and development of the roots of test subjects (*Lepidium sativum L*) was observed in extracts from lavender flowers of the common *Lamiáceae* family. The results of the calculation of the index of allelopathic activity of above-ground organs of Marquis hyssop plants show that (RI) had the option of using flower infusion at a concentration of 1:50 in plants of the second year of vegetation (2020) relative to the control (Fig. 2).

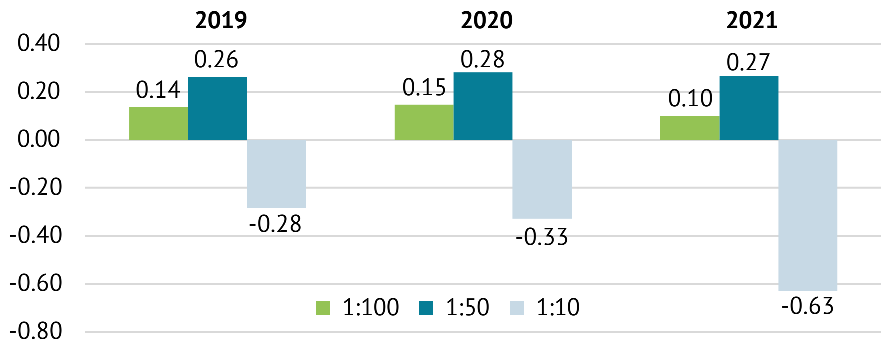

Figure 2. *Index of allelopathic activity of aerial organs of Marquis hyssop plants during the years of research (2019-2021)*

Source*: author's development*

As we can see on average over the years of research, the index of allelopathic activity of hyssop changes depending on the age of the plants and the concentration of the aqueous solution of biologically active substances of above-ground organs (Fig. 2). Thus, the highest index of allelopathic activity that caused a stimulating effect was noted at a concentration of 1:50 of the solution of flowers of plants of the second year of vegetation. The inhibitory effect was observed at a solution concentration of 1:10.

These research data are confirmed by the results of other experiments regarding the allelopathic activity of medicinal hyssop. Thus, B. Jop *et al.* (2021) proved that hyssop oil is saturated with monoterpene ketones, such as isopinocamphon – 42.1% and pinocamphon – 10.6%. Hyssop oil inhibits the germination of wheat and mustard, depending on the concentration. Visible suppression of wheat seedlings occurs already at a dose of oil of 1.0 g/l-1, and mustard – 2.8 g/l-1.

V. Pandey *et al.* (2014) obtained essential oil of hyssop from different parts of the plant: leaves, flowers and stems by hydrodistillation. It was found that the main components of the oil were cis-pinocamphon (49.7-57.7%), pinocarvone (5.5-24.9%), β-pinene (5.7-9.3%) and others. The comparative results clearly showed that the oil samples obtained from hyssop leaves and stems were quite similar in terms of cis-pinocamphon and pinocarvone content. However, the oil obtained from the flowers of the plant differed from the oil from the leaves and stems by the presence of a greater amount of pinocarvone. It is known that essential oils are mixtures of simple aliphatic and cyclic terpenoids, mainly mono- and sesquiterpenes, their alcohols and ketones with accompanying derivatives of benzoic acid and phenylpropane. Ketones, which include pinocarvone, deserve special attention. The biological effect of ketones is diverse, but despite their positive properties, it is necessary to note their possible toxic effect (Garna *et al.*, 2016). It can be assumed that the accumulation of cis-pinocamphon and pinocarvone over the years in hyssop stems, leaves and flowers gives allelopathic activity to the obtained solutions of different concentrations from parts of the hyssop plant in the third year of vegetation and from its rhizosphere zone relative to the linear growth of the roots of the test object, which requires further studies of the chemical composition of the aerial part of hyssop and its root-containing soil layer cultivated in the conditions of southern Ukraine.

