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REVIEW PAPER

CANNABIS SATIVA L. – CULTIVATION AND QUALITY OF RAW MATERIAL

Krystyna Żuk-Gołaszewska[1], Janusz Gołaszewski[2]

[1]Department of Agrotechnology, Crop Management and Agribusiness
[2]Department of Plant Breeding and Seed Production
University of Warmia and Mazury in Olsztyn, Poland

Abstract

Cannabis sativa L. is a cosmopolitan species which is widely distributed around the world, and this collective name is used to denote various botanical forms. Two varieties have economic significance: *Cannabis sativa* var. *sativa* and *Cannabis sativa* var. *indica*. They are commonly referred to as industrial cannabis/hemp and medicinal cannabis/medicinal marijuana, respectively. This paper reviews the available literature on the botanical aspects, cultivation, productivity, industrial applications, medicinal properties and environmental impacts of cannabis which influence agronomic standards for field cultivation of cannabis in north-eastern Europe. The processing suitability of cannabis is determined by the proportions of the major cannabinoids: Δ^9-*trans*-tetrahydrocannabinol (THC) and cannabidiol (CBD). Cannabis with low THC content is generally grown for industrial purposes, whereas cannabis with high THC content is cultivated for pharmaceutical applications. The existing knowledge on the cultivation of medicinal cannabis is fragmented, and the agronomic requirements of medicinal cannabis grown under field conditions in Europe have never been explored. This study describes the seeds, soil requirements, fertilization regimes, harvest of plants/herbage and the environmental benefits of medicinal cannabis grown in the field. Besides, it shows the quality parameters of medicinal cannabis and environmental aspects. The seeds contain oil, proteins, vitamins and minerals. Owing to the content of cannabinoids cannabis plants have unique medicinal properties.

Keywords: *Cannabis sativa* L., hemp, medicinal marijuana, chemical composition, pharmaceutical raw material, agrotechnology, environmental impact.

dr hab. inż. Krystyna Żuk-Gołaszewska, Department of Agrotechnology, Crop Management and Agribusiness, University of Warmia and Mazury, M. Oczapowskiego 8, 10-719 Olsztyn, Poland, e-mail: kzg@uwm.edu.pl

INTRODUCTION

Cannabis sativa L. produces much aerial biomass with unique quality parameters and a variety of applications. For centuries, this cosmopolitan species has been cultivated as a source of industrial hemp and used in the production of natural fibers, insulating boards, ropes, oil, varnish, paper, clothing and other products (biocomposites) (Citterio et al. 2003, Mehta et al. 2006). *Cannabis sativa* L. is one of the oldest species to have been cultivated around the world (Schultes 1970). In Europe, *C. sativa* L. was widely grown between the 16th and the 18th century. The following centuries witnessed a decline in cannabis cultivation, but interest in the species has been revived in recent years (Struik et al. 2000). In the European Union, the production of hemp fibers has increased by 38% (www.escaa.org).

Hemp seeds are used in the production of functional foods, animal feed and medicinal products. Hemp seeds deliver health benefits by lowering cholesterol levels and decreasing blood pressure (Sacilik et al. 2003). Bioactive peptides derived from hemp seeds are a source of natural antioxidants (Lu et al. 2010). Partially skimmed flour of *C. sativa* L. is a source of bio-compounds in the bakery industry (Apostol et al. 2015). In the less affluent regions of Eastern Europe, hemp seed oil has been used as a butter substitute and is now regarded as a delicacy and traditional food in these regions (Callaway 2004).

The significance of cannabis in the health care sector is rapidly growing on account of its medicinal properties. Medicinal cannabis (medicinal marijuana) has been legalized in more than half of the US states and in Australia, Canada, Germany, South Africa, Uruguay and other countries. These legislative changes paved the way to the development of the cannabis industry, which is the one of the fastest growing markets in the world. In the USA alone, medicinal marijuana sales topped $6.7 billion in 2016 (Arcview Market Research 2017).

