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Morphological and productive response of melon to fertilizer treatments on land of low fertility

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Abstract

Limited soil fertility and unfavorable climatic conditions significantly affect vegetable production, which requires the application of innovative fertilization strategies. In this research, the influence of organic fertilizer based on plant extracts containing phenolic compounds and phytohormones on the productive and morphological characteristics of melon (*Cucumis melo*) grown on acidic and poorly supplied soil (pH 3.74, humus 2.4%) was investigated. The experiment was set up in 2024 on the experimental field of the Institute of Vegetables in Smederevska Palanka according to a random block system in three repetitions. The treatments included one (Tr1), two (Tr2) and three (Tr3) fertilizer applications, as well as a control without fertilization. The results showed no statistically significant differences in fruit weight between treatments (1.03–1.23 kg). However, the number of fruits per plant was significantly higher in Tr3 (24), while Tr1 had the highest number of lateral branches (23.80). The largest peel thickness was determined in Tr2 (0.51 cm), which may contribute to better post-harvest durability of the fruits. The highest chlorophyll content was measured in the control variety (65.43 SPAD units), while there were no significant differences in sugar content between treatments (11.31–11.97 ºBrix). Correlation analysis showed a positive highly significant relationship between fruit mass and sugar content ($r = 0.41^{**}$), while the number of fruits and the number of side branches were negatively related ($r = -0.31^{**}$). The results indicate that organic fertilizer based on plant extracts can improve certain productive properties of melon in nutrient-poor soil conditions. Further research is needed to optimize the application strategy in different agroecological conditions.

Keywords: *Cucumis melo, plant fertilizer, fruit yield, morphological characteristics, soil fertility, sustainable agriculture*

Introduction

One of the world's biggest risks in recent decades is the production of food while preserving soil fertility and the resources necessary for survival. Due to the lack of sufficient amounts of organic fertilizer, it is essential to find an alternative that will meet the principles of sustainable plant production (Cvijanović et al., 2024). With the increase in the number of people on the planet, the need to produce more food has also increased (Raza et al., 2019). New technologies began to be sought in order to increase productivity and improve product quality. Also, by reducing the impact on the environment by adopting many mechanisms that help people reduce the use of conventional fertilizers, the use of which endangers the environment (El-

Akabawy, 2000, Stojiljković et al., 2021). In the conditions of global climate change, there could be problems in plant production, so finding effective ways to manage plant stress and improve crop yields is of great importance when it comes to economically profitable and health-safe plant production (Kumar et al., 2019). Application of large quantities of mineral fertilizers and pesticides, which are considered environmental pollutants, as well as poor management of plant residues, and insufficient application of organic fertilizers, affects soil degradation and negatively affects soil fertility (Rajičić et al., 2020; Stojiljković et al., 2021). Applying biological fertilizers reduces the use of chemical fertilizers, and encourages the restoration of microbial diversity in the soil (Sofyan et al., 2019). The use of biological fertilizers represents an alternative to the traditional approach in plant production, bearing in mind that production technology that focuses on the use of natural components tends to be economically profitable and environmentally acceptable (Šević et al., 2024; Bajagić et al., 2024). Melon is a vegetable crop that leaves high residual nitrogen in the soil after harvest (Oyediran et al., 2016). Melon is one of the most famous vegetable crops and is an excellent source of phytonutrients (Yavuz et al., 2021). It is produced all over the world, and it is estimated that about 27.5 million tons are produced annually (Li et al., 2022). Fruits differ in size, shape, skin characteristics and flesh colour depending on the genotype, applied agricultural techniques and growing conditions (Oyediran et al., 2016). In order to obtain a high yield and good quality, it is necessary that the leaf biomass produces a large amount of assimilates, which will go mainly to the fruits during their growth and development (Bartolo and Schweissing, 1998; Stojiljković et al., 2024). With the progress of agricultural production and the selection of genotypes with high yield potential, the role of fertilization also increases (Wen et al., 2022).

The work aimed to determine the influence of the application of liquid organic fertilizer of vegetable origin on certain productive and morphological characteristics of melon.

Materials and Methods

The research was carried out in 2024 on the plot of the Institute of Vegetables in Smederevska Palanka. Planting of "Ananas" melon seedlings was carried out on June 3, 2024, on plot number 6512/2, (N: 4911621 E: 496533) at 125 meters above sea level. The trial was based on a randomized block system with three replications. In each repetition, 40 plants were planted (4 rows of 10 plants each). The influence of fertilizers with plant extracts containing phenolic compounds and compounds with phytohormonal effects (commercial name of fertilizer Traiko) was investigated. The role of this fertilizer is to feed plants in cases where plants have difficulties absorbing nutrients from the soil or when it is necessary to quickly increase the content of nutrients in plants (in case of stressful conditions). This organic fertilizer is in liquid form and is applied foliarly and by watering, in the amount of 375 ml per 10 l of water. The treatments included three applications 15 days after planting every 7 days (Tr1 - one fertilizer application, Tr2 - 2 fertilizer applications, Tr3 - three fertilizer applications and control, without fertilizer application). Standard agrotechnical measures were applied in melon production (fertilization, irrigation, protection of plants from weeds, diseases and pests). The influence of fertilizers on the productive and morphological characteristics of plants was monitored: fruit weight, number of fruits per plant, number of side branches per square meter, bark thickness, chlorophyll content in the leaf and sugar content in the fruit. The number of lateral branches per square meter and the number of fruits per plant by counting in the field, on 5 plants per repetition, and the content of chlorophyll in the leaf was measured on the 5th, 10th and 15th days after the applied treatment by Portable Chlorophyll MeterCM-B (BioBase Industri, Shandong, Co., Ltd). The measurements are expressed in SPAD units. The weight of five average fruits from five plants per treatment was measured in the laboratory of the Smederevska Palanka Vegetable Institute on a technical scale (Kern & Sohn GmbH, Germany), and the sugar content was measured with a digital refractometer (Hanna instruments).

The statistical analysis of the obtained data was done in the program IBM SPSS Statistics, version 26.0. One-factorial analysis of variance (ANOVA) was used to assess the influence of factors on the examined traits, with significance levels of $p<0.05$ and $p<0.01$. Visual comparison of the mean values of different groups and assessment of the statistical significance of the difference between groups (Tuckey test) was done in the program Minitab (Trial version) and presented with Interval Plot graphics. The same program was used for Pearson's correlation analysis, to determine the relationship between the melon traits studied. The results are presented tabularly and graphically.

Soil characteristics

In order to determine the availability of nutrients to the soil, an agrochemical analysis of the soil was performed in an accredited laboratory using accredited methods. Soil acidity was determined potentiometrically. The humus content was measured using the Kotzman method. The nitrogen content was determined by calculation through the humus content, and it is shown in percentage, and easily accessible phosphorus and potassium by the AL method by the Egner-Riehm method (Table 1).

Table 1. Basic agrochemical properties of the soil in the experimental field

Depth (cm)	pH KCl	Hummus (%)	N (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	$CaCO_3$
0-30	3.74	2.40	0.12	7.07	14.51	-

The soil on which the research was conducted belongs to the group of very acidic soils (Belić et al., 2014), moderately provided with humus (Scheffer-Schachtschabel classification) and moderately provided with nitrogen, with low phosphorus content and moderately provided with potassium. Soils with an acidic reaction are characterized by low microbiological activity and the rhizosphere is limited to a shallow surface zone, so as acidity increases, the biomass of microorganisms decreases (Popović et al., 2019; Terzić et al., 2019).

Meteorological conditions

During the research period and the thirty-year average, differences in total amounts and distribution of precipitation, as well as average monthly air temperatures by month, were noted.

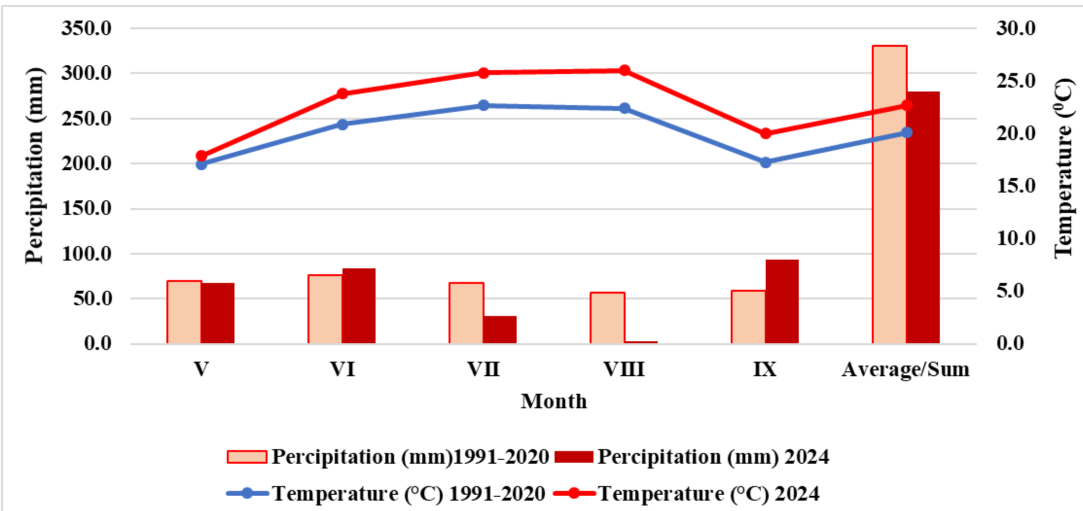


Figure 1. Mean monthly air temperatures and amount and distribution of precipitation during the melon vegetation period (2024) and multi-year period (1991-2020) in the studied area

Drought has become the main limiting factor for plant production in the world, which reduces yields in the developed world's agriculture as well (Đekić et al., 2019; Wang et al. 2024).

Results and discussion

In modern agricultural production, there is a growing need to determine a fertilization system that will be adapted to the cultivated plant species and climatic conditions in production areas with acidic soils (Popović et al., 2019; Rajičić et al., 2020; Stojiljković et al., 2021) Application of foliar fertilizers is gaining importance with the desire to increase yield and quality. Foliar fertilizers are rich in different nutrients and physiologically active substances. They contain easily accessible elements, and the effectiveness of foliar fertilizers depends on the amount of nutrients in the soil and the needs of plants for certain elements, as well as on the condition of the crop and the time of application (Miladinov et al., 2018). The obtained results of the average values of the properties examined in melon are shown in Table 2. The influence of the fertilizer factor, which was applied in three different treatments, on fruit weight did not show a statistically significant influence in relation to the control variant.

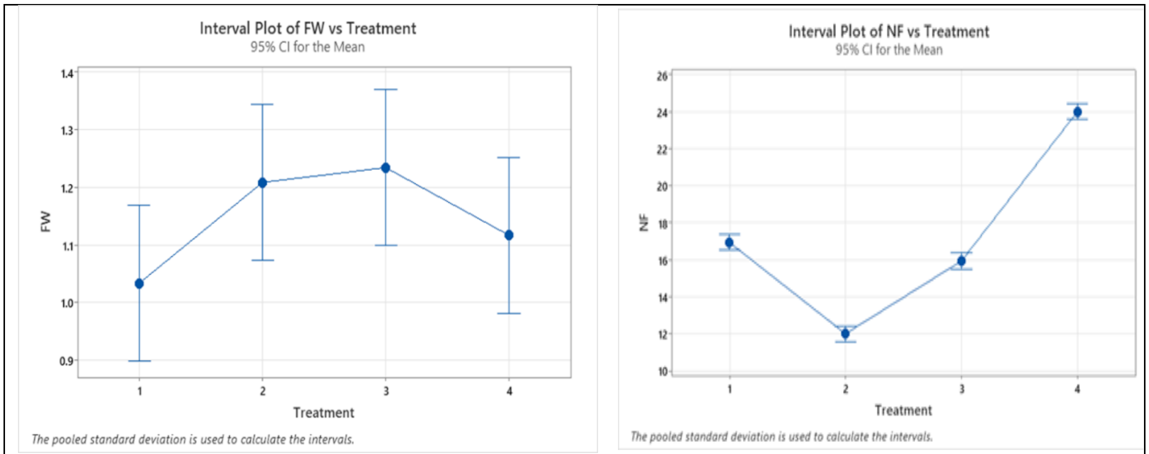
Table 2. Average values of studied traits in melon with the application of fertilizers

Treatment	Fruit weight (kg)	Number of fruits	Number of side branches (m^2)	Thickness crust (cm)	Chlorophyll (SPAD units)	Total sugars (ºBrix)
Tr1	1.21 ^{A}	12.00 ^{D}	23.80 ^{A}	0.41 ^{B}	57.31 ^{AB}	11.33 ^{A}
Tr2	1.23 ^{A}	15.93 ^{C}	18.80 ^{B}	0.51 ^{A}	56.71 ^{AB}	11.31 ^{A}
Tr3	1.12 ^{A}	24.00 ^{A}	19.80 ^{B}	0.45 ^{AB}	54.59 ^{B}	11.97 ^{A}
Control	1.03 ^{A}	16.93 ^{B}	14.80 ^{C}	0.49 ^{AB}	65.43 ^{A}	11.69 ^{A}
Average	**1.15**	**17.25**	**19.30**	**0.47**	**58.51**	**11.58**

Note: Different letters (A, B, C, D) indicate significant differences $p< 0.05$ (Tuckey test)

Comparing the treatments, no differences were found for fruit weight (Figure 2a). All three treatments in which fertilizer was applied had an approximate fruit weight. Based on the results from Table 2, it can be seen that the highest average fruit weight was measured in the Tr2 treatment (1.23 kg), while the lowest was found in the control (1.03 kg). In research (Miladinović et al., 2024; Ugrinović et al., 2024), the foliar application of different fertilizers did not show statistically significant effects on the examined traits due to the consequences of unfavorable climatic conditions (extremely high daily air temperatures). Analyzing the obtained values for the number of fruits (Table 2, Figure 2b), the best result was achieved in treatment Tr3 (24.00), where the effect of fertilizer was statistically very significant), in contrast to Tr1, where significantly fewer fruits were recorded (12.00).

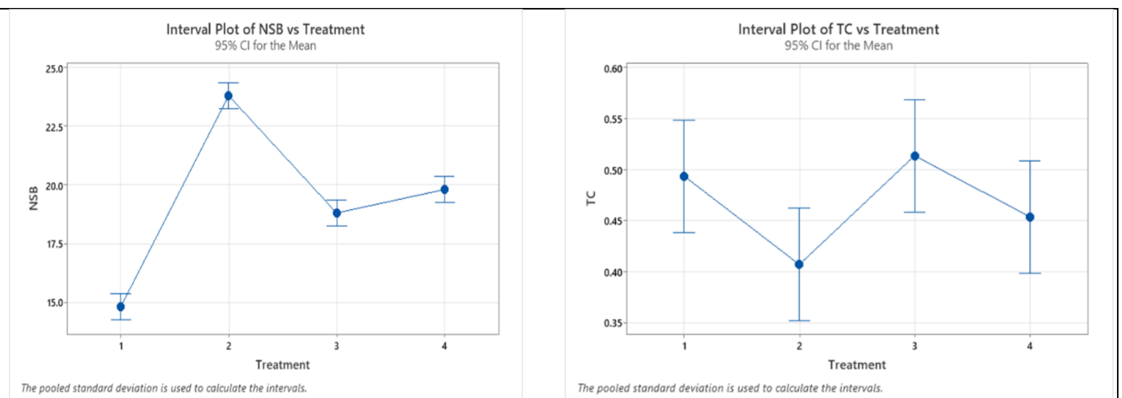
Statistically significant differences were found (table 3) in the average number of lateral branches in melon plants, where the values ranged from 14.80 to 23.80 (Table 2, Figure 3a). The highest average number of lateral branches was achieved in treatment Tr1. The highest average number of lateral branches was achieved in treatment Tr1. An important feature of the fruit, the thickness of the skin, was monitored, where a statistically significant influence of fertilizer on the obtained values was determined.



(a) **(b)**

Figure 2. Confidence interval of mean values for different groups and statistical significance of differences between groups in melon traits FW - fruit weight (**a**) and NF - number of fruits (**b**)
*Note: Treatment: 1-Tr1, 2- Tr2, 3-Tr3 and 4-Control.

In treatment Tr2, the highest average value of bark thickness of 0.51 cm was recorded (Table 2, Figure 3b). The use of foliar fertilizer affected the shape, skin color and quality of melon (Khomphet et al., 2023). Melons treated with foliar treatments showed better fruit quality values than untreated ones.



(a) **(b)**

Figure 3. Confidence interval of mean values for different groups and statistical significance of differences between groups in melon traits NSB–number of side branches (**a**) and TC – thicknesscrust (**b**).
*Note: Treatment: 1-Tr1, 2- Tr2, 3-Tr3, and 4-Control.