CONCLUSIONS

Thus, in the years of research (2019-2021), it was found that the linear growth of the roots of the test object, which was used as a watercress, was allelopathically affected by aqueous solutions from all parts of hyssop plants of the Marquis variety. Analyzing the data of the experiment, it can be concluded that aqueous solutions of the root-containing layer of the soil and above-ground organs of hyssop plants of the first and second years of vegetation had a stimulating effect on the growth of the roots of the test object. The obtained result may indicate that there is no significant accumulation of inhibitory substances in the roots of medicinal hyssop plants during the first 2 years of growth and development. Aqueous solutions of the soil layer of the root system where medicinal hyssop plants grew in the third year of vegetation have an inhibitory effect on the linear growth of watercress roots.

It was established that the variant with the use of hyssop flowers of the second year of vegetation in a concentration of 1:10 has the highest allelopathic activity. It was the largest in the leaf + stem variant at a concentration of the aqueous solution of 1:10. Accumulation of essential oil in hyssop occurs in flowers, leaves and to a lesser extent in stems. Studies confirm that substances with an inhibitory effect gradually begin to be localized in the organs of medicinal hyssop plants, which are able to accumulate essential oil, already in the second year of the crop's vegetation. On average, the index of allelopathic activity of water-soluble biologically active substances of above-ground organs of medicinal hyssop plants of the first and second years of vegetation had a stimulating effect at a solution concentration of 1:50, and an inhibitory effect when using plants of the third year of vegetation with a solution concentration of 1:10. This result confirms that the largest amount of allelochemicals, which can negatively affect the growth and development of other plants, accumulated in the third year of medicinal hyssop cultivation. It should be noted that despite the difference in the allelopathic activity of aqueous extracts from various organs of hyssop plants, the tendency to its growth occurs with each year of its cultivation in monoculture. The experiment proves that perhaps the recommended period of growing a plant in a monoculture is no more than 5 years, because already in the 3rd year of cultivation, hyssop shows a phytotoxic effect, but further research is needed for a more accurate result.

The results of the study of the allelopathic effect of hyssop plants of the Marquis variety on the growth of watercress roots showed that the assessment of their allelopathic potential is a promising direction for more effective practical use of these plants.

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CONFLICT OF INTEREST

The authors declare that the study was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest.

REFERENCES

[1] Abd-Elgawad, M.M., & Omer, E.A. (1995). Effect of essential oils of some medicinal plants on phytonematodes. *Anz. Schadlingskde, Pflanzenschutz, Umweltschutz*, 68, 82-84. doi: 10.1007/BF01908429.

[2] Aci, M.M., S--idari, R., Araniti, F., & Lupini, A. (2022). Emerging trends in allelopathy: A genetic perspective for sustainable agriculture. *Agronomy*, 12(9). doi: 10.3390/agronomy12092043.

[3] Ahmad, H., Kobayashi, M., & Matsubara, Y.-I. (2020). Changes in secondary metabolites and free amino acid content in tomato with Liliaceae herbs companion planting. *American Journal of Plant Sciences*, 11(12), 1878-1889. doi: 10.4236/ajps.2020.1112134.

[4] Aipova, R., Abdykadyrova, A.B., & Kurmanbayev, A.A. (2020). Biological products in organic agriculture. *Plant Biotechnology and Breeding*, 2(4), 36-41. doi: 10.30901/2658-6266-2019-4-o4.

[5] Amb, M.K., & Ahluwalia, A.S. (2016). Allelopathy: Potential role to achieve new milestones in rice cultivation. *Rice Science*, 23(4), 165-183. doi: 10.1016/j.rsci.2016.06.001.

[6] Ayşe, K. (2016). *Entansif tarımda kullanılan jojoba ve lavanta bitkilerinin allelopatik potansiyellerinin araştırılması*. Denizli: Pamukkale Üniversitesi Fen Bilimleri Enstitüsü Biyoloji Anabilim Dali.