The medicinal properties of cannabis and its derivatives are widely researched and continue to stir much controversy. Preclinical research has demonstrated that medicinal cannabis delivers health benefits, and the effectiveness of the first cannabis-based medication has been confirmed. Despite the above, a standard regulatory framework for legal access to medicinal cannabis has not yet been proposed. Medicinal cannabis has analgesic properties, and it alleviates the suffering of patients who experience chronic pain (Murnion 2015). However, epidemiological, clinical and laboratory studies have demonstrated a link between non-medicinal use of cannabis and adverse health effects (Hall, Degenhardt 2009). The therapeutic properties of cannabis can be attributed to cannabinoids – natural metabolites which are produced by cannabis plants. Aizpurua-Olaizola et al. (2016) identified at least 113 different cannabinoids isolated from cannabis plants. Psychoactive Δ^9-*trans*-tetrahydrocannabinol (THC or Δ^9-THC) and non-psychoactive cannabidiol (CBD) are the most widely researched and most therapeutically valuable cannabinoids. Cannabinoid extracts with high levels of THC and low levels of CBD are used in pharmaceutical research and preclinical studies. Cannabis exerts therapeutic effects owing to the synergistic interactions between various cannabinoids, but their mechanisms of action remain unknown. The beneficial effects of medicinal cannabis in the treatment of various diseases are explored by analyzing the chemical structure of cannabinoids, in particular the THC/CBD ratio in extracts.

The production of cannabis varieties with low THC content (<2 g kg^{-1}) has been legalized in the EU and Canada (Commission regulation 2000). This threshold value distinguishes between industrial and medicinal/narcotic uses of cannabis. The threshold concentrations of THC in various products have been set by the European Commission (Callaway 2008). The social acceptance of *Cannabis* and its medicinal uses also play a crucial role in the popularity of industrial hemp (Šárka Roušavá 2011). In addition, cannabis cultivation on organic farms delivers environmental benefits by reducing greenhouse gas emissions (Johanisová 2002). The benefits and practical applications of cannabis have spurred research into the cultivation, quality parameters and use of cannabis in new products. These goals require the development of suitable cultivation techniques for the production of high-quality raw material. Research into the optimal agronomic requirements of cannabis contributes to the production of cannabis for medicinal purposes and expands our knowledge of the environmental impacts of cannabis cultivation, including soil improvement, climate change abatement and bioeconomy development (Citterio et al. 2003, Yu et al. 2005, Appendino et al. 2008, Radawiec et al. 2014, Stolarski et al. 2015).

The production of cannabis-based medicinal products is a complex process, which begins with the production of raw material and ends in medicinal treatment. The production process of medicinal cannabis involves five critical stages: 1) indoor or outdoor cultivation, 2) plant quality control, 3) processing and handling of cannabis pharmaceuticals, 4) security and transportation, and 5) medicinal treatment. This study focuses on outdoor cultivation of cannabis in soil in the climate of north-eastern Europe. Recent research has considerably expanded our knowledge of the quality requirements of medicinal cannabis. However, agronomic standards for outdoor cultivation of this species in Europe have not yet been developed. The existing knowledge about the cultivation of medicinal cannabis is fragmented and based largely on junk science and/or indoor and outdoor cultivation practices, whereas the agronomic requirements of medicinal cannabis grown under field conditions in Europe have never been explored.

The main objective of this study is to provide a research background for developing agronomic standards for field cultivation of medicinal cannabis in north-eastern Europe which will deliver satisfactory yields and high-quality raw materials for pharmaceutical processing.