That fertilization is crucial for the quality of melon fruit has been stated in many studies. A lack or unbalanced diet of nutrients negatively affects the quality of melon fruits (Lopez-Zaplana et al., 2020; Roshaizak and Samad, 2024). Some of the melon fruit quality parameters, such as fruit firmness, pulp thickness, peel thickness, are affected by nitrogen associated with phosphorus (Bouzo and Munoz, 2018).

A good indicator of stressful conditions in vegetation in plants is the increased value of chlorophyll in the leaves. The influence of fertilizers is manifested in the reduced average values of this characteristic (Figure 4a). The highest chlorophyll content was measured in the control (65.43 SPAD units), shown in Table 2.

Sugars are the main source of sweetness in melon and its higher content contributes to better nutritional value, especially the energy value of the fruit. The sugar content has a highly significant effect on certain technological properties, such as the texture of the aroma and the conditions of canning of the fruits. Regarding the content of total sugar, the influence of applied fertilizer in this research was not statistically significant (Figure 4b). The measured values according to the treatments were approximate, and the highest content was in the fruits in the Tr3 treatment (11.97 ºBrix), Table 2. Foliar feeding had a positive effect on certain characteristics of the plant (plant length, leaf area, shoot weight per plant) and fruit quality, i.e. fruit diameter, fruit weight, total sugar (Morsy and Shams, 2018), while in our research there was no statistical significance for sugar content (Table 3), but the highest found in the Tr3 treatment (Table 2).

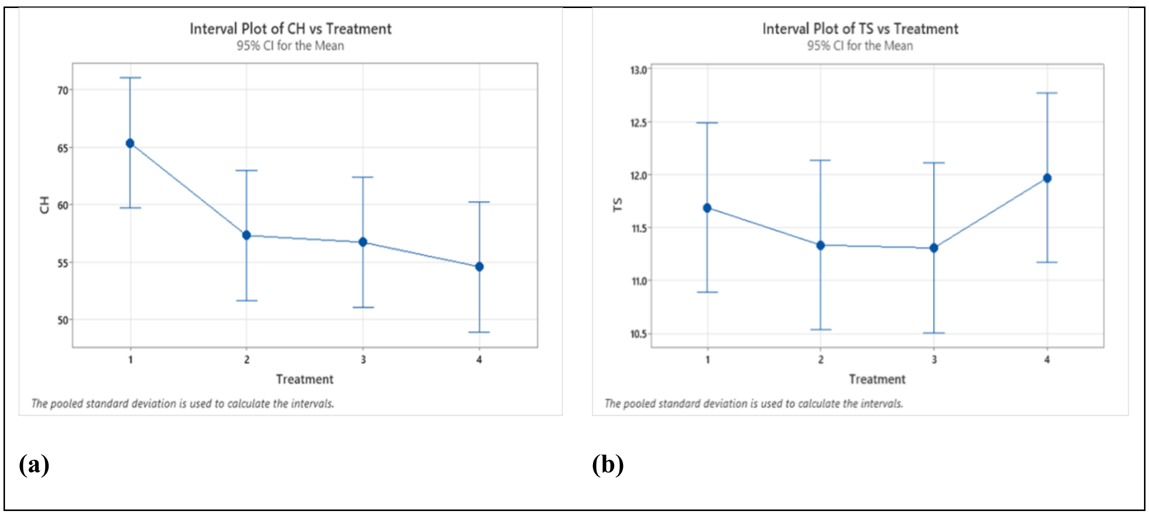


Figure 4. Confidence interval of mean values for different groups and statistical significance of differences between groups in melon traits CH– chlorophyll (**a**) and TS – total sugars (**b**).
*Note: Treatment: 1-Tr1, 2- Tr2, 3-Tr3, and 4-Control.

Based on the obtained results, it can be said that the positive impact of applying organic fertilizer with plant extracts containing phenolic compounds and compounds with phytohormone effect was established even on soils of lower fertility for vegetable production. This is especially important for areas whose values of agrochemical parameters are below optimal for vegetable production, as well as in unfavorable climatic conditions.

The correlation coefficient represents the degree of connection between traits. The correlation coefficient between the studied melon traits showed different strengths of the relationship (Figure 5). A positive and very weak correlation was established between the traits FW and TC (r=0.02) and weak relationship between FW and CH (r= 0.00). A positive, medium strong and highly significant relationship was confirmed between FW and TS (r=0.41**), while it is negative and weak with FW and NF (r=-0.13). A positive and very weak correlation was recorded between the characteristics of NF and TC (r=0.06), while there was a negative and very weak correlation between NF and CH (r= - 0.08). That trend continues with the NF and NSB traits, where the correlation coefficient is negative and shows a very weak relationship between these traits (r= - 0.31**).

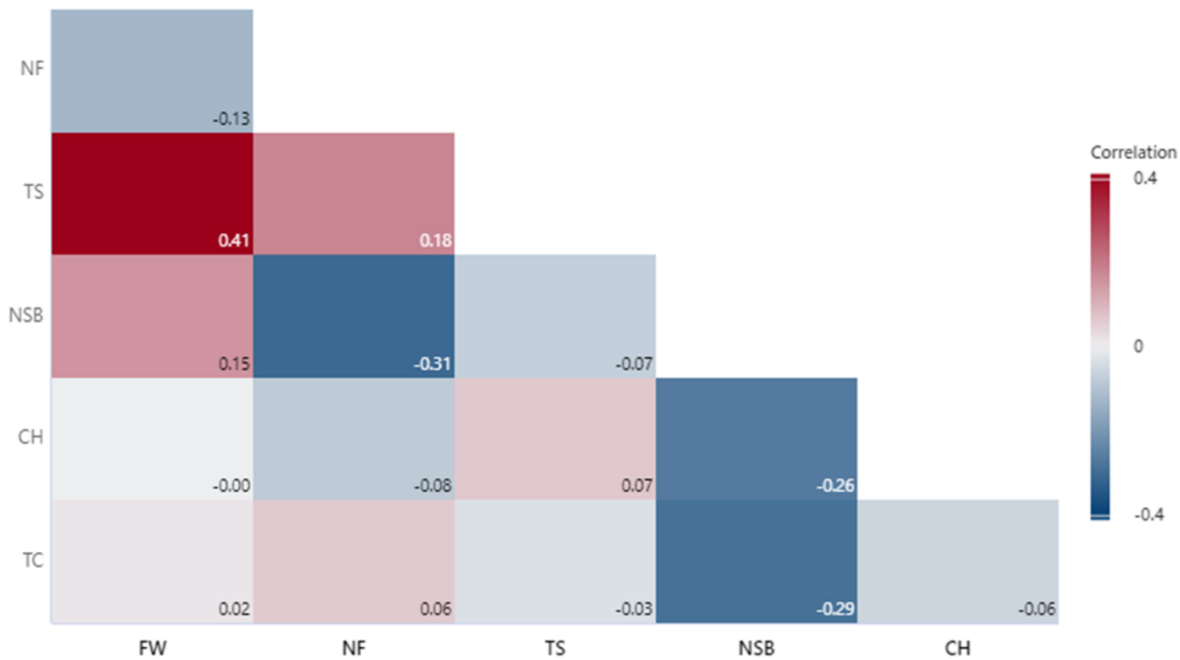


Figure 5. Correlation coefficients between the studied traits in melon (FW-fruit weight, NF-number of fruits, NSB-number of side branches, TC-thickness crust, CH-chlorophyll and TS- total sugars). Correlation is significant at the 0.01 level**; 0.05 level *.

Conclusion

The results show that the application of organic fertilizer with plant extracts had a positive effect on certain morphological and productive characteristics of melon grown on land with weaker production characteristics. Although no statistically significant differences in fruit mass were found between treatments, the number of fruits per plant was significantly higher in the treatment with three applications of fertilizer (Tr3), while the number of lateral branches was the highest in the treatment with one application (Tr1). Peel thickness was highest in the Tr2 treatment, this trait is important for better fruit persistence after harvest.

Chlorophyll content in the leaf was the highest in the control variant, which may indicate the adaptive responses of plants to stressful conditions without additional nutrition. The content of total sugars did not show statistically significant differences between treatments, although the highest values were recorded in treatment Tr3. Correlation analysis indicated different degrees of connection between the tested traits, where significant positive correlations were found between fruit weight and sugar content, while negative correlations were observed between the number of fruits and the number of lateral branches.

These results indicate that the application of fertilizers with plant extracts can have certain effects in improving the production characteristics of melon. Special importance is reflected in the possibility of growing melons on land with weaker production characteristics and unfavorable climatic conditions. Further research is necessary in order to more precisely define the optimal strategy for applying this fertilizer in different agroecological conditions.

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Morfološki i produktivni odgovor dinje na tretmane đubrivom na zemljištu niske plodnosti

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IZVOD

Ograničena plodnost zemljišta i nepovoljne klimatske prilike značajno utiču na proizvodnju povrća, što zahteva primenu inovativnih strategija đubrenja. U ovom istraživanju ispitivan je uticaj organskog đubriva na bazi biljnih ekstrakata, koje sadrži fenolna jedinjenja i fitohormone, na produktivne i morfološke osobine dinje (*Cucumis melo* L.) gajene na kiselom i hranivima siromašnom zemljištu (pH 3.74, humus 2.4%). Ogled je izveden 2024. godine na oglednom polju Instituta za povrtarstvo u Smederevskoj Palanci po slučajnom blok sistemu u tri ponavljanja. Tretmani su obuhvatali jednu (Tr1), dve (Tr2) i tri (Tr3) primene đubriva, kao i kontrolu bez đubrenja. Rezultati nisu pokazali statistički značajne razlike u masi ploda između tretmana (1.03–1.23 kg). Međutim, broj plodova po biljci bio je značajno veći u Tr3 (24), dok je Tr1 imao najveći broj bočnih grana (23.80). Najveća debljina kore utvrđena je u Tr2 (0.51 cm), što može doprineti boljoj postberbnoj izdržljivosti plodova. Najviši sadržaj hlorofila izmeren je u kontrolnoj varijanti (65.43 SPAD jedinica), dok između tretmana nije bilo značajnih razlika u sadržaju šećera (11.31–11.97 ºBrix). Korelaciona analiza je pokazala pozitivnu visoko značajnu vezu između mase ploda i sadržaja šećera ($r = 0.41^{**}$), dok su broj plodova i broj bočnih grana bili negativno povezani ($r = -0.31^{**}$). Rezultati ukazuju da organsko đubrivo na bazi biljnih ekstrakata može poboljšati određene produktivne osobine dinje u uslovima zemljišta siromašnog hranljivim materijama. Dalja istraživanja su potrebna radi optimizacije strategije primene u različitim agroekološkim uslovima.

Ključne reči: *Cucumis melo*, biljno đubrivo, prinos ploda, morfološke osobine, plodnost zemljišta, održiva poljoprivreda

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Cover crops in a sustainable cultivation system and their influence on the content of organic matter in the soil

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Abstract

Cover crops are very important, especially from the aspect of sustainability of agricultural production. This biological measure maintains or increases the level of organic matter in the soil, improves the physical properties of the soil, accumulates nitrogen in legumes, improves microbiological activity in the soil, suppresses weeds and increases soil fertility. In the research, 4 plant species were included as cover crops: common vetch, winter forage peas, winter oats and winter forage kale. The experiment was carried out on the experimental field of the Maize Institute "Zemun Polje" during two growing seasons on low-carbon chernozem. Autumn soil preparation (deep plowing and fine pre-sowing preparation) was carried out immediately before the sowing of cover crops in early November. Original seeds from the Institute for forage crops of the Institute for Agriculture and Vegetables from Novi Sad were used for sowing. In the spring before mowing, the biomass of cover crops was measured, then mowing and plowing, after which half of the plot was treated with microbiological fertilizer, which helped in the mineralization of plant residues, which would further influence the increase of soil fertility. The aim of the work is to examine different types of cover crops, which by plowing the biomass produced contribute to the increase of organic matter in the soil, prevent leaching of nutrients and have an impact on the general fertility of the soil. The highest above-ground biomass was measured in fodder kale (54040 t ha^{-1}) in the second year of the study, which had more favorable meteorological conditions. After winter oats, the content of organic matter increased the most and averaged 4.467% and 4.090%, which was statistically significantly higher compared to other cover crops.

Key words: *cover crops, sustainable cultivation system, organic matter, soil fertility.*

Introduction

The key reason for growing cover crops in a sustainable and organic agricultural production system is to increase soil fertility, reduce the occurrence of weeds, pests and diseases, as well as increase biological diversity (biodiversity) in the agroecosystem (Poeplau and Don,2015; Sturm et al., 2018; Dolijanović et al., 2020). Soil is a natural resource that represents the basic base for the production of organic matter by growing different plant species. One of the most significant forms of soil degradation is the loss of organic matter, and in recent years this process has been very intense (Jakšić et al., 2023; Rajičić et al., 2024). Application of large amounts of mineral fertilizers and pesticides, which are considered environmental pollutants, as well as poor management of plant residues, insufficient application of organic fertilizers, affects soil degradation and negatively affects soil fertility (Rajičić et al., 2020; Stojiljković et al., 2021, Rajičić et. al., 2025). In intensively cultivated land, organic matter decomposes faster, which reduces its fertility and usability, and it is also more exposed to compaction and erosion. Cover crops have an important role in protecting the soil from erosion and creating a sufficient amount of organic mass that develops during the growing season and ensures the retention of nutrients absorbed from the soil. By introducing the remains of cover crops into the soil, organic matter is introduced that encourages the work of microorganisms. If there is not enough nitrogen in the introduced organic mass, the microorganisms will use the existing N from the soil, which is why leguminous plants are often grown as cover crops. In the last few years, there has been an increasing number of researches related to the interactions of plants and certain groups of microorganisms with the aim of ecologically and economically profitable production (Cvijanović et al., 2012). For this purpose, symbiotic and associative groups of microorganisms are used in the system of growing leguminous and non-leguminous plant species. Fast-growing cover crops (grasses and cabbages) bind the soil, reduce the formation of bumps and protect it from erosion (Sarrantonio, 2007). They can be grown whenever the soil remains bare throughout the year. Small vetch, grown alone or in a mixture with cereals can reduce erosion, enrich the soil with nitrogen and organic matter (Clark, 2007). The intercropping of legumes with cereals offers scope for developing energy-efficient and sustainable agriculture (Jakšić et. al, 2024). The improvement of soil properties by growing cover crops is reflected in the reduction of soil volume by 3.5% and the reduction of the C:N ratio, especially in the deeper layers, up to 40 cm (Haruna and Nkongolo, 2015).

Cover crops reduce nitrogen losses from agricultural systems by reducing leaching of nitrates and volatilization of ammonia and nitrogen oxides into the atmosphere. The decomposition of organic matter improves the physical properties of the soil – structure, water-air regime and buffer capacity (Restovich et al., 2012). These are the so-called "prolonged effects of growing cover crops" that enable better growth and development of subsequent crops (Oljača and Dolijanović, 2013). The most common crops for green fertilization are mainly plant species from the Fabaceae family (peas, lupins, beans, lentils, clovers and alfalfa), which with the help of nitrogen fixation often provide enough N for their needs, and a significant amount remains in the soil and will be used the next crop (Blanco-Canqui et al., 2015; Cutti et al., 2016). Drought-tolerant crops that require minimal investment are preferred when selecting species.

For example, in areas where erosion is possible, the solutions are grasses, and where there is a need to improve potential fertility or reduce weediness of the soil, the best solution is leguminous species, which produce a large amount of organic matter in a relatively short period of time. Thanks to their deep roots, these species can absorb nutrients from hard-to-reach forms and deeper soil layers and move them into the plowed layer. Also, they are capable of fixing atmospheric nitrogen. Legumes as cover crops can often provide sufficient nitrogen needed for main crop production. Thiessen-Martens et al., (2005) called this feature of cover crops "fertilizer replacement value". For the maize crop, which is a high consumer of nitrogen, legumes are a good choice because they grow quickly in the fall, protect the soil during the winter, and start growing early in the spring by accumulating a large amount of nitrogen-containing organic matter (Jabran et al., 2018). Organic matter greatly affects a whole series of very important physical and chemical properties of the soil: structure, water capacity, ion sorption, content of biogenic elements (N, P, S) and others. In addition to the content of organic matter and humus, important factors of soil quality are salinity, pH. number of microorganisms and soil contamination (Dolijanović and Oljača, 2006). Soil quality should be managed to ensure optimal conditions for crop growth, development, flowering and fertilization. Nemecek et al., (2008) point out that growing peas as a cover crop reduces soil acidification by an average of 18% if peas are included in the rotation.

