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ALLELOPATHIC PROPERTIES OF HEMP

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SUMMARY

Allelopathic effects of different plant allelochemicals have become the focus of studies that aim to determine new pesticidal compounds. Plant extracts with different chemical compositions can be obtained using different methods of extraction, whereas studies dealing with allelopathic properties use biotests to obtain fast and precise results. Such studies were undertaken after noticing the allelopathic effects of industrial hemp (Cannabis sativa L.) on the surrounding crops. Trials that involve the application of hemp extracts obtained by different methods resulted in determining the hemp allelopathic effects on Stellaria media (L.)Scop., Beta vulgaris ssp. vulgaris var. vulgaris, Lupinus albus L., corn (Zea mays L.), Cyperus rotundus L., Matricaria recutita L., Lepidium sativum L., lettuce (Lactuca sativa L.), rapeseed (Brassica napus L.), wheat (Triticum aestivum L.), rye (Secale cereal M. Bieb.), Ambrosia artemisiifolia L., Chenopodium album L., and Sorghum halepense L..

Key words: *hemp, allelopathy, allelochemicals, bioherbicides*

INTRODUCTION

Recent studies have shown an increasing interest in allelopathic properties of various plant species, which can be used for determining novel pesticides in organic agriculture.
The cultivation of *Cannabis sativa* L. has demonstrated that the habitus and allelopathic properties of hemp can facilitate weed control and improve the soil structure (Berenji et al., 2001; Poisa, 2010). Hemp naturally grows in the vicinity of roads, plots, and landfills. It is also found in perennial plantations of field crops, vegetables, and forage plants (Vrbničanin, 2015). The effects of hemp on other weed species, as well as the emergence of hemp in other crop plantations, emphasized the need for investigating the hemp allelopathic effects on weed species and other cultivated crops. Future studies of hemp effects on the surrounding vegetation can facilitate the development of new pesticides.

THE HISTORY OF HEMP

Hemp is one of the first domesticated plant species (Koren et al., 2020). Originally from Central Asia, hemp was brought to East and South Asia, and Western Europe, while wild hemp populations adapted to various climate conditions (Clarke & Merlin, 2013).

Hemp can be cultivated at different altitudes and under various climate and soil conditions (Ivonyi et al., 1997). During the 1880s, the global hemp growing area amounted to 392,000 ha. The largest world hemp producers were the SSSR (126,000 ha), Asia (162,000 ha) (with India as its largest producer), and Europe (90,000 ha) (with Romania, Hungary, Poland, Italy, and Yugoslavia (the SFRY) as the largest European producers) (Jevtić et al., 1986). The increased production of synthetic fibre and cheap plant fiber (jute, kenaf, and sisal) is associated with a decline in hemp cultivation. The hemp cultivation in Yugoslavia reached its peak in 1949 with 100,000 ha devoted to hemp production, decreasing thereafter to 47,000-39,000 (1963-1967) and 18,000-12,000 ha (1970-1972) (Berenji et al., 2001). Hemp was mainly grown in Vojvodina (65.75%), as well as near Leskovac and Vranje (Jevtić et al., 1986).

The Official Gazette of SFRY confirmed the ratification of The Single Convention on Narcotic Drugs in 1964, wherein the term “cannabis plant” referred to all species of the Cannabis genus without exception. This important industrial raw material was thereby reduced to an illegal drug, thus significantly diminishing its cultivation area. Processed hemp fiber had been an important export material until 1969. However, hemp production expenditure became greater than the profit generated in the following years, which gave rise to the import of hemp fiber so as to satisfy the needs of the domestic processing industry. The lack of raw materials for the processing industry led to a significant reduction in the number of hemp processing capacities (Sikora et al., 2017).

Hemp production is important for several reasons. The existing agroecological conditions in Serbia are suitable for growing good quality hemp. However, the production capacity of the domestic hemp processing industry is significantly reduced due to complexities stemming from the import of natural hemp fibers. Therefore, the need for domestic hemp production is growing, which would provide sufficient amounts of raw material for the processing industry (Berenji et al., 2001).