BOTANICAL DESCRIPTION AND PRODUCTION VOLUME

The genus *Cannabis* is indigenous to central Asia and the Indian subcontinent. *Cannabis sativa* L. is a cosmopolitan species which is widely distributed around the world, and this collective name is used to denote various cannabis strains. *Cannabis sativa* L. is a dioecious (unisexual) species, where individual plants develop only male or only female reproductive organs (flowers). Hermaphrodites are sporadically encountered in successive generations. *Cannabis sativa* L. has different botanical varieties, two of which have economic significance: *Cannabis sativa* var. *sativa* and *Cannabis sativa* var. *indica*. These varieties are commonly referred to as industrial cannabis/ /hemp and medicinal cannabis/medicinal marijuana, respectively (Hill 1983, Small, Cronquist 1976). Cannabis subspecies are not easy to distinguish because their morphological traits differ considerably in various cultivation regimes. Numerous cultivars of *Cannabis sativa* L. have been developed, including hybrids of the above botanical varieties, which are suitable for industrial and/or pharmaceutical processing. Botanical varieties of *Cannabis sativa* L. differ in chemical composition, plant habit, agronomic requirements and suitability for processing. They contain over one hundred identified organic chemical compounds known as cannabinoids (Datwyler, Weiblen 2006).

Industrial cannabis is grown mainly for seeds, which are used in the production of hemp oil, and hemp fibers for industrial applications. In the report by Johnson (2017), the worldwide acreage in hemp cultivation, both hemp seed and hemp tow waste, amounted to 71 thousand hectares (150 thousand acres) and totalled about 170 million tonnes (375 million pounds) in 2014. The area under cannabis grown for hemp seeds in Europe increased significantly in 2011-2016 (Table 1). The highest increase was

Table 1

Field production area for *Cannabis sativa* seeds (ha) (www.escaa.org, accessed on 10 March 2017)

Country	Year					
	2011	2012	2013	2014	2015	2016
Croatia	-	-	-	-	53.1	42.5
Czech R.	-	2.4	-	-	2.4	3
Estonia	-	-	-	10	24.77	-
France	384.4	398.9	534.7	791.64	1094.9	1450.1
Germany	68.8	66.3	71,6	122.2	154.4	255.8
Hungary	8.8	54.6	28.3	35.1	87.5	93.5
Italy	10.58	16	22.5	36.4	8.13	138.4
Lithuania	-	-	0	55.5	193.5	332.4
Netherlands	-	1	6	1	12	17
Poland	56.8	188.6	25.9	19.8	104.1	116.3
Romania	1.6	-	12	19	124.6	-
Serbia	-	-	-	-	7	20
Slovenia	-	-	-	61	23	-

reported in France, where outdoor cultivation area of *Cannabis sativa* increased from 384.4 ha to 1450.1 ha. In other countries, the area under cannabis cultivation in 2016 did not reach the level noted in France in 2011. Cannabis production also increased significantly in Lithuania, where field area under cannabis increased from 55.5 ha in 2014 to 332.4 ha in 2016. In Poland, cannabis production for hemp seeds peaked in 2012 (188.6 ha).

AGRONOMIC FACTORS

The quality of cannabis products is determined mainly by the designation of raw material, cultivation regime and harvest time (Mediavilla et al. 1998).

Medicinal marijuana is grown under field conditions worldwide, whereas field-grown cannabis in Europe is used mainly for industrial purposes. For this reason, the production technology of industrial hemp is relatively well documented, whereas little is known about the key factors that influence the cultivation of medicinal cannabis. The main difference between industrial and medicinal cannabis is that medicinal cannabis is grown with the use of the sinsemilla technique where only unfertilized female flowers with a high THC content are harvested. In field production, the ratio of male and female plants is determined by genetic factors, climate and soil conditions. Female plants have to be identified, and male plants have to be eliminated during cultivation.

Cannabis seeds should be obtained from certified sources, where seeds are specifically bred to produce only female flowers.