Numerous studies confirm that leguminous cover crops improve soil quality and thus provide more favorable conditions for the growth, development and yield of main crops (Amossé et al., 2013; Hubbard et al., 2013; Tiemann et al., 2015; Somenahally et al., 2018; Elsalahy et al., 2019; Kocira et al., 2020). Cover plant species with different habitus characteristics can use light more efficiently and thus reduce its availability on the soil surface, which will lead to reduced weed emergence. The unique patterns of growth and development of the root system and the ability to adopt and activate nutrients in the soil by cover plant species in mixtures can affect more efficient use of nutrients, which directly affects the reduction of resources for weeds (Tribouillois et al., 2015). On the occasion of World Soil Day on December 5. in Novi Sad, in 2019. a scientific meeting "Ecological importance of organic matter in soil" was held in Matica srpska. Some of the solutions offered by the participants of this meeting refer to the application of different models of reduced tillage, sowing of cover crops, green fertilization, organic agriculture, improvement of irrigation, creation of varieties and hybrids tolerant to changed growing conditions due to climate change and the like. One of the conclusions is that organic matter is also recognized as a powerful weapon in the fight against climate change due to its ability to absorb large amounts of carbon, which is found in the gases responsible for creating the greenhouse effect. The consequences of climate change on soils with a high content of organic matter can be mitigated. The aim of the work is to examine the influence of the type of cover crops, after mowing and plowing of the above-ground biomass, on increasing the content of organic matter in the soil, reducing leaching of nutrients and their contribution to the general fertility of the soil.

Materials and Methods

The study of the effect of growing cover crops on the content of organic matter in the soil was carried out at the experimental field of the Maize Institute "Zemun Polje" in Zemun Polje, Serbia (44°52'N 20°20'E), at an altitude of 110 m, during a two-year period. The experiment was set up according to the split-plot system in four replications. The cover crops consisted of four types of plants, two legumes: P1-common vetch, *Vicia sativa* L. (fam. Fabaceae), P2-winter forage pea, *Pisum sativum* L. (fam. Fabaceae) and two non-leguminous species: P3-winter oats, *Avena sativa* L. (fam. Poaceae) and P4-winter forage kale, *Brassica oleracea* (L.) *convar. acephala* (fam. Brassicaceae). Cover crops were sown manually at the beginning of November, using original seeds from the Institute for Fodder Plants of the Institute of Crop and Vegetable Agriculture from Novi Sad. In both years, the main crop was winter wheat. Before sowing, soil samples were taken for agrochemical analyses: the first at a depth of 0-20 cm and the second at a depth of 20-40 cm, then in the spring after mowing the cover crops, and before sowing the main crop and in the summer after harvesting the main crop (sweet corn). Fertilization of cover crops was carried out together with basic tillage. The entire amount of P and K was introduced in the fall with MKP fertilizer (0:52:34), and the required amount of nitrogen was introduced in the spring, together with the sowing of the main crop in the form of individual Urea fertilizer. Immediately before mowing, the biomass of the cultivated cover crops was measured, and the mowing and plowing of the cover crops was done in the spring so that the crops were as lush as possible. Immediately after ploughing, a liquid microbiological fertilizer (mobilizer of nutrient elements) containing strains of proteolytic and cellulolytic bacteria in the amount of 10 l ha^{-1} was applied to the soil on half of the elementary plot which helped the mineralization of the introduced plant residues and whose application had a favorable effect on the increased fertility.

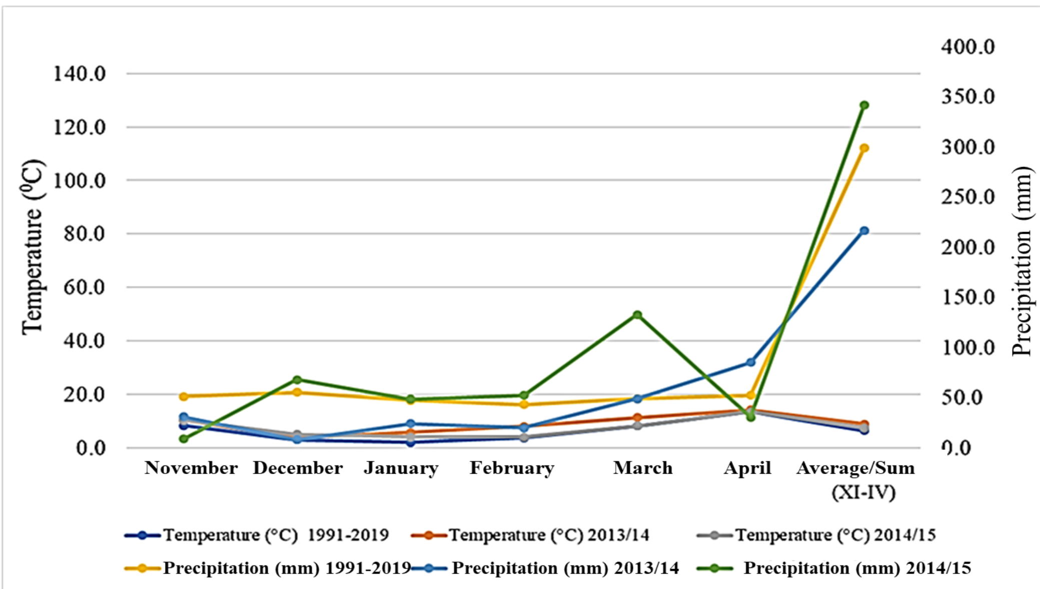
Accessible nitrogen was determined according to the method of Scharpf and Wehrmann (1975), accessible phosphorus according to the method of Olsen et al., (1954) and accessible potassium from the same solution (alkaline $NaHCO_3$) with an ion-selective electrode. The K content was also determined by ICP-OS (EPA Method 200.7. Martin et al., 1994), and the extraction of elements with Mehlich-extraction solution, according to the SRIEG 18 procedure (1983). The content of organic matter was determined according to the method of Magdoff (1996).

Table 1. Basic agrochemical properties of the soil in the experimental field

Depth (cm)	N (kg ha^{-1})	NH4 (kg ha $^{-1}$)	NO3 (kgha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Moisture (%)	P2O5 ppm (mg kg^{-1})	K2O (ppm)	pH H2O	pH nKCl
0-20	44.37	1.82	42.55	25.96	280.42	10.72	29.73	150.75	7.05	7.04
20-40	21.66	0.70	20.96	33.19	298.47	11.16	38.01	160.45		

The weakly carbonate chernozem of northeastern Srem is characterized by a humus-accumulative (Ah) horizon 0-50 cm deep, dark to dark-black in color and its textural composition is powdery-clay loam. The clay content is about 32%, powder 15% and sand 53%. This type of soil has favorable water-physical properties. The content of $CaCO_3$ in the humus accumulative layer, which does not exceed 5%, caused this low carbonate soil to have a neutral to slightly alkaline reaction of the soil solution. The content of organic C is also the highest on the surface and amounts to 1.95%.

The soil is optimally supplied with total nitrogen, the C:N ratio is quite good (average 9.39) which means that ammonia is extracted from the cells of microorganisms and can be used by plants as an assimilative. The soil is moderately provided with easily accessible phosphorus, and very provided with easily accessible potassium, which should be taken into account when determining the amount of fertilizers for fertilizing this land. In the layer 0-20 cm deep the content of organic matter is on average 3.3% and the total $CaCO_3$ is 9.7%. Based on data from autumn in the first year of research (Table 1) the chemical reaction of the soil is neutral (Ah horizon) to weakly alkaline, and with increasing depth it is increasingly basic (pH in water 7.05 and pH in KCl 7.04). The total N content is 44.37 kg ha^{-1} in the 0-20 layer and 21.66 in the 20-40 cm layer. The soil contains 29.73 and 38.01 mg of available P per 100 g of soil and 150.75 and 160.45 mg of K per 100 g of soil, respectively.



Graph 1. Meteorological conditions in the investigated locality (source RHMZS)

From the meteorological conditions mean monthly air temperatures, amounts and distribution of precipitation were considered as limiting factors of plant production. When it comes to precipitation the most important thing is its distribution during the year especially during the vegetation period of plants. In addition to supplying plants with water, precipitation enables the uptake of nutrients and minerals as well as their transport from the roots through the tree to the leaves. For this research. meteorological conditions were analyzed for the multi-year period from 1991-2019. year which were obtained from the RHMZ of Serbia as well as the meteorological conditions for the research period. Higher air temperatures in the winter and spring months during the test in the first year of the year were accompanied by a small amount of precipitation, lower than the multi-year average (341.4 and 217.2 mm). It is particularly important to highlight the small amount of precipitation in December and February, which caused a lower yield of above-ground biomass of cover crops in the first year of testing, while the second year was significantly more favorable for the growth and development of plants in terms of average air temperature (7.5 °C) and the amount and distribution of rainfall during the entire vegetation period of cover crops.

The results presented in this paper are part of a three-year research with the theme of a sustainable system of cultivation of the main crop (sweet corn) the production of which was carried out after the plowing of cover crops and those parameters were not taken into account in the analysis of the given data. The obtained results of this study were statistically processed by analysis of variance and tested by the LSD test (*Least Significant Difference Test*) in the program IBM SPSS Statistics, version 26.0. and are presented tabularly and graphically.

Results and discussion

The results shown in Table 2 show that the average yield of biomass at the investigated location was 32130 kg ha^{-1}, which represents a significant potential in improving the content of organic matter in the soil. The largest amount was measured in the second year (41780 kg ha^{-1}), and significantly lower in the first year research (22480 kg ha^{-1}). The highest biomass yield was achieved by winter fodder kale (P4), especially in the second year of the trial (54040 t ha^{-1}), which is to be expected because it is known that the optimal biomass yield of winter fodder kale is between 65-70 t ha-^{1} and in years with rainy early spring, biomass can exceed 80 t ha^{-1}. By plowing above-ground biomass during the appearance of flower buds of winter fodder kale, it is possible to introduce up to 150 kg ha^{-1} of pure N into the soil, which has the potential for multi-year and gradual release, which enables the continuous supply of the following crops in the crop rotation with this essential element for growth and development of each plant.

The lowest average biomass yield was achieved by growing winter oats, especially in the first year of testing 19675 kg ha^{-1} which is almost half less than the average green biomass yields of oats at the level of Serbia, which amount to about 30 t ha^{-1} (https://www.stat.gov.rs/). Considering the potential of winter peas and common vetch, i.e. the varieties grown in the trial, whose biomass is 40-60 and 30-50 tons per hectare, in this test the yields can be assessed as low (31955 and 29500 kg ha^{-1}). Oljača and Dolijanović, (2013) state that green fertilization enriches the soil with about 35-40 t ha^{-1} of organic matter.

Table 2. Above-ground biomass of cover crops (kg ha^{-1}) in the examined period

Year (A) / Cover crops (B)	I	II	Average
P1	18310	45600	**31955**
P2	20760	38240	**29500**
P3	19675	29240	**24458**
P4	31175	54040	**42608**
Average	**22480**	**41780**	**32130**
Factors	A	B	AB
LSD p<0.05	6494.30	9184.30	15907.80
LSD p<0.01	8906.50	12595.70	21816.30

Legend: P1-common velch; P2-winter fodder peas; P3-winter oats; P4-winter fodder kale

Species used as cover crops should produce high biomass, which is important for even coverage of the soil surface. Their C:N ratio should be balanced and should not decompose quickly thus protecting the soil, even in the early stages of growth and development of the main crops (Wallace et al., 2017). Soil not covered by vegetation is more susceptible to weeding and erosion, while a high C:N ratio leads to N losses from the system, reducing its availability to cultivated plants (Rizzardi and Silva, 2006). The content of organic matter on cover crop variants was measured in both years of testing in the spring (Table 3) ten days after plowing the biomass of the cover crops, and before sowing the main crop despite the fact that it is known that the content of organic matter does not change quickly and cannot can be fixed, and not improved in a short period of time. The initial content of organic matter from autumn in the first year of research (3.3%), when the research began is considered. Statistical analysis revealed that the content of organic matter changed under the influence of factors, both individually and in interaction regardless of the fact that winter wheat was the predominant cover crop every season. The average content of organic matter in the examined period was 3.624 and 3.812 % in the first and second soil layers. The difference in the content of organic matter by years of testing is the result of varying meteorological conditions and the amount of plowed biomass of cover crops.

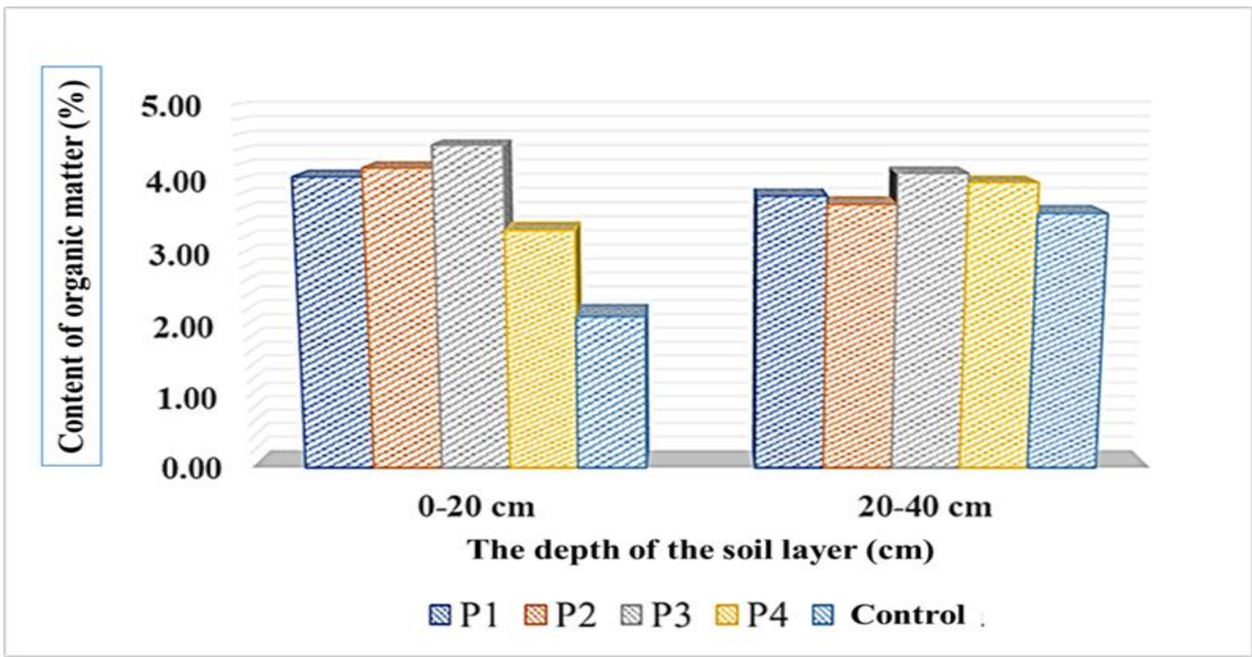
Table 3. Content of organic matter (%) in soil

Year (A)	**I**		**II**		**Average**	
Depth (cm) (C)	0-20	20-40	0-20	20-40	0-20	20-40
Cover crops (B)						
P1	3.857	3.860	4.227	3.709	4.042	3.785
P2	3.997	2.922	4.325	4.420	4.161	3.671
P3	4.386	4.208	4.547	3.971	4.467	4.090
P4	3.607	3.366	3.024	4.563	3.315	3.965
Control	3.810	2.671	4.509	4.427	2.135	3.549
Average	**3.931**	**3.405**	**4.126**	**4.218**	**3.624**	**3.812**
Factors	A	B C	AB	AC	BC	ABC
LSD p<0.05	0.04	0.07 0.04	0.13	0.07	0.11	0.27
LSD p<0.01	0.06	0.09 0.05	0.18	0.10	0.16	0.49

Legend: P1-common velch; P2-winter fodder peas; P3-winter oats; P4-winter fodder kale

The largest mass was plowed in second year of examination, and with favorable meteorological conditions, the content of organic matter was the highest in that year. The correct selection of the species grown as a cover crop certainly contributes to this, because the selection of the species implies a preliminary assessment of the agro-ecological conditions of the climate, with a special emphasis on the distribution and amount of precipitation, the occurrence of early autumn and late spring frosts, soil properties (Ugrenović and Ugrinović, 2014). In terms of impact on increasing the content of organic matter in the soil, the best results were achieved by winter oats. After winter oats, the content of organic matter increased the most and averaged 4.467 and 4.090%, which was statistically significantly higher compared to other cover crops. Ugrenović et al., (2024) state in their results that mixtures in cover crops significantly increase microbiological activity in the soil, which contributes to an increase in organic matter.

The increase in the level of organic matter depends on the amount of biomass formed in the cover crop and the C:N ratio in the plant residues, which is affected by the plant species and the time when the cover crop is destroyed (Restovich et al., 2012). Plant residues of cover crops with a low C:N ratio such as Fabaceae decompose faster than those with a high ratio as is often the case with species of the Poaceae family.