[7] Canarini, A., Kaiser, C., Merchant, A., Richter, A., & Wanek, W. (2019). Root exudation of primary metabolites: Mechanisms and their roles in plant responses to environmental stimuli. *Frontiers in Plant Science*, 10(157), 1-19. doi: 10.3389/fpls.2019.00157.

[8] Ćeranić, A., Doppler, M., Büschl, C., Parich, A., Xu, K., Koutnik, A., Bürstmayr, H., Lemmens, M., & Schuhmacher, R. (2020). Preparation of uniformly labelled 13C- and 15N-plants using customised growth chambers. *Plant Methods*, 16(1), 2-15. doi: 10.1186/s13007-020-00590-9.

[9] Cheng, F., & Cheng, Z. (2015). Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanisms of allelopathy. *Frontiers in Plant Science*, 6(102), 1-16. doi: 10.3389/fpls.2015.01020.

[10] Dallali, S, Rouz, S., Aichi, H., & Ben Hassine, H. (2017) Phenolic content and allelopathic potential of leaves and rhizosphere soilaqueous extracts of white horehound (Maribum vulgare L.). *Journal of New Sciences, Agriculture and Biotechnology*, 39(3), 2106-2120. Retrieved from https://www.jnsciences.org/agri-biotech/57-volume-39/303-phenolic-contentand-allelopathic-potential-of-leavesand-rhizosphere-soilaqueous-extracts-of-white-horehound-maribum-vulgare-l.html.

[11] Dobrovolskyi, P., Andriichenko, L., Kachanova, T., & Manushkina, T. (2021). Creating hyssop phytocenoses in anthropogenically transformed ecosystems. *E3S Web of Conferences*, 255, 01009. doi: 10.1051/e3sconf/202125501009.

[12] Dragoeva, A.P., Nanova, Z.D., & Kalcheva, V.P. (2010). Allelopathic activity of micropropagated Hyssopus officinalis L., Lamiaceae, water infusions. *Revista Brasileira de Farmacognosia*, 20(4), 513-518. doi: 10.1590/s0102-695x2010000400009.

[13] Grodzinsky, A.M. (1991). *Allelopathy of plants and soil fatigue*. Kyiv: Naukova Dumka.

[14] Grodzinsky, A.M. (1992). *Fundamentals of chemical interaction of plants*. Kyiv: Naukova Dumka.

[15] Harna, S.V., Vladimirova, I.M., & Burda, N.B. (2016). *Modern phytotherapy: Teaching manual*. Kharkiv: Printing shop Madrid.

[16] Hussain, M.I., Danish, S., Sánchez-Moreiras, A.M., Vicente, Ó., Jabran, K., Chaudhry, U.K., Branca, F., & Reigosa, M.J. (2021). Unraveling sorghum allelopathy in agriculture: Concepts and implications. *Plants (Basel),* 10(9), 1795. doi: 10.3390/plants10091795.

[17] Jop, B., Krajewska, A., Wawrzyńczak, K., Polaszek, K., & Synowiec, A. (2021). Phytotoxic effect of essential oil from hyssop (Hyssopus officinalis L.) against spring wheat and white mustard. *Biology and Life Sciences Forum*, 3(1), 13. doi: 10.3390/IECAG2021-09711.

[18] Khalid, S.T.A. (2002). Use of allelopathy in agriculture. *Asian Journal of Plant Sciences*, 1(3), 292-297. doi: 10.3923/ajps.2002.292.297.

[19] Kornienko, V.I. (2021). *Medicinal plants in clinical veterinary medicine. A study guide for students of zoo-veterinary universities and faculties*. Kharkiv: National University.

[20] Kucheryavyi, O.V. (2020). *Formation and development of allelopathy in Ukraine: Agricultural aspect (second half of the 20th – beginning of the 21st century)*. Pereyaslav: Pereyaslav-Khmelnytsky State Pedagogical School Hryhory Skovoroda University.

[21] Laurent, S., & Feth, Z.H. (2019). Determination of root exudate concentration in the rhizosphere using 13c labeling. *Bio Protoc*, 9(9), 1-7. doi: 10.21769/BioProtoc.3228.