Hemp can be grown on soils contaminated with heavy metals. It is irreplaceable in crop rotation under organic farming conditions. As a fast-growing species, it has an average growth of 50 cm a month. With its habitus and allelopathic relationships, hemp has the ability to combat weeds and improve the soil structure of its cultivation areas (Poisa, 2010).

CONTEMPORARY HEMP PRODUCTION

Different parts of industrial hemp plants are used as raw materials in the production of about 25,000 products. Hemp cultivation involves the utilization of hemp biomass for bast fiber or hurd production. Hemp inflorescence and leaves are used as raw materials in the pharmaceutical and cosmetic industries, whereas hemp seeds are used for the production of edible oil (Johnson, 2014).

Industrial hemp is cultivated as a source of fiber with medium to high tensile strength. Up to 50% of hemp fiber products are used for the fishing industry, sea and river fleets, construction, shipbuilding, and the oil industry (Bouloc, 2013). Owing to its hydrophilic properties, hemp fibre is an important raw material in the textile and leather industries. Long fibers are used for cordage, fishing nets, ship ropes, tarpaulins, horse equipment, and military equipment, whereas short fibers are used for producing ropes, packing yarns, core ropes, cable yarns, etc. Fibres of male plants are suitable for making fabrics because they are soft, strong and of similar quality to flax fiber. Fibers obtained from female plants are coarse, firm and used for making cordage. Harvested before maturity, hemp fibers are soft, thin and strong (similar to flax). Despite an increasing number of synthetic fibers in the market, hemp fibers have not decreased in value. Hemp has a high hurd content, yielding significantly more hurds per 1 ha than woody plant species in a year. Annual hurd yields obtained from pine forests approximate to 2.5 m^3/ha, whereas annual hemp hurd yields approximate to 10-20 m^3/ha (Jevtić et al., 1986). Hurds are used for synthetic fibre production, paper and construction material. Hurds make up around 65% of the stem weight. Hurds are used as raw materials in the chemical industry and for the production of thermoisolation materials in the construction industry (Bouloc, 2013).

Hemp can be used as livestock feed or as an energy source (namely biogas, biodiesel or solid fuels). Hemp seeds are used for vegetable oil and oil cake production, as well as for medicinal purposes. Seeds contain up to 30% oil, which can be separated mechanically (Leonard et al., 2019). Refined hemp oil corresponds in colour and taste to oils of the highest quality and can be used in the food industry. Hemp oil belongs to the group of fast-absorbing oils. The unsaturated fatty acid content of hemp oil makes it useful in the production of varnishes and oil paints. Hemp seeds are also used as bird feed. The use of hemp seed as animal feed results in increased egg production and lower disease incidence in chickens (Silversides & Lefrancois, 2010). About 65 kg of oil cake can be obtained from 100 kg hemp seeds. The feed value of 1 kg of these cakes corresponds to the feed value of 2.5 kg of potatoes, 4.9 kg of sugar beet head and leaf silage, and 4.5 kg of corn stalk silage. According to the content of easily digestible proteins, it corresponds to the value of 2.85 kg of oats, 3 kg of barley, 3.2 kg of corn, 25.3 kg of potatoes, and 25.3 kg of corn stalk silage (Jevtić et al., 1986).

Industrial hemp can be used in biofuel production for briquettes and pellets, and as biomass for biogas production. Seeds can also be used to obtain biodiesel from the oil it contains (Kolarikova et al., 2013). The energy value of hemp is 3,760 kcal/kg, slightly lower than the energy of coal (4,800 kcal/kg) and significantly higher than thermal energy of wood (2,700 kcal/kg). Hemp hurd ash can be used as a fertilizer because it contains 24% CaO, 4.85% P_2O_5, 6.3% K_2O (Poisa & Adamovis, 2011).

The world areas devoted to hemp cover 105,576 ha, while the largest producers are China, North Korea, Chile, France, Germany, and Great Britain. The hemp growing areas in Serbia approximate to 200 ha (Pejić et al., 2018).