Cannabis plants do not have specific soil requirements, and the most important factor is the pH of soil, which should be close to neutral or slightly alkaline. Acidic soil should be limed before sowing. The yield and pharmaceutical quality of cannabis plants are determined mainly by a plant variety and agricultural treatments, in particular sowing date, fertilization, seeding rate and watering. Nitrogen is the main soil macronutrient which interacts with THC in cannabis plants. According to research, soil nitrogen levels are closely correlated with the THC content of cannabis leaves and their position on the plant. Coffman and Gentner (1975) and Haney and Kutscheid (1973) demonstrated that the nitrogen content of vegetative plant parts was positively correlated with THC levels. In a study by Hemphill et al. (1980), the THC content of leaves decreased gradually from the top to the bottom of the plant. Bócsa et al. (1997) found that high soil nitrogen levels led to a greater reduction in the THC content of older than younger cannabis leaves (at the top of the plant). According to Struik et al. (2000), nitrogen fertilization influences plant habit, leaf surface area and the dry matter yield of stems. Cannabis plants have a particularly high demand for nitrogen in early stages of the vegetative development. When leaves look dull and turning yellowish, it complementary nitrogen fertilization may be required in the later stages. However, such symptoms can be also induced by a low pH level or excess water in the soil. The demand for phosphorus and potassium increases during flowering, and cannabis plants grown for medicinal purposes should be supplied with bioavailable forms of both macronutrients in the flowering stage.

The length of the growing season of cannabis cultivars differs across climate zones and is closely correlated with flowering and harvesting dates. Early-sown cannabis is characterized by prolonged vegetative development and relatively longer stems (Sengloung et al. 2009). Generative maturity could be delayed, and in extreme cases, plants are harvested with undeveloped flowers. In the Polish climate, the optimal date for sowing cannabis is late April or early May.

Medicinal cannabis should have a bushy growth habit with a large number of side shoots, numerous leaves and inflorescences. A low seeding rate leading to relatively low plant density per m^2 promotes a bushy habit. A higher seeding rate produces taller plants with fewer and more evenly distributed side shoots. The optimum density is 20,000 plants per hectare, but in some production systems, it can be increased to 30,000 or even 40,000 plants per hectare to maximize the quality of raw materials for pharmaceutical processing (García-Tejero et al. 2014, Hall et al. 2014). In a different study, plant densities were 120, 240 and 360 plants m^{-2} (Amaduci et al. 2008). The yield of medicinal cannabis is mainly reported on a per plant basis. On average, the wet weight of yield to dry weight of plant and to dry weight of dry product is characterized by the ratio 10:3:1. For example, the empirically-based yield of sinsemilla cultivated under indoor conditions reported by the Office for Medicinal Cannabis (the Netherlands) is as follows: wet plant 115.3 g, dry plant 32.4 g, dry plant yield 10.0 g (World Drug Report 2006). Caulkins (2010) reports that precise figures on yields of outdoor medicinal cannabis are difficult to found, but the author estimated that the yield of medical-grade bud can amount to about 650 kg ha^{-1} (575 pounds per acre per year).

QUALITY PARAMETERS OF INDUSTRIAL CANNABIS

Cannabis varieties with low THC content (below 1%) and high CBD content which are grown for seeds and/or hemp are classified as agricultural crops. Seed output per ha ranges from 1700 to 2000 kg. The physical properties of hemp seeds are correlated with their moisture content. In a study by Sacilik et al. (2010), the moisture content of hemp seeds ranged from 8.62 to 20.88% on a dry matter basis. Seed sphericity, surface area and thousand-seed weight increased from 0.795 to 0.808, 9.4 to 10.3 mm^2, and 15.3 to 16.9 g, respectively. In turn, bulk density, true density and porosity decreased from 557.5 to 512.3 kg m^{-3}, 1043.0 to 894.8 kg m^{-3}, and 46.5 to 42.7%.