[22] Mominul Islam, A.K.M., Thiti, S., Md Parvez, A., Shukor Juraimi, A., & Kato-Noguchi, H. (2022). Allelopathic properties of Lamiaceae species: Prospects and challenges to use in agriculture. *Plants*, 11(11), 1478. doi: 10.3390/plants11111478.

[23] Mykhalska, L., Schwartau, V., & Kremenchuk, R. (2018). Phytomeliorative properties of plants of Lavandula angustifolia L. in conditions of cultivation in the Forest-Steppe zone of Ukraine. *Bulletin of Agrarian Science*, 96(10), 55-60. doi: 10.31073/agrovisnyk201810-08.

[24] Pandey, V., Verma, R.S., Chauhan, A., & Tiwari, R. (2014). Compositional variation in the leaf, flower and stem essential oils of Hyssop (Hyssopus officinalis L.) from Western-Himalaya. *Journal of Herbal Medicine*, 4, 85-89. doi: 10.1016/j.hermed.2013.12.001.

[25] Polyak, Y.M., & Sukcharevich, V.I. (2019). Allelopathic interactions between plants and microorganisms in soil ecosystems. *Biology Bulletin Reviews*, 9(6). doi: 10.1134/s2079086419060033.

[26] Reigosa, M.J., Pedrol, N., & González, L. (2010). *Allelopathy: A physiological process with ecological implications*. Netherlands: Springer.
[27] Rozhkov, A.O. (2016). *Theoretical aspects of research*. Kharkiv: Maidan.
[28] Sadeqifard, S, Mirmostafaee, S., Joharchi, M.R., Zandavifard, J., Azizi, M., & Fujii, Y. (2022). Evaluation of allelopathic activity interactions of some medicinal plants using fractional inhibitory concentration and isobologram. *Agronomy*, 12(12), 3001. doi: 10.3390/agronomy12123001.
[29] Scavo, A., Abbate, C., & Mauromicale, G. (2019). Plant allelochemicals: Agronomic, nutritional and ecological relevance in the soil system. *Plant and Soil*, 442(1-2), 23-48. doi: 10.1007/s11104-019-04190-y.
[30] Shahid, A. (2021). *Varietal features of white mustard performance formation depending on sowing and mineral nutrition rates under the conditions of the northeastern Forest-Steppe of Ukraine*. (Doctoral thesis, Sumy National Agrarian University, Sumy, Ukraine).
[31] Shinwari, M., Shinwari, M., & Fujii, Y. (2013). Allelopathic activity of medicinal plants and weeds from Pakistan. *Allelopathy Journal*, 32(2), 223-232. Retrieved from https://www.researchgate.net/publication/257358252.
[32] Sira, L.M. (2022). Allelopathy of plants. *Pharmaceutical encyclopedia*. Retrieved from https://www.pharmencyclopedia.com.ua/article/2698/alelopatiya-roslin.
[33] Sorokina, S.I., & Hnatiuk, N.O. (2017). Biological activity of secretion of plant matter and soil from hyssop species (Hyssopus officinalis). *Scientific Bulletin of UNFU*, 27(3), 121-123. doi: 10.15421/40270327.
[34] Storozhyk, L. (2019). Allelopathic potential of sugar sorghum seeds. *Journal of Microbiology, Biotechnology and Food Sciences*, 9(1), 93-98. doi: 10.15414/jmbfs.2019.9.1.93-98.
[35] Vivanco, J.M., & Baluska, F. (2012). *Secretions and exudates in biological systems*. London: Springer Heidelberg Dordrecht.
[36] Williamson, B.G., & Richardson, D. (1988). Bioassays for allelopathy: Measuring treatment responses with independent controls. *Journal of Chemical Ecology*, 14(1), 181-187. doi: 10.1007/bf01022540.
[37] Wolski, T., Baj, T, & Kwiatkowski, S. (2006). Hyzop lekarski (Hyssopus officinalis L.) zapomniana roślina lecznicza, przyprawowa oraz miododajna. *Annales Universitatis Mariae Curie-Skłodowska Sectio DD Medicina Veterinaria,* 61, 1–10. Retrieved from https://czasopisma.up.lublin.pl/index.php/mv/article/view/3557.
[38] Zaimenko, N.V., Pavlyuchenko, N.A., Didyk, N.P., Ellanska, N.E., & Ivanytska, B.O. (2021). Allelopathic interactions and the biogeochemical cycle of carbon in nature. In *Global consequences of the introduction of plants under conditions of climate change: Materials of the scientific conference with international participation dedicate on the 30th anniversary of the Independence of Ukraine, the National Botanical Garden named after M.M. Hryshka of the National Academy of Sciences of Ukraine* (31-33). Kyiv: National University.
[39] Zawiślak, G. (2013). The chemical composition of essential hyssop oil depending on plant growth stage. *Acta Scientiarum Polonorum. Hortorum Cultus = Ogrodnictwo*, 12(3), 161-170. Retrieved from https://www.researchgate.net/publication/267032698.
[40] Zheljazkov, V.D., Jeliazkova, E.A., & Astatkie, T. (2021). Allelopathic effects of essential oils on seed germination of barley and wheat. *Plants*, 10(12), 2728. doi: 10.3390/plants10122728.
[41] Zorikova, O., Manyakhin, A., Koldaev, V., Moiseenko, L., & Litvinova, E. (2017). Allelopathic activity of patrinia scabiosifolia and patrinia rupestris. *Biomed Pharmacol*, 10(2), 651-658. doi: 10.13005/bpj/1152.