THE CHEMICAL COMPOSITION OF HEMP

Hemp contains 483 chemical compounds: 60 cannabinoids and 140 terpenes (Brenneisen, 2007). The chemical composition of hemp varies significantly depending on environmental conditions. Cannabinoids and terpenes are protective substances which defend hemp plants from insects and plant diseases, thus significantly reducing the need for pesticide application in hemp plantations (Pate, 1994). As such, hemp is suitable for growing in organic production systems. The maturity and position of plant organs, plant gender, cultivated variety, phenophase, weather conditions, and sampling methods affect the content of cannabinoids in the hemp plant material.

Secondary metabolites of cannabis include cannabinoids, terpenoids, flavonoids, steroids, alkaloids, and lignans (Janatova et al., 2018). Phytocannabinoids are a group of cannabinoids that are synthesized in the form of resin in the glandular hairs of industrial hemp. The most common cannabinoids are tetrahydrocannabinol (THC), cannabinol (CBN), cannabidiol (CBD), cannabichromen (CBC), and cannabigerol (CBG) (Drinić et al., 2018). In addition to cannabinoids, the resin also contains terpenes, which provide its characteristic odor.

The content of hemp essential oils depends on the hemp variety, plant gender, growing conditions, plant parts, harvesting time, drying conditions, and storage (Brenneisen, 2007). Hemp essential oils are obtained from the activity of endogenous or exogenous secretion plant tissues. The biological role of hemp essential oils is to attract insects for pollination purposes, inhibit germination of other plants, and protect the plant from herbivory insects and other pests. Hemp essential oils prevent overtranspiration and microorganism development, thus reducing the possibility of infections.

Hemp essential oils are composed of volatile substances and their chemical composition varies after the moment of harvesting (Meier & Mediavilla, 1998). Terpenes give hemp essential oils their characteristic scent. The predominant terpenes found in different hemp varieties are b-myrcene (46.1+/-2.6%), a-pinene (14.0+/-1.5%), and a-terpinolene (10.2+/-1.8%) (Casano et al., 2010).

Hemp stem is composed of the ‘bark’, i.e. the outer part of the stem outside the vascular cambium, and the ‘core’, i.e. the inner tissue. Hemp bark and core have different chemical compositions. The bark is made up of 67% cellulose, 13% hemicelluloses, and 4% lignin, whereas the core consists of 38% cellulose, 31% hemicelluloses, and 18% lignin (Van der Werf et al., 1995). Barks have longer fibers, higher cellulose contents and lower lignin contents then the core. Chemical analyses of hemp stems at different stages indicate a slight decrease in lignin contents and increases in alpha-cellulose and plant height (Kamat, 2000).

HEMP AS A WEED SPECIES

The development of chemical industry and the requirement of modern agriculture for novel pesticides have resulted in more intensive research of the allelopathic relationship between plant species. The noticeable inhibitory effect of hemp on weed species after harvesting, reflected in the reduced weed emergence in hemp plots, have attracted the attention of researchers and prompted studies dealing with the allelopathic effects of hemp on the surrounding vegetation. The allelopathic effect of cultivated plants on weed species can be encouraged by plowing down the crops exerting allelopathic effects. A more precise determination of chemical compounds that cause the allelopathic effects of cultivated crops can result in the development of new bioherbicides.

The past abundance of hemp in Vojvodinian fields has resulted in its scattered emergence as a weed species in the vicinity of roads, plot borders, landfills, or even on arable land. Hemp grows in perennial plantations of field crops, vegetables and forage plants (Vrbničanin, 2015).

Weeds are undesirable plant species that grow in plantations and cause damage to cultivated crops. Weeds compete with cultivated crops for water, light, and nutrients, thus decreasing the yield of cultivated crops (Siddiqui et al., 2010). Yield decrease caused by weed emergence can be as high as 34% (Jabran et al., 2015). Considering its fast growth and height (reaching up to 5 m), hemp as a weed species is very competitive and can easily overtake the light source from cultivated crops (Clarke & Merlin, 2013).

In addition to a significant influence of hemp habitus on the surrounding vegetation, hemp should also be analyzed for its allelopathic effect on other weed species emerging in hemp cultivation plots. Moreover, the emergence of hemp in the cultivation plots of other plants accentuates the need for investigating its allelopathic effects on other plant species.