Graph 2. Average values of organic matter content (%)

It is considered that the ideal C:N ratio is 10:1, while it is favorable from 10:1 to 20:1, and unfavorable when it is >20:1. After the destruction of the grass cover crop, the plant residues on the soil surface have a high C:N ratio, which causes a very slow decomposition and in the long term affects the increase of the content of organic matter in the soil (Diekow et al., 2005). Plants from the grass family accumulate nutrients, especially N through the roots, and they remain in the soil after harvest, so according to Popović

(2010), over 70 kg of N ha^{-1} can be accumulated in three months, which becomes accessible to plants more slowly.

On the other hand, the plant remains of butterfly plants are decomposed faster, due to the lower C:N ratio, so they have less effect on increasing the content of organic matter in the soil than grass cover crops (Fageria et al., 2005). Vuyyuru et.al., (2020) state that after plowing sugarcane crop residues, the content of organic matter in the soil and the total C/N ratio increased, which resulted in higher microbiological activity. Cultivation of cover crops and their plowing contributes to the increase of the biomass of microorganisms in the soil, the increase of the biological activity of the soil, the development of saprophytic microflora that prevents the development of numerous diseases of cultivated plants (Motta et al., 2007). The loss of organic matter from the soil can be 20-40% or more, which significantly affects the quality of the soil and water. Soil quality is reduced by limiting microbial activity that is important for healthy and sustainable agriculture (Garten, 2002). It is considered that the content of organic matter, as the best indicator of soil fertility and quality, is most influenced by external factors and poor soil management (Šeremešić, 2015). The amount of green mass that is plowed is 10-20 t ha^{-1} (2-4 t dry matter ha^{-1}), 0.7 - 3.0 t of roots, and about 100 kg N ha^{-1} for legumes (Vukadinović and Vukadinović, 2012).

Conclusion

The results of this research show that growing cover crops is a promising method of sustainable agriculture with the potential to improve soil quality and mitigate the consequences of soil degradation. Based on the two-year results, we can conclude that there was an increase in the content of organic matter in the soil, which was largely influenced by the biomass yield of cover crops. The most significant influence on the biomass yield of cover crops was the meteorological conditions, i.e. the air temperature and the distribution of precipitation during the growing season. In the second year of the research, the highest average biomass of cover crops was measured (41780 kg ha^{-1}), while the lowest was measured in the first year (22480 kg ha^{-1}), which was also meteorologically unfavorable. The variant with a cover crop of winter fodder kale had the highest yield in the second year, and the smallest on the variant with winter oats in the first year. After growing winter oats, the content of organic matter increased the most (depth 0-20 cm - 4.467 and depth 20-40 cm - 4.090%). The short-term benefit can often be lower than the invested funds and work, and the need to grow cover crops should be considered for each specific case, especially considering the long-term benefit (preventing erosion and preserving the agroecosystem, increasing soil fertility).

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Pokrovi usevi u održivom sistemu gajenja i njihov uticaj na sadržaj organske materije u zemljištu

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Apstrakt

Pokrovni usevi su veoma važni posebno sa aspekta održivosti poljoprivredne proizvodnje. Ova biološka mera održava ili povećava nivo organske materije u zemljištu, poboljšava fizička svojstva zemljišta, akumulira azot u mahunarkama, poboljšava mikrobiološku aktivnost u zemljištu, suzbija korov i povećava plodnost zemljišta. U istraživanje su kao pokrovni usevi uključene 4 biljne vrste: obična grahorica, ozimi krmni grašak, ozimi ovas i ozimi krmni kelj. Eksperiment je sproveden na oglednom polju Instituta za kukuruz "Zemun Polje" tokom dve vegetacione sezone na slabo karbonatnom černozemu. Jesenja priprema zemljišta (duboko oranje i fina predsetvena priprema) sprovedena je neposredno pred setvu pokrovnih useva početkom novembra. Za setvu je korišćeno originalno seme Zavoda za krmno bilje Instituta za ratarstvo i povrtarstvo iz Novog Sada. Na proleće, pre košenja i zaoravanja merena je nadzemna biomasa pokrovnih useva, nakon čega je polovina parcele tretirana mikrobiološkim đubrivom, koje je pomoglo u mineralizaciji biljnih ostataka i dodatno uticalo na povećanje plodnosti zemljišta. Cilj rada je ispitivanje različitih vrsta pokrovnih useva, koji zaoravanjem nadzemne biomase doprinose povećanju sadržaja organske materije u zemljištu, sprečavaju ispiranje hranljivih materija i utiču na opštu plodnost zemljišta. Najveća nadzemna biomasa je izmerena kod ozimog krmnog kelja (54040 t ha^{-1}) u drugoj godini istraživanja, koja je imala povoljnije meteorološke uslove. Nakon ozimom ovsa, sadržaj organske materije se najviše povećao i prosečno je iznosio 4.467% i 4.090%, što je bilo statistički značajno više u poređenju sa ostalim pokrovnim usevima.

Ključne reči: *pokrovni usevi, održivi sistem proizvodnje, organska materija, plodnost zemljišta.*

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Ailanthus altissima: invazivna vrsta u savremenim ekosistemima

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Izvod

Ailanthus altissima je invazivna drvenasta vrsta poreklom iz Kine i severnog Vijetnama, koja se proširila na sve kontinente osim Antarktika. Zbog brzog rasta, intenzivne vegetativne i generativne reprodukcije, kao i otpornosti na nepovoljne uslove, predstavlja ozbiljan ekološki i ekonomski problem. Širenje ove vrste ugrožava prirodna staništa istiskivanjem autohtonih vrsta i narušavanjem ekološke ravnoteže, dok u urbanim sredinama može izazvati infrastrukturne štete. Suzbijanje otežava sposobnost regeneracije putem korenovih izdanaka i velika produkcija semena koje vetar može raspršiti na velike udaljenosti. Trenutni pristupi suzbijanju uglavnom se oslanjaju na hemijske tretmane ubrizgavanjem herbicida u stablo, ali nijedan od njih nije u potpunosti efikasan. Mehaničko uklanjanje se takođe primenjuje ali često dovodi do još intenzivnijeg rasta. Istraživanja bioloških metoda kontrole, uključujući upotrebu specijalizovanih patogena i herbivora još uvek nisu dala konačne rezultate. S obzirom na negativne ekološke i ekonomske posledice, neophodno je kontinuirano praćenje populacija ove vrste i sprovođenje integrisanih mera suzbijanja. Efikasna strategija kontrole zahteva kombinaciju hemijskih, mehaničkih i bioloških metoda uz podizanje svesti javnosti o značaju pravovremenog reagovanja u cilju ograničavanja njenog daljeg širenja.

Ključne reči: *Ailanthus altissima*, invazivne vrste, ekološki uticaj, suzbijanje.

Poreklo i globalna distribucija *Ailanthus altissima*

Ailanthus altissima (Mill.) Swingle – pajasen ili kiselo drvo, pripada porodici Simaroubaceae i poreklom je iz severoistočnih i centralnih delova Kine, kao i sa Tajvana i Korejskog poluostrva (Kowarik and Säumel, 2007). Introdukcija ove vrste započela je još tokom 18. veka, kada je seme preneto u Evropu sa ciljem njegovog uzgajanja kao ukrasne biljke. Prvi zvanični zapisi o njenom unošenju u Evropu potiču iz 1740-ih godina, kada je seme doneseno u Pariz tokom kontinentalne ekspedicije kroz Sibir (Sladonja et al., 2015). Ova vrsta je potom prvi put zasađena u Londonu 1751. godine, dok se u Parizu intenzivnije koristi od 1875. godine, naročito kao alternativa platanima za ozelenjavanje gradskih ulica i javnih površina (DAISIE, 2014). U Severnoj Americi, *A. altissima* se pojavila krajem 18. veka, kada je uvedena kao ukrasno drvo koje je prvobitno sađeno u urbanim sredinama, ali se vrlo brzo proširila širom kontinenta, naročito u državama poput Pensilvanije, Ohaja, Viskonsina i Nebraske (Rebbeck et al., 2017). Zahvaljujući svojoj sposobnosti brzog rasta i prilagodljivosti, danas je ova vrsta široko rasprostranjena ne samo u Evropi i Severnoj Americi, već i u drugim delovima sveta, uključujući Aziju, Južnu Ameriku, Australiju i Afriku.

Osim prirodne kolonizacije, ova vrsta se u nekim regionima uzgaja na plantažama zbog visokog sadržaja celuloze, a plantažni uzgoj je prisutan u Austriji, istočnoj Evropi, Argentini, Urugvaju, Indiji i na Novom Zelandu (DAISIE, 2014). Pored industrijske eksploatacije, *A. altissima* se u prošlosti koristila za ozelenjavanje industrijskih područja i urbanih sredina sa visokim stepenom zagađenja vazduha, jer pokazuje visoku toleranciju na aerozagađenje i nepovoljne ekološke uslove (Rebbeck et al., 2017). Njena sposobnost prilagođavanja različitim klimatskim uslovima i tipovima zemljišta omogućila joj je izuzetno brzo širenje izvan prirodnog areala. U Evropu je prvobitno uneta sredinom 18. veka pre svega u dekorativne svrhe, ali se ubrzo pokazala kao izrazito invazivna vrsta, koja je u mnogim regionima postala dominantna u odnosu na autohtonu vegetaciju (Sladonja et al., 2015). Danas je prisutna u različitim klimatskim zonama, ali je njena najveća zastupljenost zabeležena u toplijim delovima umerene zone gde uspešno kolonizuje degradirana i antropogeno narušena staništa (Kowarik and Säumel, 2007). Njena otpornost na ekstremne urbane uslove, kao i sposobnost da raste na različitim tipovima zemljišta, dodatno olakšavaju njen ekspanzivni rast i uspešnu adaptaciju na nove ekosisteme (Di Cocco et al., 2024). Jedan od ključnih faktora koji doprinose invazivnom uspehu *A. altissima* jeste njena izuzetna ekološka plastičnost i sposobnost brzog kolonizovanja antropogeno narušenih staništa (Petruzzellis et al., 2019). Ova vrsta se često može pronaći duž saobraćajnica, u urbanim sredinama, na napuštenim poljoprivrednim parcelama, ali i na degradiranim zemljištima gde brzo formira guste zasade koji otežavaju rast drugih biljnih vrsta (Casella and Vurro, 2013). Njeno prisustvo predstavlja ozbiljan problem u gradovima, gde njen snažan korenski sistem može izazvati značajne infrastrukturne štete, uključujući pucanje betonskih površina, destabilizaciju temelja objekata i narušavanje drenažnih sistema, što može dovesti do dodatnih ekonomskih troškova za sanaciju i održavanje urbanih područja (Casella and Vurro, 2013). Osim ekoloških i infrastrukturnih posledica, *A. altissima* može imati i negativne efekte na ljudsko zdravlje. Poznato je da njen polen izaziva alergijske reakcije kod osoba koje su osetljive na aeroalergene, dok kontakt sa njenim listovima može izazvati dermatološke iritacije, poput crvenila i osipa (Ballero et al., 2003). Ovi aspekti dodatno doprinose njenom statusu problematične invazivne vrste, posebno u urbanim i prigradskim sredinama, gde može predstavljati rizik ne samo za ekosistem, već i za stanovništvo. Suzbijanje i eliminacija *A. altissima* predstavljaju ozbiljan izazov za ekološke stručnjake i upravljače zelenim površinama, s obzirom na njenu izuzetnu sposobnost brzog širenja i regeneracije (Giunti et al., 2010). Pored visokog semenskog potencijala, ova biljka se efikasno razmnožava vegetativnim putem, razvijajući snažne bočne korene koji omogućavaju formiranje novih stabala čak i nakon mehaničkog uklanjanja matičnog drveta (Giunti et al., 2010). Njena invazivna prednost dodatno je pojačana alelopatskim efektima; izlučuje hemijske supstance u okolno zemljište koje inhibiraju klijanje i rast autohtonih biljnih vrsta, čime efikasno dominira nad konkurentskim vrstama u ekosistemima koje kolonizuje (Rebbeck et al., 2017).

Invazivne vrste predstavljaju jedan od glavnih izazova u očuvanju biodiverziteta i stabilnosti ekosistema, a pravovremena i tačna informacija o njihovom rasprostranjenju, dinamici širenja, biološkim karakteristikama i uticaju na lokalne vrste i staništa ključna je za prepoznavanje problema i preduzimanje adekvatnih mera upravljanja (Kowarik and Säumel, 2007). S obzirom na invazivni karakter ove vrste i njene ozbiljne ekološke, ekonomske i zdravstvene posledice, od suštinskog je značaja objediniti i sistematski predstaviti dostupna saznanja o ovoj vrsti. Ovaj rad ima za cilj da pruži sveobuhvatan pregled osnovnih bioloških i ekoloških karakteristika ove vrste, njenih mehanizama širenja, kao i negativnih posledica koje izaziva u prirodnim i antropogenim sredinama. Poseban akcenat stavljen je na strategije suzbijanja, uključujući mehaničke, hemijske i biološke metode kontrole, kao i na mogućnosti primene integrisanog pristupa u upravljanju njenim populacijama.

Biologija i ekologija *Ailanthus altissima*

Ailanthus altissima odlikuje se izuzetno brzim rastom, pri čemu, u zavisnosti od ekoloških uslova staništa, može dostići visinu u rasponu od 18 do čak 30 metara. Maksimalni životni vek ove vrste procenjuje se na približno 130 godina, iako se u prirodnim populacijama retko beleže primerci stariji od 50 godina (Davies, 1943). Ova činjenica sugeriše da različiti ekološki i antropogeni faktori značajno utiču na dugovečnost ove biljke, što dodatno naglašava kompleksnost njenog životnog ciklusa i adaptivnih strategija (Miller, 1990). Listovi su neparno perasto složeni i mogu dostići dužinu između 30 i 100 cm. Svaki listić poseduje specifične žlezdaste zupce pri osnovi, što predstavlja jedan od ključnih taksonomskih karakterakoji omogućavaju preciznu identifikaciju i diferencijaciju ove vrste u odnosu na srodne biljke (Davies, 1943). Cvetovi *A. altissima* variraju u boji, pri čemu se nijanse kreću od bledo žućkaste do crvenkaste, a grupisani su u terminalne cvasti, koje postaju naročito uočljive tokom perioda intenzivnog cvetanja. Plod ove biljke je samar, čija boja može varirati od svetlo žućkaste do intenzivno crvene. Njegove morfometrijske osobine, uključujući veličinu, masu i debljinu perikarpa, u velikoj meri zavise od ekoloških faktora specifičnih za stanište u kojem se biljka razvija (Kovarik and Säumel, 2007). Jedno odraslo drvo može proizvesti i do 300 000 semena tokom jedne vegetacione sezone, što ovoj vrsti osigurava visok potencijal za brzo širenje populacije i kolonizaciju novih staništa. Ova vrsta uspeva na širokom spektru zemljišnih tipova, od ekstremno siromašnih i stenovitih supstrata do bogatih aluvijalnih tala, pokazujući izuzetnu toleranciju na različite hemijske karakteristike zemljišta, uključujući visok stepen alkalnosti i prisustvo soli (Kovarik and Säumel, 2007). Pored prilagodljivosti različitim pedološkim uslovima, *A. altissima* pokazuje izuzetnu otpornost na nepovoljne faktore životne sredine, uključujući produžene periode suše, značajne nivoe zagađenja vazduha i zemljišta, kao i niske koncentracije esencijalnih hranljivih materija (Sladonja et al., 2015). Ova sposobnost joj omogućava da opstane čak i u ekstremno nepovoljnim uslovima u kojima većina drugih biljnih vrsta ne može preživeti (Sladonja et al., 2015). Seme ove vrste odlikuje se visokom klijavošću koja se kreće u rasponu od 64% do čak 98%. Međutim, njegova održivost značajno opada tokom vremena, nakon godinu dana skladištenja prosečna stopa klijanja smanjuje se na približno 75%, dok nakon dve godine dostiže svega 60% (Sladonja et al., 2015). Za razliku od nekih drugih invazivnih biljaka, *A. altissima* skladišti seme koje ostaje održivo samo ograničen vremenski period u zemljištu. Istraživanja ukazuju da se stopa klijanja semena koje je bilo inkubirano u sloju hrastovog lišća tokom petogodišnjeg perioda drastično smanjuje na svega 1,9%, dok se seme skladišteno u mineralnom zemljištu pokazalo značajno otpornijim, zadržavajući prosečnu stopu klijanja od približno 75% (Rebbeck and Jolliff, 2018). Među različitim ekološkim faktorima koji utiču na klijavost semena, temperatura se izdvaja kao jedan od najvažnijih. Istraživanja pokazuju da viši temperaturni raspon pozitivno utiče na proces klijanja, dok prisustvo svetlosti, iako može imati određenu ulogu, nije presudan faktor za uspešno klijanje (Pepe et al., 2020). Optimalni temperaturni raspon za klijanje semena kreće se u intervalu od 25/30°C, pri čemu se na temperaturi 30/20°C postiže značajno viša stopa klijanja u poređenju sa nižim temperaturnim rasponima, poput 15/6°C (Soler and Izkuierdo, 2024). Biološki proces disperzije igra ključnu ulogu u dugoročnom opstanku i širenju biljnih vrsta, jer omogućava reproduktivnim strukturama biljaka da se prenesu na udaljenije lokacije od matičnih jedinki, čime se smanjuje kompeticija i otvaraju nove mogućnosti za kolonizaciju staništa. Iako bi se moglo pretpostaviti da je udaljenost koju seme može preći proporcionalna njegovoj masi, istraživanja pokazuju da je ovaj faktor manje značajan u poređenju sa visinom biljke i specifičnim morfološkim adaptacijama koje omogućavaju efikasnu disperziju u različitim ekološkim uslovima (Kovarik and Säumel, 2008). Kod *A. altissima*, primarna disperzija odvija se putem vetra, dok sekundarni mehanizmi uključuju vodu i transport od strane životinja, kao što su ptice i mravi (Bossard et al., 1957; Kaproth and McGraw, 2008; Planchuelo et al., 2016; Thomson et al., 2011). Vetar, kao glavni abiotski faktor u procesu širenja semena, igra dominantnu ulogu u prostornom rasporedu populacija ove vrste (Soler and Izquierdo, 2024). Plodovi samare poseduju specifičnu morfološku strukturu koja im omogućava efikasan transport vetrom na velike udaljenosti. Zahvaljujući maloj masi seme može biti nošeno vazdušnim strujama i preći razdaljine i do 200 metara od matične biljke (Kota, 2024). Pored generativnog načina razmnožavanja, vegetativno razmnožavanje ima veliki značaj u dugoročnom opstanku i širenju *A. altissima*, omogućavajući ovoj vrsti da brzo zauzima nove prostore i ostvaruje kompetitivnu prednost nad autohtonim vrstama u degradiranim ekosistemima (Miller, 1990). Jedan od najznačajnijih aspekata vegetativnog razmnožavanja jeste sposobnost biljke da razvija nove izdanke iz korena, čime se formiraju guste populacije koje dodatno olakšavaju kolonizaciju i stabilizaciju na osvojenim staništima (Miller, 1990). Ovaj oblik razmnožavanja omogućava biljci da preživi čak i kada su nadzemni delovi oštećeni ili uklonjeni, čime se dodatno povećava njena invazivnost i otpornost (Miller, 1990).