Hemp seeds contain valuable nutrients and compounds such as oil, proteins, vitamins and minerals (CALLAWAY 2008, HOUSE et al. 2010). They are a rich source of protein (20-25%), carbohydrates (20-30%), fat (25-35%), insoluble fiber minerals and bio-compounds (10-15%). APOSTOL et al. (2015) demonstrated that partially defatted hemp seed flour contained 31.26% protein, 7.84% ash, 11.63% total fat and 49.27% carbohydrates on a dry matter basis. Partially defatted hemp seeds are also a good source of bio-compounds, mainly fiber (45.87% DM). The addition of hemp seed flour to wheat flour can enhance the nutritional quality of bakery products. Hemp seed flour has a healthy amino acid profile. GIRGIH et al. (2014) demonstrated that hemp seed peptides participate in the upregulation of the antioxidant enzyme defence system, radical scavenging and inhibition of lipid peroxidation. The results reported in spontaneously hypertensive rats (SHR) correlate with radical scavenging and metal chelating activities of hemp meal *in vitro*. Therefore, the addition of hemp seed meal protein hydrolysate (HMH) to animal diets can deliver antioxidant and potentially therapeutic effects.

The seeds of *C. sativa* are rich in essential oils with health-promoting properties. Fresh oil is green because chlorophyll occurs naturally in mature seeds (OOMAH et al. 2002, DA PORTO et al. 2012). The health benefits of hemp seed oil are associated with the predominance of unsaturated fatty acids in its fatty acid profile (around 80%) and the high content of phytosterols (DEFERNE, PATE 1996). Hemp seed oil contains only around 10% of unsaturated fatty acids. With their high content of polyunsaturated fatty acids, hemp seeds are suitable for the production of printer's ink, wood preservatives, detergents and soaps. Hemp seeds are characterized by a healthy ratio of linoleic acid to linolenic acid (3:1), essential polyunsaturated fatty acids in human nutrition. These properties make hemp seed oil highly suitable for the production of light body oils and lipid-enriched creams which penetrate deeply into the skin (OOMAH et al. 2002). Linoleic acid (50-70%) and α-linolenic acid (15-25%) are involved in the formation of neuronal membranes and act as biochemical substrates for short-lived chemical messengers such as prostaglandins, leukotrienes and eicosanoids (HORROBIN et al. 1994). Microwave treatment increases the concentrations of carotenoids and other pigments in hemp seed oil while decreasing its *p*-anisidine value. Hemp seed oil is characterized by high kinetic stability during heating and cooling. Microwave treatment enhances the protective effects of hemp seed oil upon heating (lower melting temperatures and higher oxidation temperatures) (OOMAH et al. 2002).

The mineral compounds in hemp seeds are listed in Table 2. Depending on the source of raw material, i.e. registered varieties (CALLAWAY et al. 2004, MIHOC et al. 2012), dietary ingredients (GIBB et al. 2005), flour component (APOSTOL et al. 2015), nutrient values in official statistics (USDA 2016) the content of elements in seeds vary greatly. The cannabis seeds are a rich source of macroelements: potassium (4.63-28.2 g kg^{-1}), phosphorus (11.2-11.6 g kg^{-1}), calcium (1.44-9.55 g kg^{-1}), magnesium (2.37-6.94 g kg^{-1})

Table 2

Elemental composition of hemp seeds

Elements	CALLAWAY (2004)	GIBB et. al. (2005)	MIHOC et. al. (2012)	APOSTOL et. al. (2015)	USDA (2016)
	finola variety	dietary ingredients	Five Romanian varieties	partially defatted flour	nutrient values
Ca (g kg^{-1})	1.45	4.10	1.44-9.55	2.86	0.70
P (g kg^{-1})	11.6	11.2	-	-	16.5
Mg (g kg^{-1})	4.83	5.60	2.37-6.94	6.12	7.00
K (g kg^{-1})	8.59	8.80	4.63-28.2	13.0	12.0
Na (g kg^{-1})	0.12	0.20	-	0.45	0.05
Fe (mg kg^{-1})	0.14	-	1.13-2.40	-	0.08
Cu (mg kg^{-1})	20.0	-	10.0-12.0	19.3	16.0
Mn (mg kg^{-1})	70.0	-	63.0-110	-	76.0
Zn (mg kg^{-1}	70.0	-	42.0-94.0	69.0	99.0

and sodium (0.05-0.45 g kg^{-1}). At the same time, they contain large amounts of microelements: Mn (63-110 mg kg^{-1}), Zn (42.0-94.0 mg kg^{-1}), Cu (10.0-12.0 mg kg^{-1}) and Fe (1.13-2.40 mg kg^{-1}).