ALLELOPATHY

The term “allelopathy” was first used by the Austrian plant physiologist Molisch (1937). The term derives from the Greek words “alleloon”, which means “mutual”, and “pathos”, which means “to endure”, referring to the damaging mutual relationship of different organisms (Rizvi et al., 1992; Chon & Nelson, 2012). Allelopathy was defined as a natural phenomenon that occurs when plants and other organisms (algae, bacteria and fungi) affect the surrounding organisms by using different chemical compounds, while their allelopathic effect can be either stimulating or inhibitory (Rice, 1984).

Allelopathic effect occurs due to secondary metabolites (Farooq et al., 2011) or allelochemicals, which are the products of different plant physiological processes (Farooq et al., 2011; Bhadoria, 2011). Authors dealing with allelopathic properties of various allelochemicals have determined a number of important secondary metabolites such as phenols, alkaloids, flavonoids, terpenoids, momilactones, hydroxamic acids, brasinosteroids, jasmonates, salicylates, glucosinolates, carbohydrates, and amino acids (Kruse et al., 2000; Jabran & Farooq, 2012). The action of allelochemicals depends on the applied concentration (Einhellig, 1986): inhibitory effects are expressed at higher concentrations and stimulating effects can occur at lower concentrations (Narwal, 1994).

The allelopathic relationship between cultivated crops can be determined by crop rotation, cover crops, intercropping, mulching, plowing down crop residues, or the application of aqueous extracts (Farooq et al, 2013). The following weed species have been found to exert allelopathic effects on certain cultivated species: *Cyperus esculentus, Rumex crispus, Xantium strumarium, Helianthus tuberosus, Sorghum halepense, Chenopodium album, Amaranthus retroflexus, Ambrosia artemisiifolia, and Avena* sp. (Šćepanović et al., 2007).

The knowledge about the allelopathic relationship between plants can be of significant importance to weed, pest and disease control in agricultural production. The possibility of using allelopathy to improve the productivity of cultivated crops and the synthesis of new compounds with pesticidal properties (with reduced negative impacts on the environment) have recently attracted the increased attention of researchers, becoming the focus of their scientific studies (Cheng & Cheng, 2015).

ALLELOPATHIC COMPOUNDS

As compounds with different structures, allelochemicals have a diverse mode of action. Certain allelopathic compounds interfere with cell division, whereas others have an inhibitory effect on hormone biosynthesis, mineral intake and transport (Rizvi et al., 1992), cell membrane permeability (Harper & Balke, 1981), stomatal oscillations, photosynthesis (Einhellig & Rasmussen, 1979), respiration, protein metabolism (Kruse et al., 2000), water balance (Rice, 1984), and plant growth.

The existence of allelopathic relationship between certain plant species is determined by examining the effect of different plant extracts on other species. Allelochemicals are present in all plant parts: roots, trees, leaves, buds, flowers, pollen, fruits, and seeds (Putnam & Tang, 1986; Alam et al., 2001). Under certain conditions, they are released into the environment where they affect the surrounding vegetation. Using different extraction processes, it is possible to extract different compounds from plant material. Dry or fresh plant material can be used in bioassays to prove the existence of allelopathic relationship between the plants considered. To prove the allelopathic effect of certain extracts, it is best to use bioassays performed in a laboratory, i.e. under controlled conditions, with high sensitivity and a relatively short execution time (Mahmoodzadeh et al., 2015).

Allelopathic action can be determined under field experimental conditions using the "combined sowing" of crops and plant species examined for their allelopathic properties. The overall impact on both weed and cultivated plant species is thereby monitored and recorded. The rotation of the crops examined for their allelopathic properties and other cultivated crops provides an insight into the prolonged effect of certain allelopathic substances that remain in the soil.

Fresh or dried, whole or ground plant parts of hemp (leaves, straw and seeds) can be used as mulch or plowed down for testing allelopathic properties in field experiments. However, the most popular formulations for testing allelopathic properties are extracts that can be obtained from fresh or dry plant material. Different extraction processes, different conditions of the same extraction, and different solvents produce extracts of different chemical compositions.