Genetička varijabilnost

Ailanthus altissima je tetraploidna vrsta sa brojem hromozoma 2n = 64 (Ivanova et al., 2006), čija genetska varijabilnost među populacijama predstavlja ključni faktor u njenoj sposobnosti prilagođavanja različitim ekološkim uslovima. Proučavanje izoenzimskih frekvencija unutar sekundarnog raspona ove vrste omogućilo je precizniju analizu genetske strukture populacija i istaklo značajne razlike u osobinama semena i visini stabala između različitih geografskih područja (Feret et al., 1974). Ove razlike, koje su prvobitno uočene u okviru severnoameričkih populacija, sugerišu postojanje selektivnih pritisaka koji su oblikovali morfološke i fiziološke karakteristike vrste u invazivnom arealu (Feret et al., 1974). Jedan od najuočljivijih obrazaca varijabilnosti odnosi se na širinu semena i ukupnu biomasu biljaka, koji se menjaju u zavisnosti od geografske širine. Na severu kontinenta, populacije proizvode šire i teže seme u poređenju sa južnijim populacijama, što može predstavljati adaptivni odgovor na specifične uslove klime i dostupnosti resursa (Feret et al., 1974). Istovremeno, istraživanja su pokazala da stabla u zapadnim delovima Severne Amerike, posebno u Kaliforniji, dostižu veću visinu od onih u istočnim regionima, što može ukazivati na razlike u ekološkim faktorima poput količine padavina, tipa zemljišta i konkurencije sa drugim vrstama (Feret et al., 1974). Zanimljivo je da, uprkos ovim varijacijama, analiza nije pokazala jasnu povezanost između specifičnih klimatskih parametara i uočenih morfoloških osobina, što otvara mogućnost da unutrašnji genetski faktori imaju dominantnu ulogu u regulaciji ovih karakteristika (Feret et al., 1974). Uporedna analiza populacija iz Severne Amerike i Kine pružila je dodatne dokaze o značajnim fenotipskim razlikama između ove dve provenijencije. Konkretno, od ukupno 14 ispitivanih osobina rasta 11 je pokazalo značajne varijacije, pri čemu su invazivne populacije u Severnoj Americi imale izraženiju tendenciju ka većoj visini stabala i smanjenoj alokaciji biomase u korenov sistem (Feret and Bryant, 1974). Ovaj obrazac rasta sugeriše da su jedinke u novom arealu evoluirale tako da favorizuju strategije brzog rasta i kompetitivne dominacije, što im omogućava efikasnije zauzimanje prostora i nadmetanje sa autohtonim vrstama (Feret and Bryant, 1974). Osim toga, severnoameričke populacije imaju veće listove u odnosu na kineske, što može doprineti većoj fotosintetskoj efikasnosti i ubrzanom metabolizmu biljaka u invazivnom području (Feret and Bryant, 1974). Uprkos činjenici da su severnoameričke populacije najverovatnije potekle iz ograničenog broja početnih unosa semena, nije uočen negativan efekat smanjenja biološke sposobnosti. Ovaj nalaz sugeriše da je genetska raznovrsnost u novom arealu ostala na relativno visokom nivou, što je ključno za dugoročnu uspešnost invazivnih populacija (Feret and Bryant, 1974). Pored toga, analiza učestalosti izoenzima između kineskih i severnoameričkih populacija pokazala je izuzetnu sličnost, što ukazuje da nije došlo do značajnog gubitka genetičke varijabilnosti tokom kolonizacije novog staništa. Umesto toga, primećene morfološke promene mogu se objasniti delovanjem selektivnih pritisaka koji su favorizovali određene genotipove sa bržim rastom i većom kompetitivnošću u odnosu na autohtone biljke

(Feret and Bryant, 1974). Feret and Bryant (1974) zaključuju da su, tokom perioda od približno 200 godina od prve introdukcije *A. altissima* u Severnu Ameriku, značajne promene u genetskoj strukturi populacija nastale kao rezultat selekcije jedinki sa najpovoljnijim karakteristikama rasta. Ove promene su verovatno bile podstaknute ljudskim faktorima, s obzirom na to da su biljke sa izraženim poželjnim osobinama, poput bržeg rasta i veće visine, bile češće korišćene za dalje razmnožavanje, čime su dodatno učvršćene selektivne prednosti u invazivnim populacijama (Feret and Bryant, 1974). Dugotrajna studija koja je obuhvatila desetogodišnje ispitivanje semenskih izvora dodatno je potvrdila da među različitim provenijencijama postoji značajna varijabilnost u stopama mortaliteta i ključnim osobinama rasta. Ove razlike sugerišu da je adaptacija *A. altissima* u novim staništima rezultat složene interakcije genetskih i ekoloških faktora, pri čemu oba aspekta imaju ključnu ulogu u oblikovanju fenotipskih osobina biljaka (Feret, 1985). Iako invazivne populacije pokazuju izuzetnu sposobnost prilagođavanja različitim uslovima staništa, ostaje otvoreno pitanje u kojoj meri su ove promene rezultat prirodne selekcije, a u kojoj meri ljudskog uticaja kroz svesno ili nesvesno favorizovanje pojedinih genotipova (Feret, 1985). U kontekstu globalnih promena životne sredine i sve većeg širenja invazivnih vrsta, razumevanje genetskih mehanizama adaptacije *A. altissima* može imati šire implikacije za ekologiju i evoluciju invazivnih biljaka. Nastavak istraživanja u ovoj oblasti mogao bi pružiti dublji uvid u procese koji omogućavaju brzu kolonizaciju novih ekosistema, kao i u potencijalne strategije za upravljanje populacijama ove vrste u područjima gde predstavlja ekološki i ekonomski izazov.

Ekološka fleksibilnost i invazivni potencijal *Ailanthus altissima*

Izuzetna ekološka prilagodljivost *A. altissima* u kombinaciji sa njenom sposobnošću brzog širenja i efikasne adaptacije na heterogene ekološke uslove, omogućava joj da se uspostavi kao dominantna invazivna vrsta u širokom spektru ekosistema na globalnom nivou (Di Cocco et al., 2024). Ova vrsta ne samo da uspešno kolonizuje degradirane ekosisteme, već i pokazuje visoku otpornost na širok spektar stresnih faktora sredine, uključujući dugotrajne periode suše, intenzivno aerozagađenje, kontaminaciju zemljišta te ekstremno siromašne pedološke uslove, što je čini posebno kompetitivnom u odnosu na autohtone biljne vrste (Knüsel et al., 2019). Na taj način, ne samo da se efikasno takmiči sa autohtonim vrstama, već ih u mnogim slučajevima nadmašuje i potiskuje, čime dolazi do značajnog smanjenja biodiverziteta i promene strukturne dinamike zaraženih ekosistema (Sladonja et al., 2015). Osim što pokazuje izuzetnu toleranciju na različite tipove zemljišta i može opstati čak i u pedološkim uslovima sa ekstremno niskim sadržajem hranljivih materija, ova vrsta ne pokazuje značajan gubitak vitalnosti niti redukciju biološke aktivnosti, što joj omogućava formiranje stabilnih i samoodrživih kolonija ne samo na neplodnim i erodiranim terenima, već i na bogatim aluvijalnim zemljištima, gde uspešno konkuriše autohtonoj flori (Sladonja et al., 2015). Iako je sposobna da preživi i u ekstremnim sušnim uslovima preferira peskovita i dobro drenirana zemljišta, dok pokazuje značajno smanjenu otpornost na dugotrajnu izloženost visokim nivoima vlage, što može limitirati njenu distribuciju u močvarnim i periodično plavljenim područjima. Ova vrsta je izuzetno tolerantna na širok raspon pH vrednosti zemljišta, pri čemu uspeva na blago kiselim, neutralnim i umerenim alkalnim supstratima, dok može podneti prisustvo soli do koncentracije od 0,6%, što je značajno viša granica u poređenju sa mnogim drugim drvenastim vrstama invazivnog karaktera (Medina-Villar et al., 2016; DAISIE, 2014). U svom autohtonom arealu, naročito u severoistočnim oblastima Kine, *A. altissima* je pokazala sposobnost da podnese ekstremno niske temperature do -35°C, dok se na lesnim visoravnima i u planinskim predelima sa dominantnim krečnjačkim supstratima ponaša kao tipična pionirska vrsta, koja efikasno kolonizuje otvorene prostore, doprinosi stabilizaciji supstrata i menja sukcesijske procese unutar ekosistema (Rebbeck et al., 2017). Jedan od ključnih mehanizama koji značajno doprinosi invazivnom potencijalu ove vrste jeste sposobnost aseksualne reprodukcije, što joj omogućava brzo prostorno širenje i efikasno zauzimanjenovih staništa (Chuman et al., 2015). Vegetativni izdanci koji se razvijaju iz korenovog sistema mogu formirati guste i dugovečne populacije, koje ne samo da stvaraju senku i značajno smanjuju dostupnost svetlosti drugim biljkama, već i aktivno inhibiraju njihovu regeneraciju kroz fizičku i alelopatsku interakciju sa okolinom (Chuman et al., 2015). Ova osobina daje *A. altissima* značajnu kompetitivnu prednost u odnosu na autohtone biljne vrste, omogućavajući joj da rapidno formira dominantne populacije koje dugoročno menjaju strukturnu i funkcionalnu dinamiku ekosistema (Miller, 1990). Kada su nadzemni delovi biljke oštećeni usled prirodnih faktora, poput požara, jakih vetrova ili mehaničkih oštećenja izazvanih ljudskom aktivnošću, biljka pokazuje izuzetno brzu regenerativnu sposobnost zahvaljujući svom snažno razvijenom korenovom sistemu, koji omogućava gotovo momentalnu obnovu jedinke (Miller, 1990; Sladonja et al., 2015). Ovaj proces regeneracije omogućava biljci ne samo da preživi u nepovoljnim uslovima gde bi mnoge druge vrste imale poteškoća sa dugoročnim opstankom, već i da osigura kontinuiranu prisutnost u zaraženim ekosistemima, čime dodatno doprinosi njenom invazivnom statusu. Novi izdanci koji nastaju iz korenovog sistema i panjeva ubrzano prerastaju u odrasle jedinke, čime se ubrzava zauzimanje novih prostora i širenje u različitim staništima (Miller, 1990; Sladonja et al., 2015). Morfološke karakteristike listova kod novih izdanaka pokazuju značajnu varijabilnost u zavisnosti od toga da li su izdanci proistekli iz korenskih klica ili iz semenki (Hu, 1979; Kovarik and Säumel, 2007). Izdanci koji potiču iz korena često pokazuju širok spektar fenotipske varijabilnosti, uključujući jednostavne listove i perasto složene listove sa pet listića. Za razliku od toga, izdanci razvijeni iz semena u najvećem broju slučajeva formiraju listove sa tri listića. Ovakve morfološke razlike najčešće se javljaju kod mladih izdanaka, dok odrasle biljke tipično razvijaju perasto složene listove sa znatno većim brojem listova (Hu, 1979; Kowarik and Säumel, 2007). Ova morfološka varijabilnost može predstavljati ključni indikator ekološke adaptabilnosti koju *A. altissima* ostvaruje u različitim stanišnim uslovima. Na primer, u aridnim oblastima biljke sa jednostavnijim listovima mogu imati povećanu sposobnost zadržavanja vode usled smanjene transpiracione površine, što predstavlja adaptivni mehanizam koji doprinosi povećanoj toleranciji na deficit vlažnosti u pedosferi (Hu, 1979; Kovarik and Säumel, 2007). Suprotno tome, u vlažnijim staništima, gde je dostupnost vode veća i evapotranspiracija nije ograničavajući faktor, prisustvo složenijih listova može doprineti optimizaciji fotosintetske efikasnosti i ubrzanju vegetativnog rasta, što dodatno povećava kompetitivni potencijal ove vrste u takvim ekološkim uslovima (Hu, 1979; Kovarik and Säumel, 2007).