Antioxidants play an important role in the contemporary approach to nutrition that involves health promotion and disease prevention. Antioxidants occur naturally as four homologs: α-, β-, γ-, δ-tocopherols, where α-tocopherol is commonly known as vitamin E (BAGCI et al. 2003, YU et al. 2005). BAGCI et al. (2003) demonstrated that hemp seed oil is a rich source of tocopherols. The most abundant compound was γ-tocopherol, (89.11%), followed by α-tocopherol (5.66%), β-tocopherol (0.33%) and δ-tocopherol (4.90%). These bioactive compounds can directly interact with and quench stable DPPH and ABTS+ cation radicals, form chelating complexes with transition metals, absorb oxygen radicals generated by AAPH (ORAC), and prevent lipid peroxidation in human LDL. The antioxidant properties of tocopherols protect membrane lipids, DNA and proteins against free radicals and radical-mediated oxidative damage (YU et al. 2005).

QUALITY PARAMETERS OF MEDICINAL CANNABIS

Unlike industrial cannabis, medicinal cannabis is cultivated mainly for its female flowers (buds), which are abundant in tetrahydrocannabinolic acid (THCA, a precursor of THC), the major cannabinoid with therapeutic properties. Tetrahydrocannabinolic acid is also extracted from leaves, although the THCA content of leaves is 10-fold lower in comparison with flowers (around 1-2%).

In medicinal marijuana, the concentration of THCA ranges from 10% to 20-30% or more, and it is much higher than in industrial hemp (FRITSCHI 2006).

Formally, cannabis plants whose flowers and leaves are used in the pharmaceutical industry are classified as horticultural crops. Medicinal marijuana is generally characterized by a high content of THCA and a low content of cannabidiolic acid (CBDA). Industrial hemp with low THCA content and high CBDA content is grown for seeds and/or hemp, and it is classified as an agricultural crop. Industrial cannabis is characterized by low (below 1%) content of THCA and a CBD:THC ratio higher than 1. Regardless of the cultivation regime, cannabinoids undergo partial or complete decarboxylation from acidic to neutral form (e.g. THCA → THC, CBDA → CBD) during drying, storage and thermal processing.

Cannabis plants exert psychotropic effects when their THC content approximates 1%. In the European Union and in other countries, only cannabis with less than 0.2% HTC content (0.3% in Canada) may be legally grown. The distinction between industrial and therapeutic/psychotropic uses of cannabis is made based on the above threshold value. Industrial cannabis is characterized by relatively high levels of CBD. A mixture of CBD and THC can deliver health benefits because CBD reduces the psychoactive effects of THC; however, high concentrations of CBD are not desirable in pharmaceutical products (BMA, 1997). Cannabis plants with a high CBD:THC ratio are generally more suitable for industrial than medicinal use. The results of studies investigating CBD levels, the CBD:THC ratio and the ability of CBD to reduce the psychoactive effects of THC are inconclusive. The first comprehensive study analyzing variations in the cannabinoid composition of cannabis plants was conducted in 1973 by SMALL and BECKSTEAD. Based on THC and CBD concentrations in the dry matter of cannabis flowers, the cited authors identified 3 chemical phenotypes (chemotypes) of cannabis: chemotype I – THC>0.3% and CBD<0.5%, chemotype II – predominance of CBD and various concentrations of THC, and chemotype III – marginal levels of THC. FOURNIER et al. (1987) identified other chemotypes characterized by low concentrations of both THC and CBD or the predominance of cannabigerol (CBG). In a selective breeding study, DE MEIJER et al. (2003) crossed 4 inbred lines of cannabis with pure CBD or THC chemotypes. F_1 hybrids were self -fertilized. In F_2 hybrids, the three chemotypes (pure CBD, mixed CBD-THC, and pure THC) were segregated in a 1:2:1 ratio. The authors concluded that the CBD/THC ratio is progeny specific and is transferred to F_2 individuals.