The application of certain extracts with allelopathic properties can reduce the applied doses of herbicides by as much as half (Cheema et al., 2003). Allelochemicals reduce weed competition with cultivated crops, thus improving crop growth and yield. Allelopathic substances can have a significant effect on changing the composition of weed flora, but also on crop growth and yield, and can potentially be used as a weed control measure (Singh et al., 2001).

BIOHERBICIDES

The best known example of the allelopathic effect of cultivated crops on weed species is the effect of aqueous sorghum extract (*Sorghum bicolor* Moench). Concentrated aqueous sorghum extract significantly affects weed species such as *Chenopodium album, Phalaris minor, Fumaria indica* and *Rumex dentatus* in wheat crops (Cheema & Khaliq, 2000). Sorghum extract significantly reduced weeds in cotton, sunflower and certain bean varieties, thus increasing their yield by 3-59% (Cheema et al., 2012). Cheema et al. (2003) indicated that the combined application of sorghum extract with sunflower, eucalyptus, sesame, brassica and rice extracts is much more effective than the use of one single extract.

The observed inhibitory effect of hemp on the neighboring plant species such as chickweed (Stupnicka-Rodzynkiewicz, 1970), lupine, beets, brassicas (Good, 1953), and corn (Pandey & Mishra, 1982), as well as on weeds in hemp cultivation plots, have attracted a significant interest in the allelopathic properties of hemp.

Srivastava & Das (1974) confirmed the inhibitory effect of aqueous hemp extract on the germination of *Cyperus rotundus* L, whereas Stupnicka-Rodzynkiewicz (1970) proved the inhibitory effect of hemp aqueous extract on the germination of weed species *Matricaria recutita* L. and *Lepidium sativum* L. Mahmoodzadeh et al. (2015) examined the allelopathic properties of hemp root extract and hemp shoot on lettuce under laboratory conditions. They confirmed the inhibitory effect of the shoot extract on lettuce germination, whereas the root extract exhibited no significant effect. Malinauskaite (2018) examined the effect of hemp extract on rapeseed. The applied extracts were obtained from hemp seeds and ground parts of the plant. All the tested concentrations of the plant extract had an inhibitory effect on rapeseed vigor, germination, and root and shoot length.

Pudelko et al. (2014) examined the allelopathic properties of hemp on monocotyledons (wheat and rye) and dicotyledonous species (lupine and rapeseed). The germination of monocotyledonous species was reduced, with all species exhibiting an inhibitory effect on root length at the highest concentration of application. By introducing them into the soil, Rueda-Ayala et al. (2015) examined the competitive relationship between 17 different plant species and different weed and cultivated plant species. The experiments were performed in pots and the most pronounced inhibitory effect was exhibited by *Festuca rubra* L., *Avena strigosa* Schreb.and *Cannabis sativa* L. as cover crops on lettuce, maize and tested weed species.

Konstantinović et al. (2017a; 2017b) observed the allelopathic effect of different extracts on the germination and initial development of *Ambrosia artemisiifolia* L. The inhibitory effect of hemp essential oil on the initial growth of *Chenopodium album* L. (Konstantinović et al., 2017c) was also confirmed. Konstantinović et al. (2019) observed the oxidative stress in *Sorghum halepense* L. leaves after hemp extract treatments.

CONCLUSION

Contrary to the abundance of biopesticides in the market, there is an insufficient number of preparations based on allelochemicals with herbicidal action. The influence of allelochemicals on weed plant species should therefore be investigated. The literature data clearly confirm the allelopathic effects of hemp. Hemp contains more than 400 chemical compounds (Turner et al., 1980). Hemp leaf glands release dozens of volatile compounds into the environment such as terpenes, ketones and esters, which give the plant species its characteristic odor. Although a number of chemical compounds with proven pesticidal properties have been isolated from hemp, the specific ratio of these compounds may be the active component by which hemp affects various organisms in its immediate environment (McPartland, 1997). Additional research on the allelopathic properties of hemp will provide a more detailed insight into the mechanism of hemp impact on the surrounding vegetation.

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