Alelopatski potencijal

Ailanthus altissima predstavlja jednu od najinvazivnijih biljnih vrsta u svetu, a njegova sposobnost širenja i dominacije u različitim ekosistemima u velikoj meri se oslanja na proizvodnju širokog spektra bioaktivnih jedinjenja (Heisey, 1990). Ove hemijske supstance omogućavaju mu ne samo efikasnu odbranu od biljojeda i patogena, već i izražen alelopatski efekat koji negativno utiče na rast i razvoj drugih biljaka koje se nalaze u njegovoj blizini (Lawrence et al., 1991). Ova osobina čini ga veoma uspešnim u kolonizaciji novih područja i potiskivanju autohtone vegetacije, čime menja ekološku ravnotežu u ekosistemima u koje je unet. Među ključnim jedinjenjima koja doprinose ovom procesu posebno se izdvaja ailanton, poznat po svojoj visokoj fitotoksičnosti i snažnom uticaju na mnoge biljne vrste (Mergen, 1959; Heisey, 1990, 1996; Lawrence et al., 1991). Najveće koncentracije ailantona prisutne su u kori korena, odakle se ova supstanca oslobađa u okolno zemljište putem korenovih izlučevina. Ovaj mehanizam omogućava *A. altissima* da značajno utiče na vegetaciju u svojoj neposrednoj okolini, stvarajući nepovoljne uslove za klijanje i rast drugih biljnih vrsta (Heisei, 1996). Alelopatske supstance koje luči mogu delovati direktno na semena i sadnice drugih biljaka, smanjujući njihovu klijavost, brzinu rasta i sposobnost usvajanja hranljivih materija iz zemljišta. Prema istraživanju koje je sproveo Heisei (1996), ailanton je identifikovan kao najefikasnija fitotoksična komponenta ove biljke. Eksperimentalni podaci pokazali su da čak i pri relativno niskim koncentracijama, poput 0,7 ml/L, ailanton može izazvati inhibiciju rasta korenovog sistema za 50% kod osetljivih biljnih vrsta (Thompson, 2008). Takvi rezultati naglašavaju značajnu kompetitivnu prednost ove vrste u odnosu na druge biljke, jer sprečava njihovu regeneraciju i održava dominaciju na osvojenim područjima. Osim hemijskog uticaja, *A. altissima* može prouzrokovati i promene u fizičko-hemijskim karakteristikama zemljišta, što dodatno otežava rast drugih biljnih vrsta u njegovom okruženju. Istraživanja su pokazala da ova vrsta može značajno uticati na pH vrednost zemljišta, često ga čineći kiselijim, što negativno utiče na biljke koje preferiraju neutralne ili alkalne uslove (Hu, 1979; Kovarik and Säumel, 2007). Povećana kiselost tla može ometati usvajanje esencijalnih hranljivih elemenata kod biljaka koje nisu tolerantne na ovakve promene. Takođe, smanjuje dostupnost ključnih hranljivih materija, uključujući azot i fosfor, čime se stvaraju dodatno nepovoljni uslovi za rast ne samo biljaka već i mikroorganizama u tlu koji zavise od ovih resursa (Hu, 1979; Kovarik and Säumel, 2007). Ova degradacija kvaliteta zemljišta dovodi do dugoročnih promena u biljnim zajednicama, smanjujući biodiverzitet i menjajući ekosistemsku dinamiku. Terenska istraživanja su potvrdila da alelopatske supstance koje oslobađa *A. altissima* mogu značajno inhibirati rast biljaka u njegovoj neposrednoj okolini (Lawrence, 1991). Međutim, rezultati studija koje su se bavile fenomenom autotoksičnosti ove vrste su neujednačeni. Dok su neki eksperimenti pokazali da zalivanje sadnica ekstraktom lista *A. altissima* dovodi do slabijeg rasta, istraživanje Heisei (1996) nije zabeležilo nikakve negativne efekte na sadnice koje su tretirane ailantonom. Ove razlike mogu biti posledica varijabilnosti u sastavu i koncentraciji bioaktivnih jedinjenja, koji zavise od faktora kao što su starost biljke, godišnje doba ili specifični uslovi životne sredine. Moguće je i da različiti delovi biljke produkuju različite kombinacije hemijskih jedinjenja što dodatno komplikuje tumačenje njihovog uticaja na biljni svet. Brojna naučna istraživanja potvrdila su da ekstrakti korena, stabla i lišća *A. altissima* mogu značajno inhibirati klijanje i rast različitih biljnih vrsta u eksperimentima izvedenim u kontrolisanim uslovima staklenika i biotestova (Mergen, 1959; Voigt and Mergen, 1962; Heisei, 1990; De Feo et al., 2003). Hemijske analize su otkrile prisustvo različitih metabolita u tkivima ove biljke (Ogura et al., 1977). Među najzastupljenijim jedinjenjima izdvajaju se β-karbolini, kantin-6-on alkaloidi, kumarini i kvasinoidi. Njihova biološka uloga može uključivati ne samo alelopatske efekte već i zaštitu biljke od biljojeda i patogena, čime se dodatno osigurava njena uspešnost u invaziji novih staništa. Najveće koncentracije toksičnih jedinjenja pronađene su u korenu biljke, dok su umereni nivoi prisutni u mladim izdancima (Heisei, 1990; Lawrence et al., 1991). Suprotno tome, najmanja količina ovih supstanci zabeležena je u drvetu, kori stabla i sitnim cvastima. Interesantno je da toksičnost listova varira u zavisnosti od godišnjeg doba, kako listovi stare, njihova fitotoksičnost se smanjuje, što je u korelaciji sa redukcijom nutritivnog sadržaja (Heisei, 1990; Lawrence et al., 1991). Ova sezonska promena može biti evolucijski mehanizam koji optimizuje alokaciju resursa u biljci i prilagođava njenu hemijsku odbranu ekološkim uslovima. Sve ove karakteristike potvrđuju da prisustvo fitotoksičnih jedinjenja u *Ailanthus altissima* omogućava ovoj vrsti ne samo da se efikasno brani od biljojeda i patogena, već i da značajno utiče na vegetaciju u svom ekološkom okruženju. Smanjenjem klijanja i rasta konkurentskih biljnih vrsta, ona stvara uslove za sopstvenu dominaciju u ekosistemima u koje je unesena. Ovi mehanizmi, u kombinaciji sa sposobnošću prilagođavanja različitim ekološkim uslovima, čine *Ailanthus altissima* jednom od najinvazivnijih biljaka u mnogim delovima sveta (Heisei, 1990; Lawrence et al., 1991).

Metode suzbijanja

Herbicidi su najčešće korišćena i najučinkovitija metoda za suzbijanje *A. altissima*, što potvrđuju brojne studije koje su analizirale efikasnost različitih aktivnih supstanci (Tjosvold and McHenri, 1986; EPPO, 2020; Kok et al., 2008). Efikasnost tretmana u velikoj meri zavisi od koncentracije aktivnog sastojka, načina aplikacije i vremenskih uslova tokom tretmana. Različite hemijske supstance, kao što su triklopir (samostalno ili u kombinaciji s fluroksipirom ili aminopiralidom) i glifosat pokazale su visoku stopu mortaliteta tretiranih jedinki (DiTomaso and Kyser, 2007; Fogliatto et al., 2020). Ovi herbicidi se mogu primenjivati različitim tehnikama, uključujući direktno ubrizgavanje u stabla i prskanje folijarnih delova biljke. Pored direktne aplikacije herbicida, mehaničke metode u kombinaciji sa hemijskim tretmanima mogu značajno doprineti eradikaciji *A. altissima*. Tehnike poput bušenja stabala i ubrizgavanja herbicida specijalizovanim sistemima, kao što su E-Z-Ject Lance (ubrizgavanje herbicidnih kapsula) ili metoda Hack and Squirt (prskanje herbicida direktno na rezove izvedene na stabljici), pokazale su se relativno efikasnim u kontroli ove vrste (DiTomaso and Kyser, 2007; Kok et al., 2008). Najpouzdaniji rezultati postignuti su primenom nerazređenog glifosata, koji se pokazao kao najefikasniji herbicid za suzbijanje ove vrste (Tjosvold and McHenri, 1986). Nasuprot tome, triklopir primenjen metodom hack-and-squirt nije dao zadovoljavajuće rezultate, jer nije postignuta potpuna eradikacija biljke (DiTomaso i Kyser, 2007). Efikasnost aplikacije herbicida na bazalni deo kore zavisi od prečnika stabala. Istraživanja su pokazala da je razblaženi triklopir imao visok stepen uspešnosti kod stabala manjeg prečnika (Tjosvold and McHenri, 1986; Burch and Zedaker, 1970; Johnson, 2011; Eck and McGill, 2007; Bowker and Stringer, 2010), dok su mešavine triklopira + fluroksipira, aminopiralida + fluroksipira i glifosata bile manje efikasne kod stabala većih dimenzija (DiTomaso and Kyser, 2007; Fogliatto et al., 2020). Međutim, primena nerazređenih formulacija ovih herbicida značajno je povećala njihovu efikasnost (Tjosvold and McHenri, 1986; Fogliatto et al., 2020; DiTomaso and Kyser, 2007). Fizičko uklanjanje stabala, uključujući sečenje panjeva, ne predstavlja dugoročno održivu metodu kontrole populacije *A. altissima*. Constán-Nava et al. (2010) utvrdili su da čak i kontinuirano uklanjanje panjeva tokom nekoliko godina nije dovelo do trajnog suzbijanja populacije. Kombinacija mehaničkih i hemijskih tretmana nije značajno smanjila broj novih izdanaka u petogodišnjem periodu, ali je dovela do redukcije biomase, visine i broja listova preostalih jedinki (DiTomaso and Kyser, 2007; Constán-Nava et al., 2010). Kako bi se povećala efikasnost eradikacije *A. altissima* i smanjila njena kompetitivna prednost u ekosistemu, Constán-Nava et al. (2010) preporučuju strategiju integrisanog pristupa, koja obuhvata kombinovanu primenu sečenja panjeva, tretiranja herbicidima (glifosat) i pošumljavanja autohtonim vrstama u okviru programa ekološke restauracije. Očekuje se da bi ovakva multifaktorijalna strategija smanjila sposobnost invazivne vrste da kolonizuje obnovljene ekosisteme, istovremeno podstičući regeneraciju autohtone vegetacije i dugoročnu ekološku stabilnost područja (DiTomaso and Kyser, 2007; Constán-Nava et al., 2010). Pored mehaničkih i hemijskih metoda suzbijanja, biološka kontrola predstavlja potencijalno održivo rešenje za regulaciju populacije *A. altissima*. Istraživanja ukazuju da grinje iz roda *Aculus* spp., specijalizovani fitofagni organizmi koji se hrane listovima *A. altissima*, mogu imati značajnu ulogu u biološkoj kontroli ove invazivne vrste (Marini et al., 2021; Skvarla et al., 2021; De Lillo et al., 2022; Kashefi et al., 2022). Takođe, kornjaši *Eucryptorrhynchus brandti* i *Eucryptorrhynchus chinensis* pokazali su visok stepen preferencije prema *A. altissima* u odnosu na druge biljne vrste (Ding i et al., 2006). Gljive igraju ključnu ulogu u biološkoj kontroli *A. altissima*, pri čemu su određeni patogeni iz rodova *Verticillium, Alternaria i Cercospora* pokazali visok potencijal u suzbijanjuove invazivne vrste (Ding et al., 2006).

Suzbijanje *A. altissima* zahteva multifaktorijalni pristup koji uključuje kombinaciju hemijskih, mehaničkih i bioloških metoda. Iako su hemijski tretmani, prvenstveno primena herbicida, najefikasniji način kontrole, njihova primena mora biti pažljivo planirana i prilagođena prečniku stabala, vrsti tretmana i koncentraciji aktivnog sastojka kako bi se postigli optimalni rezultati. Mehaničke metode, poput sečenja stabala i uklanjanja panjeva, imaju ograničenu efikasnost kada se koriste samostalno, jer *A. altissima* poseduje snažnu sposobnost ponovne regeneracije putem adventivnih izdanaka. S druge strane, biološka kontrola, koja podrazumeva korišćenje prirodnih neprijatelja poput insekata i patogenih gljiva, predstavlja dugoročno održivo rešenje koje može doprineti značajnom smanjenju populacije ove vrste. Stoga je integrisana strategija suzbijanja važna za očuvanje ekološke stabilnosti i zaštitu autohtonih ekosistema, jer omogućava kombinovanje različitih metoda radi povećanja njihove efikasnosti i smanjenja negativnog uticaja na životnu sredinu. Dalja istraživanja biološke kontrole i integrisanih metoda suzbijanja *A. altissima* su neophodna kako bi se razvile efikasne, ekološki prihvatljive i dugoročno održive strategije.

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***Ailanthus altissima*: an invasive species in modern ecosystems**

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Abstract

Ailanthus altissima is an invasive woody species native to China and northern Vietnam, which has spread to all continents except Antarctica. Due to its rapid growth, intensive vegetative and generative reproduction, and resistance to unfavourable conditions, it poses a serious ecological and economic problem. The spread of this species threatens natural habitats by displacing native species and disrupting ecological balance, while in urban areas, it can cause infrastructural damage. Its control is complicated by its ability to regenerate through root suckers and the high production of seeds that can be dispersed over long distances by wind. Current control approaches mainly rely on chemical treatments by injecting herbicides into the trunk, but none of these methods are entirely effective. Mechanical removal is also used but often leads to even more vigorous growth. Research on biological control methods, including the use of specialized pathogens and herbivores, has yet to yield definitive results. Given the negative ecological and economic consequences, continuous monitoring of this species' populations and the implementation of integrated control measures are necessary. An effective control strategy requires a combination of chemical, mechanical, and biological methods, along with raising public awareness of the importance of timely action to limit its further spread.

Key words: *Ailanthus altissima*, invasive species, ecological impact, suppression

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Antibacterial activity of plant essential oils and possibilities of application as biopesticides in plant production

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Abstract

Pathogenic microorganisms, primarily bacteria and fungi, cause plant diseases, which lead to a significant loss of plant yields. For a long time, efforts have been made to reduce the loss of plant yields, primarily with the use of chemical agents for plant protection, but also with the selection of strains resistant to phytopathogens and other pests. However, the intensive use of chemical agents in crop production leads to environmental pollution and threats to food safety. For the above reasons, the application of biological preparations (biopesticides) is recommended as an environmentally acceptable way of managing plant diseases and the environment. The aim of this paper is to describe the antibacterial activity of the essential oils (EOs) of plants and the possibilities of their application as natural biopesticides in crop production, by reviewing the scientific literature and research. The applicable literature was analysed in this review paper. The results of numerous *in vitro* and *in vivo* scientific studies indicate that the essential oils of plants exhibit strong antibacterial effects on phytopathogenic bacteria, the causative agents of plant diseases, as well as that they can be successfully used in plant production.

Keywords: essential oils, antibacterial activity, phytopathogenic bacteria, biological preparations, environmental pollution, food safety.

Introduction

In crop production, biopesticides can supress phytopathogenic organisms (bacteria and fungi) and plant pests without adversely affecting agroecosystems. Until the discovery of biopesticides, the control of phytopathogens and pests in plant production depended almost exclusively on chemical pesticides, which caused environmental pollution. Nevertheless, numerous scientific evidences appeared on the resistance of pests and weeds to pesticides in crops (Đukić et al., 2007; Marinković and Marinković, 2012; Golijan Pantović et al., 2023). The biological methods are based on the use of natural enemies against pests such as bacteria, fungi and nematodes. Biopesticides provide an environmentally friendly way to manage plant diseases and represent one of the most significant discoveries in biotechnology, which is used in the production of health-safe food. Also, they have significant potential to replace or reduce the use of chemical pesticides and the costs of their production. A significant number of products based on plant essential oils are available on the market, which are used in plant protection as fungicides, herbicides, and exhibit strong antibacterial activity against phytopathogenic bacteria. Phytopathogenic bacteria, the causative agents of plant diseases, are one of the most significant factors affecting the reduction of crop yields. Plant pathogenic bacteria (PPB) are important plant pathogens widely spread all over the world and it is estimated that approximately 150 species are responsible for different plant diseases (Đukić et al., 2007; Aguilar-Marcelino et al., 2020; Golijan and Sečanski, 2021; 2022; Šarčević-Todosijević et al., 2022; Golijan Pantović et al., 2023).

Essential oils are specific plant products, usually in a liquid state, that contain complex mixtures of volatile compounds - most often monoterpenes, sesquiterpenes and phenylpropane compounds. Monoterpenes and sesquiterpenes are classes of compounds from the terpene group, characterized by the number of isoprene units that make them up: monoterpenes consist of two isoprene units, while sesquiterpenes consist of three isoprene units. Both groups of compounds are widely represented in nature, especially in plants, and are known for their diverse biological activities and roles in ecosystems. Phenylpropane compounds are compounds containing a phenyl ring bonded to propene, more specifically those with an allyl group bonded to a benzene ring, having the parent structure of allylbenzene (Kovačević, 2004; Inamuddin et al., 2023).

The most common way to obtain essential oils is steam distillation, while for citrus fruits, pressing of fresh plant tissue is often used. Essential oils can be further processed to separate the individual ingredients. These oils are mainly obtained from vascular plants, especially rich aromatic plants from families such as: Asteraceae, Lamiaceae, Apiaceae, Rutaceae, Myrtaceae and Lauraceae. Aromatic plants contain volatile oils that give off pleasant scents when touched or crushed. They're used in cooking, perfumes, herbal remedies, and their scents can also act as a natural defense mechanism against herbivores. Essential oils are found in different parts of the plant: in flowers (chamomile), leaves (mint, lemon balm), tree bark (cinnamon, sandalwood, juniper), root (parsley), rhizome (iris), fruits (anise, citrus), seeds (walnut). Different parts of the same plant can contain oils that are similar in composition, but also significantly different. Most aromatic plant raw materials (drugs) contain less than 1% essential oil, but there are exceptions - for example, clove bud contains over 15% oil. Essential oils are produced in the plant secretory tissues. Plant secretory tissues, responsible for producing and releasing various substances, are broadly categorized into two main types: external (exogenous) and internal (endogenous). Sometimes these cells are organized into special structures, such as glands and glandular hairs, which are found on the surface of plants, especially in the Asteraceae and Lamiaceae families. Glandular hairs, also known as trichomes, are epidermal outgrowths in plants that secrete or absorb substances, with the two main types being peltate and capitate hairs, distinguished primarily by the morphology of their secretory head (Kovačević, 2004; Šarčević-Todosijević et al., 2019a).

The aim of this manuscript is to review the scientific literature and point to plant species as potential sources of compounds, primarily essential oils, with pronounced antimicrobial effects on phytopathogenic bacteria.

Materials and Methods

The data analysis method was applied in the manuscript. The data were collected from previous scientific studies. The research within present manuscript is theoretical and overview character and uses data and research from relevant journals, textbooks, monographs, and original and review scientific papers published in scientific journals and at scientific conferences.

Results and Discussion

Biopesticides used in the treatment of plant diseases are obtained from organisms originating from natural ecosystems, as well as products of their life activity. They include microorganisms and products of their metabolic activity, essential oils and other plant extracts, products of secondary plant metabolism. The first microbial biopesticides used were strains of *Bacillus thuringiensis*. Each strain of this bacterium produces a different mixture of proteins and specifically kills one or a few related species of insect larvae. For target insect species, a specific strain of *B. thuringiensis* produces a protein that causes the mortality of individual insects (Đukić et al., 2007; Marinković and Marinković, 2012). Biological plant protection products can also be pesticide substances produced by transgenic plants based on genetic material inserted into a given plant using genetic engineering techniques. For example, researchers have inserted a gene from the *B. thuringiensis*, which codes for a pesticide protein, into the genetic material of a plant, so that the transgenic plant produces this protein that is lethal to some insects species (Đukić et al., 2007; Šarčević-Todosijević et al., 2019a; Filipović et al., 2021).