Marijuana contains antibacterial cannabinoids, mostly cannabidiol (1b), cannabichromene (2), cannabigerol (3b), Δ9-tetrahydrocannabinol (4b) and cannabinol (5). APPENDINO et al. (2008) demonstrated that the above cannabinoids were potent antimicrobials against a variety of methicillin-resistant *Staphylococcus aureus* (MRSA) strains. Similar results were reported by BANCROFT (2007), who found that non-psychotropic cannabinoids can be used as systemic antibacterial agents. A combination of cannabinoids can also be used as a source of cheap and biodegradable antibacterial agents in the production of cosmetics (McGrath 2003).

ENVIRONMENTAL ASPECTS

Cannabis cultivation delivers environmental benefits. Cannabis plants produce large amounts of aerial biomass, which protects soil against excessive drying and limits weed growth. Cannabis roots are decomposed after harvest, they loosen the soil and constitute a rich source of organic matter. Cannabis plants are environmentally friendly crops which do not require extensive pesticide treatments. Cannabis plants are capable of binding around 2.5 tons of CO_2 per hectare, thus limiting the greenhouse effect. The roots and shoots of cannabis plants absorb heavy metals, and they effectively remove contaminants from the soil environment, including copper which is toxic to plants at high concentrations (Bona et al. 2007, Mihoc et al. 2012). Cannabis plants are tall and their roots penetrate soil to a depth of over 1 meter. Zatta et al. (2012) report that root biomass can be recorded up to 2 m depth, although 50% of roots are in the upper 20 cm of soil. Cannabis is a fast-growing species that forms dense stands. In a study by Citterio et al. (2003), Cd, Ni and Cr were accumulated mainly in the roots and were partially translocated to aerial plant parts. Cannabis grown for industrial processing effectively remediates soils contaminated with heavy metals and improves soil quality (Linger et al. 2002). The cadmium content of cannabis shoots ranged from 14 to 66 $\mu g\ g^{-1}$, and it was determined by Cd levels in soil.

The optimal agronomic practice for growing medicinal marijuana also has to generate high environmental and economic profits. For this reason, nutrient-rich residues from harvesting operations, including hemp stalk fibers and cannabis extracts, should be processed, too. Cannabis residues can be naturally recycled for various purposes, they can serve as feedstock for numerous bioproducts (e.g. Wibowo et al. 2004, Yu et al. 2005, Mohanty et al. 2005) and/or can be thermochemically processed into biofuels and used as soil improvers (e.g. Amaducci et al. 2008, Radawiec et al. 2015).

SUMMARY

Cannabis sativa L. is a cosmopolitan species with a wide variety of botanical forms. The content of metabolites in cannabis plants is significantly influenced by soil and climate conditions. The processing suitability of cannabis is determined by the content of natural plant metabolites – cannabinoids, in particular the proportions of psychoactive Δ^{9}-*trans*-tetrahydrocannabinol (THC or Δ^{9}-THC) and non-psychoactive cannabidiol (CBD). Cannabis plants with low THC content are classified as agricultural crops for industrial processing, whereas plants with high THC content are used in the pharmaceutical industry. Industrial hemp is grown mainly for seeds and fiber, whereas medicinal marijuana is cultivated for its flowers and leaves. Industrial hemp has numerous applications, and it is a key resource in biobased economy. Owing to their health-promoting properties, the seeds of industrial hemp are used in the production of dietary supplements and herbal preparations. Cannabis plants have unique medicinal properties, and cannabis-derived pharmaceuticals are used in the treatment of many diseases, in particular chronic pain. The development of agronomic standards for sustainable cultivation of medicinal marijuana in the European climate will increase the quality of raw materials for pharmaceutical processing. Cannabis plants also deliver environmental benefits by increasing the organic matter content of soil and lowering greenhouse gas emissions.

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