Алелопатична активність рослин *Hyssopus officinalis* L.

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Анотація. Необхідність у фітомеліорації спонукає на введення у культуру рослин, які не тільки будуть мати декілька напрямків використання отриманої сировини, але й сприяти оздоровленню ґрунтів та бути добрим попередником для подальшого успішного вирощування наступних за ними сільськогосподарських культур. Відомо, що ефіроолійні культури активізують розвиток корисної мікробіоти та запобігають ґрунтовтомі. В статті наведено результати досліджень впливу на алелопатичну активність частин рослин гісопу лікарського (*Hyssopus officinalis* L.) сорту Маркіз з врахуванням вікових особливостей в умовах змін клімату півдня України. Метою роботи було виявити вплив алелопатичної активності водних екстрактів листків, стебел та квіток гісопу, ґрунту у зоні ризосфери та віку рослин на ріст коренів крес-салату. У процесі дослідження використовувалися емпіричні методи, зокрема, експеримент. В результаті проведених досліджень з культурою гісопу лікарського першого, другого та третього років вегетації на базі дослідного поля Миколаївського національного аграрного університету впродовж 2019-2021 років виявлено оптимальну концентрацію водних екстрактів культури зі стимулюючим ефектом. Показана залежність алелопатичної активності водорозчинних біологічно активних речовин надземних органів рослин гісопу лікарського і виявлено концентрацію розчину, яка визиває інгібуючий ефект. Так, найбільш висока алелопатична активність відмічалась на варіанті з використанням квіток гісопу лікарського рослин другого року вегетації в концентрації 1:10. Водні розчини шару ґрунту кореневої системи, де зростали рослини гісопу лікарського третього року вегетації, мають інгібуючий ефект на лінійний приріст коренів крес-салату. Найбільшою вона була у варіанті листок + стебло при концентрації водного розчину 1:10. Це говорить про те, що необхідно використовувати культуру гісопу лікарського в сівозміні обережно враховуючи її особливості онтогенезу. Отримані результати матимуть практичне застосування у підприємствах різних форм власності, які будуть мати бажання вирощувати культуру гісопу лікарського та використовувати його в структурі сівозміни

Ключові слова: гісоп лікарський; крес-салат; водні екстракти; концентрація розчину; алелопатія; стимулювання; інгібуючий ефект