Many authors (Džidić-Uzelac, 2014; Popović et al., 2019; Popović et al., 2021; Šarčević-Todosijević et al., 2019a) state the importance of allelopathy as a biological phenomenonin which a particular organism produces one or more metabolites that regulate ecological relationships in a given ecosystem, affecting the germination, growth, survival and reproduction of other organisms. Plants with allelopathic effects can be used as bioherbicides, growth regulators and the basis for the synthesis of new herbicidal preparations. Extracts of the plant species *Sorghum bicolor* exhibit inhibitory effects on many weed species in various crops such as wheat, cotton and sunflower (Kandhro et al., 2015; Bošković, 2021). These metabolites may have beneficial or harmful effects on target organisms and members of biocenoses. Allelochemicals are products of secondary metabolism, which are not necessary for the basic life processes of an allelopathic organism, but provide it with a competitive advantage, since they regulate ecological relationships in ecosystems. Among these compounds, alkaloids, heterosides, saponosides, terpenes or aromatic compounds (essential oils) exhibit significant biological activity. Essential oils belong to the group of secondary plant metabolites, i.e. allelopathic substances, which organic agriculture successfully uses to protect plant crops from certain phytopathogens and pests (Kovačević, 2004; Šarčević-Todosijević et al., 2019a). A protective effect is also achieved by planting aromatic plants near crops (Džidić-Uzelac, 2014; Popović et al., 2019; Popović et al., 2021; Šarčević-Todosijević et al., 2019a; Bošković, 2021; Šarčević-Todosijević et al., 2023; Filipović et al., 2023).

According to numerous studies (Đukić et al., 2007; Filipović et al., 2021, 2023; Golijan Pantović et al., 2023) phytopathogenic fungi lead to a significant decrease in crop yields. A review of the literature has shown that essential oils and compounds based on essential oils inhibit the growth of mycelium of a large number of phytopathogenic fungi. Kiniec et al. (2024) tested essential oils (EOs) from grapefruit, rosemary, pine, sage, and thyme against *Cercospora beticola*, the main sugar beet pathogen. Thyme (*Thymus vulgaris*) EO showed the strongest antifungal activity, with a minimum inhibitory concentration (MIC) of 0.313 mL/L for most fungal isolates, including multi-resistant ones. Field tests confirmed its effectiveness. The findings suggest thyme EO is a promising, eco-friendly option for managing *C. beticola*. Carta et al. (1996) reported the fungicidal effect of *Salvia officinalis* essential oil against *Botrytis cinerea*. Arras and Usai (2001) determined strong fungicidal effect of *Thymus vulgaris* on *Alternaria citri* by affecting spore germination. Lee et al. (2007) confirmed the antifungal effect of 39 essential oils on the growth of mycelium of *Botrytis cinerea*, *Colletotrichum gloeosporioides*, *Fusarium oxysporum*, *Pythium ultimum* and *Rhizoctonia solani*. In the research of Gaber et al. (2025) *Salvia officinalis* (sage) methanolic extract as a biocontrol agent was tested in laboratory (*in vitro*) and field (*in vivo*) conditions on four isolates of *Fusarium oxysporum* f. sp. *lycopersici*. It showed control of mycelial growth (up to 88.7%) and reduction of spore germination (up to 84.5%) at concentrations of 2.5–20 mg/ml, with significant reduction in disease severity on tomatoes. Molecular docking analyzes identified metabolites from the extract that target fungal enzymes such as tomatinase (Gaber et al., 2025). In addition to phytopathogenic fungi causing crop yield losses, a significant number of fungal species produce mycotoxins and affect food safety. Mycotoxins are secondary metabolites of fungi, and can cause numerous human and animal diseases, and even death. The species of the genus *Fusarium*, such as *F. verticillioides* and *F. proliferatum*, are the most important producers of the mycotoxin fumonisin B1, which is the most common contaminant of corn. *F. dlamini* and *F. anthophilum* may also be significant producers of fumonisin B1 (Nelson et al., 1992). The compound anethole isolated from the plant *Illicium verum* exhibits antifungal activity on the growth of mycelium of the fungi *Fusarium graminearum* and *Fusarium oxysporum* (Huang et al., 2010). *Foeniculum vulgare* essential oil, whose main component is also anethole, has an inhibitory effect on *Fusarium graminearum* and *Fusarium moniliforme* (Singh et al., 2006). *Rosmarinus officinalis* essential oil is used as an insecticide and broad-spectrum fungicide in plant production. Products containing essential oils of *Syzygium aromaticum* are used as herbicides, fungicides and germination inhibitors (Gorunović and Lukić, 2001; Hall and Fernandet, 2004).

The mechanism of antifungal action of essential oils is based on their effect on the fungal cell membrane, i.e. the destruction of the cell structure, which leads to cell death, as well as the inhibition of spore germination, mycelium growth and cellular respiration (Madigan et al., 1997; Harris, 2002).
About 350 bacteria, which are pathovars or subspecies belonging to the phyla Proteobacteria, Actinobacteria, and Firmicutes, are known to be phytopathogenic (Leonard et al., 2017). Studying the effects of essential oils (EOs) on morphology of bacteria improves understanding of potential mechanisms of action. Plant secondary metabolites, including essential oils, inhibit bacterial growth by various mechanisms. There are five basic mechanisms of action of the natural product on the bacterial cell, namely: disintegration of the cell wall, destabilization of the passage of protons through the cell membrane, prevention of electron flow, prevention of active transport and coagulation of cell contents (Sikkema et al., 1995; Šarčević-Todosijević et al., 2019b). Among antibacterial substances of plant origin, as emphasized, essential oils stand out, which are traditionally used as a natural alternative to chemical biocides and antibiotics (Sikkema et al., 1995; Madigan et al., 1997; Šarčević-Todosijević et al., 2019b).

The main constituents of the mastic-leaf prickly ash essential oil are linalool (28.2%), limonene (13.2%), and sabinene (12.1%). The antibacterial activity of this essential oil can be a result of the increased permeability of cell membranes, and the leakage of intracellular constituents. The susceptibility of tested Gram-positive bacteria was greater than that of Gram-negative bacteria (Diao et al., 2013).

Table 1. presents the summary of antibacterial activity of EOs extracted from different plants. In their study, authors Erkan et al. (2012) compared antibacterial activities of EO extracted from leaves of curry leaf tree (*Murraya koenigii* L., Rutaceae) against the bacterium *Listeria innocua* by two methods: solvent-free microwave extraction (SFME) and the conventional hydro-distilled oil (HD). The main constituents of EO obtained by SFME were α-copaene (44.3%), β-gurjunene (25.5%), isocaryophyllene (12.1%), β-caryophyllene (8.7%) and germacrene D (2.9%). DPPH radical scavenging activities of EOs recorded by both methods were relatively low (10-24%). Absolute inhibition of the *Listeria innocua* growth was observed with SFME EO at 400 μg/mL (minimum

inhibitory concentration) and HD EO at 600 µg/mL. Li et al. (2019) stated that EO extracted from fingered citron (*Citrus medica* L. var. *sarcodactylis*) exhibited moderate antibacterial activity against bacterial strains *Escherichia coli, Staphylococcus aureus, Bacillus subtilis* and *Micrococcus luteus* using *in vitro* antibacterial tests. The higher the concentration and exposure time of EO, the more seriously the morphology of the tested bacteria was altered and damaged. EO significantly reduced the growth rate of surviving bacteria and led to the cellular disruption. The intracellular material leaked, and consequently cells died (Li et al., 2019).

Table 1. Summary of antibacterial activity of EOs from different plants

Essential oil from plant species	**Target bacteria**	**Effect of essential oils on target bacteria**	**References**
Thymbra spicata L. var. *spicata*	*Erwinia amylovora*$^{(-)}$ *Erwinia carotovora* pv. *carotovora*$^{(-)}$ *Clavibacter michiganensis* subsp. *michiganensis*$^{(+)}$ *Pseudomonas syringae* pv. *syringae, tumefaciens*$^{(-),}$ *Xanthomonas axonopodis* pv. *vesicatoria*$^{(-)}$	significant antibacterial activity	Basim et al. (2000)[a]
Origanum vulgare	*Staphylococcus aureus*$^{(+)}$ *Pseudomonas aeruginosa*$^{(-)}$	strong antibacterial effect	Lambert et al. (2001)[a]
Rosa damascene	*Xanthomonas axonopodis* spp. *vesicatoria*$^{(-)}$	significant antibacterial activity	Basim and Basim (2003)[a]
Coriandrum sativum *Foeniculum vulgare* var. *vulgare*	*Echerichia coli*$^{(-)}$ *Bacillus megaterium*$^{(+)}$	significant antibacterial activity	Lo Cantore et al. (2004)[a]
Cuminum cyminum L. *Carum carvi* L.	*Escherichia coli*$^{(-)}$ *Pseudomonas syringae* pv. *phaseolicola*$^{(-)}$ *P. syringae* pv. *pisi*$^{(-)}$ *P. syringae pv. syringae*$^{(-)}$ *P. syringae* pv. *aptata*$^{(-)}$ *P. syringae pv. apii*$^{(-)}$ *P. syringae* pv. *atrofaciens*$^{(-)}$ *P. syringae pv. lachrymans*$^{(-)}$ *P. syringae* pv. *maculicola*$^{(-)}$ *P. syringae* pv. *tomato*$^{(-)}$ *P. syringae pv. glycinea*$^{(-)}$ *P. cichorii*$^{(-)}$ *P. viridiflava*$^{(-)}$ *P. corrugate*$^{(-)}$ *P. tolaasii*$^{(-)}$ *P. reactans*$^{(-)}$ *P. agarici*$^{(-)}$ *Erwinia carotovora* subsp.	significant antibacterial activity	Iacobellis et al. (2005)[a]

	carotovora(-) *E. carotovora* subsp. *atroseptica*(-) *E. herbicola*(-) *Agrobacterium tumefaciens*(-) *Burkholderia gladioli* pv. *agaricicola*(-) *Ralstonia solanacearum*(-) *Xanthomonas campestris* pv. *phaseoli*(-) *X. campestris* pv. *phaseoli var. fuscans*(-) *X. campestris* pv. *vesicatoria* *X. campestris* pv. *campestris*(-) *Bacillus megaterium*(+) *Clavibacter michiganensis* subsp. *michiganensis*(+) *C. michiganensis* subsp. *sepedonicus*(+) *Curtobacterium flaccumfaciens pv. flaccumfaciens*(+) *C. flaccumfaciens* pv. *betae*(+) *Rhodococcus fascians*(+)		
Origanum vulgare L. *Acorus calamus* L. *Achillea millefolium* L. *A. filipendulina* L. *A. cartilaginea* L. *Carum carvi* L. *Mentha x piperita* L.	*Erwinia carotovora* subsp. *carotovora 1122*(-) *Xanthomonas vesicatoria 67*(-) *Psudomonas marginalis* pv. *marginalis 1763*(-) *P. syringae* pv. *syringae 1139*(-) *P. syringae* pv. *syringae 1*(-) *P. syringae* pv. *tomato 506*(-) *Bacillus* sp. *1044*(+)	significant effectiveness in inhibiting the growth of phytopathogenic bacteria, essential oils rich in phenolic compounds (thymol and carvacrol) are particularly effective	Vasinauskiene et al. (2006)[a]
Matricaria chamommilla *Mentha piperita* *M. spicata* *Lavandula angustifolia* *Ocimum basilicum* *Thymus vulgaris* *Origanum vulgare* *Salvia officinalis* *Citrus limon* *C. aurantium*	*Pseudomonas tolaasii*(-)	the greatest and widest activity was expressed by the oregano EO, while carvacrol had the highest antifungal activity	Soković and van Griensven (2006)[a]
Daucus carota sativa	*Staphylococcus aureus*(+)	moderate to strong antimicrobial activity	Imamu et al. (2007)[a]
Components of some essential oils,	*Escherichia coli*(-) *Pseudomonas syringae* pv.	considerable antibacterial	Lo Cantore et al. (2009)[a]

terpenoids and phenylpropanoids, eugenol	*phaseolicola*$^{(-)}$ *P. syringae* pv. *pisi*$^{(-)}$ *P. syringae* pv. *syringae*$^{(-)}$ *P. syringae* pv. *apii*$^{(-)}$ *P. syringae* pv. *atrofaciens*$^{(-)}$ *P. syringae* pv. *lachrymans*$^{(-)}$ *P. syringae* pv. *maculicola*$^{(-)}$ *P. syringae* pv. *tomato*$^{(-)}$ *P. syringae* pv. *glycinea*$^{(-)}$ *P. cichorii*$^{(-)}$ *P. viridiflava*$^{(-)}$ *P. corrugate*$^{(-)}$ *P. tolaasii*$^{(-)}$ *P. reactans*$^{(-)}$ *P. agarici*$^{(-)}$ *Erwinia carotovora* subsp. *atroseptica*$^{(-)}$ *Agrobacterium tumefaciens*$^{(-)}$ *Burkholderia gladioli* pv. *agaricicola*$^{(-)}$ *Ralstonia solanacearum*$^{(-)}$ *Xanthomonas campestris* pv. *phaseoli*$^{(-)}$ *X. campestris* pv. *phaseoli* var. *fuscans*$^{(-)}$ *X. campestris* pv. *vesicatoria*$^{(-)}$ *X. campestris* pv. *campestris*$^{(-)}$	activity was shown by terpenoid and phenylpropanoid derivatives containing phenol and alcohol functionalities, eugenol, a phenylpropanoid compound, demonstrated notable efficacy against *Xanthomonas campestris* pv. *phaseoli*	
Foeniculum vulgare Mill. var. *vulgare* *Anethum graveolens* L.	*Pseudomonas syringae* pv.*tomato*$^{(-)}$ *Erwinia carotovora* pv. *carotovora*$^{(-)}$ *Xanthomonas axonopodis* pv. *vesicatoria*$^{(-)}$ *Agrobacterium tumefaciens*$^{(-)}$ *Clavibacter michiganensis* subsp. *michiganensis*$^{(+)}$ *Listeria monocytogenes*$^{(+)}$ *Staphylococcus aureus*$^{(+)}$ *Escherichia coli*$^{(-)}$ *Salmonella enteritidis*$^{(-)}$ *Salmonella thyphimirium*$^{(-)}$	significant antibacterial activity, higher concentrations caused stronger bacterial growth inhibition	Soylu et al. (2009)[a]
Cymbopogon citrates *Mentha arvensis* *Mentha piperita* *Eucalyptus globules*	*Pseudomonas fluorescens*$^{(-)}$	significant bacterial growth inhibition	Tyagi and Malik (2010)[a]
Origanum vulgare L. *Thymus vulgaris* L. *Thymus serpyllum* L.	*Escherichia coli*$^{(-)}$ *Salmonella choleraesuis* $^{(-)}$ *Proteus mirabilis* *Staphylococcus aureus*$^{(+)}$ *Enterococcus faecalis*$^{(+)}$	significant antibacterial activity, high activity against Gram-positive bacteria	Lević et al. (2011)[a]
Murraya koenigii L.	*Listeria inocua*$^{(+)}$	absolute inhibition of the *Listeria innocua*	Erkan et al. (2012)[ab]

Eugenia caryophylata *Cinnamomum zelanicum* *Datura metel*	*Erwinia carotovora* (-)	strong antibacterial activity, *Datura metel* extract showed weaker activity	Al-Ani et al. (2012)[ab]
Satureja hortensis	*Clavibacter michiganensis* (+) *Pseudomonas syringae*(-)a *Xanthomonas axanopodis*(-) *Xanthomonas campestris*(-)	strong antibacterial activity	Kotan et al. (2013)[ab]
Zanthoxylum schinifolium	*Staphylococcus aureus*(+) *Staphylococcus epidermidis*(+) *Bacillus subtilis*(+) *Salmonella typhimurium*(-) *Pseudomonas aeruginosa*(-) *Shigella dysenteriae*(-) *Escherichia coli*(-)	significant antibacterial activity, the susceptibility of tested Gram-positive bacteria was greater than that of Gram-negative bacteria	Diao et al. (2013)[a]
Eucalyptus globules	*Pseudomonas aeruginosa*(-)	significant antibacterial activity	Pereira et al. (2014)[a]
Thymus vulgaris *Origanum majorana*	*Pseudomonas aeruginosa*(-)	significant antibacterial activity, stronger than some antibiotics used in the study	El-Hosseiny et al. (2014)[a]
Teucrium polium	*Streptomyces scabies*(+) *Brenneria nigrifluens* (-) *Pantoea agglomerans*(-) *Rhizobium radiobacter*(-) *Rhizobium vitis*(-) *Xanthomonas campestris*(-) *Ralstonia solanacearum*(-)	significant antibacterial activity, higher oil concentrations resulted in stronger inhibition	Purnavab et al. (2015)[a]
Satureja hortensis *Calamintha nepeta*	*Agrobacterium tumefaciens*(-) *Bacillus pumilus*(+) *Clavibacter michiganensis* subsp. *michiganensis*(+) *Enterobacter intermedius*(-) *Erwinia caratovora* subsp. *caratovora*(-) *Erwinia chrysanthemi*(-) *Pseudomonas cichorii*(-) *Pseudomonas corrugate*(-) *Pseudomonas fluorescens*(-) *Pseudomonas syringae pv. syringae*(-) *Pseudomonas syringae pv. syringae*(-) *Pseudomonas syringae pv.*	significant antibacterial activity, greater activity of essential oils against Gram-positive bacteria	Gormez et al. (2015)[a]

	syringae(-) *Pseudomonas syringae pv. syringae*(-) *Pseudomonas syringae pv. phaseolicola*(-) *Pseudomonas syringae pv. pisi*(-) *Pseudomonas syringae pv.tabaci*(-) *Pseudomonas syringae pv. tomato*(-) *Ralstonia solanacearum*(-) *Xanthomonas axonopodis pv. campestris*(-) *Xanthomonas vesicatoria*(-)		
Allium sativum	*Rhodococcus fascians* (+) *Agrobacterium tumefaciens* (-) *Erwinia amylovora* (-)	garlic essential oils obtained by hydrodistillation and extraction with diethyl ether showed significant inhibition of bacterial growth	Soltan et al. (2016)[a]
Citrus aurantium *Citrus aurantifolia*	*Xanthomonas citri*(-)	significant antibacterial activity	Mirzaei-Najafgholi et al. (2017)[a]
Rosmarinus officinalis	*Staphylococcus aureus*(+) *Bacillus subtilis*(+) *Escherichia coli*(-) *Proteus vulgaris*(-) *Pseudomonas aeruginosa*(-) *Listeria monocytogenes*(+) *Salmonella enteritidis*(-) *Salmonella typhimurium*(-)	EOs and their components showed a higher antibacterial activity against Gram-positive bacteria than against Gram-negative bacteria	Stojiljkovic et al. (2018)[ab]
Citrus medica L. var. *sarcodactylis*	*Escherichia coli*(-) *Staphylococcus aureus*(+) *Bacillus subtilis*(+) *Micrococcus luteus*(+)	significant antibacterial activity, greater activity of essential oils against Gram-positive bacteria such as *S. aureus*	Li et al. (2019)[a]
Thymus vulgaris *Cymbopogon citratus*	*Solanum lycopersicum*(-)	significant antibacterial activity	Bagy et al. (2019)[ab]
Thymus vulgaris *Cymbopogon citrates* *Solanum torvum*	*Xanthomonas axanopodis*(-)	pronounced antibacterial effect, significant reduction of bacterial growth *in vitro*	Bagy et al. (2019)[ab]

Cynara cardunculus	*Pseudomonas syringae*(-) *Xanthomonas perforans*(-)	significant antibacterial activity	Scavo et al. (2019)[a]
Dysphania ambrosioides	*Pseudomonas syringae*(-)	significant antibacterial activity	Mohamed et al. (2019)[a]
Lantana camara	*Ralstonia solanacearum*(-)	strong biological effects, limonene showed the strongest effect	Mohamed et al. (2019)[a]
Eriocephalus africanus	*Agrobacterium tumefaciens* (-) *Dickeya solani* (-) *Erwinia amylovora* (-) *Pseudomonas cichorii*(-)	bacteriostatic or bactericidal effects, the strongest effect was observed against *D. solani*	Behiry et al. (2020)[a]
Cinnamomum verum	*Agrobacterium tumefaciens* (-)	membrane disruption and bacterial death	Lee at al. (2020)[a]
Pinus halepensis	*Agrobacterium tumefaciens* (-) *Dickeya solani* (-) *Ralstonia solanacearum*(-) *Pectobacterium atrosepticum*(-)	ferulic and tannic acids showed strong antibacterial effects, especially against *Dickeya solani*	Ashmawy et al. (2020)[a]
Dysphania ambrosioides	*Agrobacterium tumefaciens* (-) *Erwinia amylovora* (-)	strong *in vitro* antibacterial activity against *Erwina amylovora* and moderate activity against *Agrobacterium tumefaciens*	Zefzoufi et al. (2020)[a]
Citharexylum spinosum *Bougainvilla spectabilis*	*Dickeya solani* (-)	strong antibacterial effects	Ashmawy et al. (2020)[a]
Bougainvilla spectabilis	*Pectobacterium carotovorum*(-)	weaker antibacterial activity	Ashmawy et al. (2020)[a]
Apium graveolens *Curcuma longa*	*Erwinia amylovora* (-)	strong antibacterial activity	Akhlaghi et al. (2020)[ab]
Origanum vulgare	*Erwinia rhapontici*(-) *Xanthomonas campestris*(-)	strong bactericidal action	Simirgiotis et al. (2020)[a]
Cinnamomum cassia	*Klebsiella pneumoniae*(-) *Serratia marcescens*(-)ab	cell membrane damage	Vasconcelos et al. (2020)[a]

		(evidenced by protein leakage) in *S. marcescens*, cell lysis	
Origanum vulgare *Allium sativum* *Ocimum basilicum* *Cinnamomum zeylanicum* *Syzygium aromaticum* *Thymus vulgaris*	*Clavibacter michiganensis* (+) *Ralstonia* sp. *Ralstonia solanacearum*(-)	strong antibacterial efficacy	Orzali et al. (2020)[ab]
Corymbia citriodora	*Ralstonia solanacearum*(-)	strong bacteriostatic activity	Tu et al. (2020)[a]
Tagetes patula *Solanum torvum*	*Ralstonia solanacearum*(-)	strong efficacy	Vanti et al. (2020)[a]
Thymbra spicata *Thymus serpyllum* *Origanum syriacum*	*Rhizobium radiobacter*(-)	strong antibacterial activities	Bozkurt et al. (2020)[a]
Thymus serpyllum *Origanum syriacum*	*Pseudomonas savastanoi*(-)	strong antibacterial activities	Bozkurt et al. (2020)[a]
Tagetes patula	*Ralstonia solanacearum*(-)	strong antibacterial properties	Villada-Ramos et al. (2021)[a]

[a] *in vitro* study; [b] *in vivo* study; [ab] both *in vitro* and *in vivo* study; (+) Gram positive bacterium, (-) Gram negative bacterium

Turgis et al. (2009) observed antimicrobial activity of mustard EO against bacteria *Escherichia coli* O157: H7 and *Salmonella typhi.* Results indicated that mustard EO damaged bacterial cell membranes of *E. coli* and *S. typhi*, where the loss of cellular structures was essential for the survival of bacteria, as the treatment resulted in the reduction of both ATP concentration and intracellular pH. The membrane and cell wall disintegrated as a direct effect of the reduction in ATP production at the cell membrane. According to the study of Helander et al. (1998) regarding the activities of selected constituents of EOs (carvacrol, (+)-carvone, thymol, and trans-cinnamaldehyde) against bacteria *E. coli* O157:H7 and *S. typhimurium*, it was reported that carvacrol and thymol decreased the intracellular ATP concentration of E. coli and also increased extracellular ATP, indicating disruptive action on the cytoplasmic membrane. Oregano EO predominantly includes two main components, thymol and carvacrol, and their mixture can cause inhibition action against the two following bacteria: *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Lambert at al., 2001). According to Lo Cantore et al., (2004) EOs of cilantro (*Coriandrum sativum*) and fennel (*Foeniculum vulgare* var. *vulgare*) could be used as efficient natural bactericides in protection against bacterial diseases of plants and in seed treatments, especially, in organic agriculture. These authors studied *in vitro* antibacterial activity of EOs of these two plant species against bacteria *Escherichia coli* and *Bacillus megaterium* and 27 phytopathogenic bacterial species. Basim and Basim (2003) stated that the EO extracted from Damask rose (*Rosa damascena*) petals could be a useful control agent in the management of the disease caused by the bacterium *Xanthomonas axonopodis* spp. *vesicatoria* in tomato and pepper plants. Soković and van Griensven (2006) tested EOs of chamomile (*Matricaria chamomilla*), peppermint (*Mentha piperita*), German pepperming (*M. spicata*), English lavender (*Lavandula angustifolia*), basil (*Ocimum basilicum*), thyme (*Thymus vulgari*), oregano (*Origanum vulgare*), bsage (*Salvia officinalis*), lemon (*Citrus limon*), bitter orange (*C. aurantium*) and their components: linalyl acetate, linalool, limonene, α-pinene, β-pinene, 1,8-cineole, camphor, carvacrol, thymol and menthol for the inhibitory activity against the *Agaricus bisporus, Verticillium fungicola* and *Trichoderma harzianum* and the bacterium *Pseudomonas tolaasii*. The greatest and widest activity was expressed by the oregano EO, while carvacrol had the highest antifungal activity among the assayed compounds.

Akhlaghi et al. (2020) observed effects of plant EOs on the growth and virulence factors of pathogen *Erwinia amylovora* that caused fireblight, a contagious disease affecting primarilty plant members of the family Rosaceae. EOs of celery (*Apium graveolens*) seed and turmeric (*Curcuma longa*) demonstrated the greatest decrease in the impact of *E. amylovora* virulence factors. Celery seed and turmeric EOs reduced the disease development caused by *E. amylovora* on unripe pear fruits by 41.71 and 30.17%, respectively. The corresponding percentages in pear seedling amounted to 26.9 and 16.7%, respectively. Diao et al. (2013) indicated that fennel seeds EO disrupted membrane integrity, as a consequence of electrolyte leakage and the losses of protein and sugar contents of targeted bacteria. Rosemary EO, due to its health benefits, is very important for medicinal uses. It is characterised by its powerful antibacterial, cytotoxic, anti-mutagenic, antioxidant, anti-phlogistic and chemopreventive properties. For this reason, Stojiljkovic et al. (2018) observed antibacterial effects of rosemary EO on some Gram-positive and Gram-negative bacteria: *Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Proteus vulgaris, Pseudomonas aeruginosa, Listeria monocytogenes, Salmonella enteritidis, Salmonella typhimurium.* Rosemary EO mainly contained 1, 8-cineol, camphor, α-pinene, limonene, camphene and linalool. EOs and their components showed a higher antibacterial activity against Gram-positive bacteria than against Gram-negative bacteria regarding the effect on the bacteria cell wall. The cell wall of Gram-negative bacteria does not allow permeation of hydrophobic molecules as readily as the cell wall of Gram-positive bacteria. Generally, EOs are less able to affect the cell growth of the Gram-negative bacteria (Nazzaro et al., 2013).

Rosemary and clove EOs in combination exhibited significant inhibitory effect against the following Gram-positive and Gram-negative bacteria: *Staphylococcus aureus, Staphylococcus epidermidis, Bacillus subtilis, Escherichia coli, Proteus vulgaris* and *Pseudomonas aeruginosa*. The synergetic effect of this combination was observed when it was applied against the opportunic pathogenic yeast *Candida albicans*, but antagonistic effect was detected when it was applied against the fungus *Aspergillus niger* (Fu et al., 2007).

Bacteria secrete small signalling molecules to communicate with their external environment and with other bacteria of the same kind (cell-cell communication - *quorum sensing*). These chemical signal molecules are called autoinducers. The Gram negative bacteria use small molecules such as acyl homoserine lactones (HSLs), whereas the Gram positive bacteria use larger peptide-based molecules (modified oligopeptides) (Madigan et al., 1997; Parsek and Greenberg, 2000). *Quorum sensing* (QS) is involved in biofilm production, motility, swarming, stress resistance and virulence (Faleiro, 2011). The EOs of rose, geranium, lavender, rosemary and clove appear to be very effective as QS inhibitors, while orange and juniper EOs seem to have no anti-QS properties (Khan et al., 2009; Szabó et al., 2010).

The formation of a biofilm is one of the mechanisms of EO activities on bacterial cells. Bacteria in dense populations form a biofilm matrix that protects individual bacterium within the biofilm from external stressors. The formation of biofilms is one of the fundamental reasons for a failure of antimicrobial agents: 65-80% of infections are considered to be related to the formation of biofilms (Coenye and Nelis, 2010). By studying the effects of EOs extracted from several species of oregano on respiratory pathogens, Piasecki et al. (2023) found out that biofilms of bacteria *Haemophilus influenzae* and *Haemophilus parainfluenzae* showed an obvious reduction in the occurrence of bacterial clusters due to the action of marjoram EO. The clove EO showed potential anti-*quorum sensing* activity. *Quorum sensing* takes part in the formation of bacterial biofilm through the intercellular chemical signalling mechanism used for monitoring cell density. Biofilms need an adequate density to induce the QS signal accumulation that will regulate gene expression. Many QS activated genes are beneficial for the biofilm formation and secretion of proteases, siderophores, and toxins (Gerdt and Blackwell, 2014).

Volatile organic compounds, for instance the ones formed by the rhizospheric bacteria *Pseudomonas fluorescens* B-4117 and *Serratia plymuthica* IC1270, can inhibit the cell-cell communication by acyl homoserine lactones (AHLs) signalling molecules produced by different bacteria (*Agrobacterium*, *Chromobacterium*, *Pectobacterium* and *Pseudomonas*) and be involved in bacterial QS. Tyagi and Malik (2010) studied the antibacterial activity of lemon grass, common mint, peppermint and eucalyptus EOs (in liquid as well as in vapour phases) and negative air ions (NAI) against the bacterium *Pseudomonas fluorescens*. The bacterium was exposed to lemon grass oil vapour, negative air ions and their combination for four hours. Combined effect in eliminating bacterium was greater (91.8%) than the elimination rate achieved by lemon grass oil vapour alone (72%) or negative air ions alone (50.9%).

It was observed that the pH homeostasis might weakened by the action of EOs on the membrane that becomes incapable to block protons. According to Ultee et al. (1999), the exposure of the foodborne pathogen *Bacillus cereus* cells to carvacrol (0.25 mM to 0.5 mM) reduced the pH gradient, while the pH gradient was totally lost at the carvacrol concentration of 1 mM or higher.

Conclusion

Pesticides and mineral fertilizers, which are intensively used in the protection and fertilization of plants in agricultural production, cause pollution of all components of the environment and negatively affect food safety. Biopesticides and microbiological fertilizers are an alternative to chemical synthetic preparations and involve the use of plants, beneficial microorganisms, or products of their metabolism in plant protection. The most important products of plant secondary metabolism, which have been used since ancient times as biological agents in the protection of plants, are essential oils. *In vitro* and *in vivo* studies showed antimicrobial and pesticidal effects of essential oils.

The results of numerous scientific studies indicate that these compounds can be successfully used in the ecologically acceptable protection of plant crops from phytopathogens. In addition to increasing crop yields, the use of essential oils as biopesticides in crop production contributes significantly to the production of healthy food and environmental protection.

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Antibakterijska aktivnost etarskih ulja biljaka i mogućnosti primene kao biopesticida u biljnoj proizvodnji

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Izvod

Patogeni mikroorganizmi, prvenstveno bakterije i gljive, uzrokuju biljne bolesti, koje dovode do značajanog gubitka biljnih prinosa. Već dugo se čine napori da se smanje gubici biljnih prinosa, najčešće primenom hemijskih sredstava za zaštitu bilja, ali i selekcijom sojeva otpornih prema fitopatogenima i ostalim štetočinama. Međutim, intenzivna primena hemijskih sredstava u biljnoj proizvodnji dovodi do zagađenja životne sredine i ugrožavanja zdravstvene bezbednosti hrane. Iz navedenih razloga, preporučuje se primena bioloških preparata (biopesticida), kao ekološki prihvatljivog načina upravljanja biljnim bolestima i životnom sredinom. Cilj ovog rada je da se, uvidom u naučnu literaturu i istraživanja, opiše antibakterijska aktivnost etarskih ulja biljaka i mogućnosti njihove primene kao biopesticida u biljnoj proizvodnji. U ovom preglednom radu, analizirana je dostupna literatura. Rezultati brojnih sprovedenih *in vitro* i *in vivo* naučnih istraživanja ukazuju da etarska ulja biljaka ispoljavaju snažne antibakterijske efekte na fitopatogene bakterije, uzročnike biljnih bolesti, kao i da se mogu uspešno koristiti u biljnoj proizvodnji.

Ključne reči: etarska ulja, antibakterijska aktivnost, fitopatogene bakterije, bipreparati, zagađenje životne sredine, bezbednost hrane.

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