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AGRONOMY | REVIEW ARTICLE

# A comprehensive review of the production technology of *Cannabis sativa* L. with its current legal status and botanical features

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ABSTRACT

*Cannabis sativa* L. is an annual, deciduous, dimorphic, flowering plant that is distributed all over the world. Despite its tremendous and handy usage in medicinal and other areas, the cultivation, production, and trade of cannabis are illegal in most of the countries. It is so because of some of its harmful side effects on human health when consumed haphazardly or addictively. Following the declaration made by the UN Assembly, some countries, including the Republic of South Africa, Canada, Germany, Australia, Colombia, and Indonesia, have legalized the indoor cultivation and production of cannabis, as well as cannabis-based products. Cannabis can thrive in a wide range of climatic and ecological conditions. Cannabis can be propagated via seeds, cuttings, grafting, micropropagation, etc. The plants are mainly cultivated for their chemical constituents like tetrahydrocannabinol (THC), cannabidiol, cannabinol, etc., which are extracted from their dried flowers. This study illustrates the production technology, current legal status, and botanical characteristics of *Cannabis sativa*.

**Keywords:** *Cannabis sativa* L., botanical aspects, production technology, legal status

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## 1 Introduction

*Cannabis sativa* L. (marijuana; Cannabaceae) is a multicultural species broadly disseminated worldwide. It is a yearly, dioecious, shrubby, monotypic genera of blooming plant assumed to have emerged in the Northwest Himalayas (i.e., Asia) and has been practiced quite so much as ten thousand years ago (Government of Canada, 2022; Máthé, 2015; Papastylianou et al., 2018; Żuk-Gołaszewska et al., 2018). However, others believe cannabis is a plant native to Central and Eastern Europe, which is still up for discussion (Nagy et al., 2019). Cannabis is recognized as an ecologically responsible multi-functional crop, and the diversified array of options that it can generate has piqued the interest of a wide variety of sectors (Johnson, 2019), including crop production, synthetic fibres, automobiles, manufacturing, bio-energy, fuel, personal care products, pharmacological, reusable composite industries, and so on; producing nearly 2,500 goods (Adesina et al., 2020; Deng et al., 2019; Mola et al., 2021; Papastylianou et al., 2018; Struik et al., 2000; Tang et al., 2016). Cannabis has gradually regained its relevance in agriculture as demand for non-food commodities, and other food byproducts have increased (Adesina et al., 2020). In accordance to a report by Grand View Research, the global legal marijuana market is projected to reach USD 73.6 billion by 2027 (Grand View Research, 2020). Further, many countries have shown a growing inclination towards large-scale cannabis cultivation, resulting in substantial production yields (Table 1).

According to the World Health Organization (WHO), approximately 21,000 plant species utilized

**Table 1.** List of countries with their cannabis cultivation area and production estimates

| Country | Estimated annual production (t) | Estimated area of cultivation (ha) |
|---|---|---|
| Morocco | 38,000 - 340,000 | 47,000 - 134,000 |
| Afghanistan | 1,500 - 3,500 | 5,500 - 10,000 |
| Mexico | 7,500 - 9,000 | 11,000 - 13,000 |
| United States | Difficult to estimate due to legal and illegal production | 321,000 (legal cultivation only) |
| Colombia | 1,000 - 2,500 | 7,000 - 8,000 |

Source: United Nations Office on Drugs and Crime (2021)

for medical reasons. Nonetheless, only roughly 100 of them are cultivated, particularly for the pharmaceutical sector, and they will all be found in an agricultural setting (Potter, 2013). Outdoor medicinal cannabis production is a risky endeavour. This highly controlled product has a high retail monetary value and distinct desirability, making it susceptible to individuals with an inquisitive, opportunistic, or malevolent aim (Cerrato et al., 2021; Potter, 2013). There are probably over 100 cannabinoids identified, derived from the simultaneous biogenesis of polyketids and terpenoids. *C. sativa*'s chemistry is undeniably complicated since it contains flavonoids, stilbenoids, quinones, sugars, alkaloids, polyketides, and terpenoids (Máthé, 2015). Because of its medical characteristics, cannabis's importance in the medical industry quickly expands (Żuk-Gołaszewska et al., 2018).

The production of *Cannabis sativa* L. is a rapidly growing industry, fueled by the increasing legalization and decriminalization of cannabis in many countries. However, there is a need for a comprehensive review of the current state of knowledge on its production technology, legal status, and botanical features, which can help guide researchers, policymakers, and growers in this field. Despite the increasing interest in the production of *Cannabis sativa* L., there is a lack of comprehensive and up-to-date reviews that cover its production technology, legal status, and botanical features in one study. Therefore, this study aims to fulfill this gap and further intend to: (1) Review the current state of knowledge on the production technology of *Cannabis sativa* L., including cultivation, processing, and extraction techniques; (2) Examine the legal status of *Cannabis sativa* L. in different countries and the regulatory frameworks governing its production and use; and (3) Describe the botanical features of *Cannabis sativa* L. and their implications for its production and use.

## 2 Legal status of cannabis

The legal position of cannabis remains very contentious. Cannabis is now the most widely farmed, trafficked, and misused narcotics in the world because of its propensity to have a significant health-related effect, change sensory perception and create ecstasy and euphoria (Gonçalves et al., 2020; Papastylianou et al., 2018). According to the United Nations Office on Drugs and Crime (UNODC) World Drug Report 2005, cannabis cultivation is common throughout Africa, the Americas, Asia, and Europe, with a total production of 47,000 tons of cannabis in 2004 (Stambouli et al., 2005). Subsequent utilization in between overall populace visualizes an accumulation of young adults and teenagers (20-24 years old), varying from 2% to 5% of the populace (in 2010, there were approximately 13 million cannabis-dependent people); however, the most significant number (10-13%) are recorded in North America (Gonçalves et al., 2020). As a result, current judicial bodies in the United States and Australia restrict the growth of cannabis and closely properly regulate its production (ElSohly et al., 2017; Johnson, 2019; Specchio et al., 2020). However, the Medicines and Healthcare products Regulatory Agency (MHRA) later said in 2016 that goods containing CBD used for medicinal reasons are deemed medicines and are subject to conventional licensing criteria (Specchio et al., 2020). Consequently, according to annexes I and II of the 1971 United Nations Convention on Psychotropic Drugs, dronabinols and delta-9-tetrahydrocannabinol (D9-THC) are categorized as psychotropic substances (Papastylianou et al., 2018). As a result, the legal status of cannabis cultivation changed, resulting in a rapidly increasing industry (Bilodeau et al., 2019). However, it should be noted that cannabis production is legally allowed in certain countries, and information on their production status can be obtained (Table 2). A historic decision at the United Nations (UN) on December 2nd, 2020, finally acknowledged the medical use of cannabis, a plant that has been utilized pharmacologically for 1000 years, following a recommendation from specialists at the World Health Organization (WHO) (Spanagel and Bilbao, 2021; Specchio et al., 2020). According to the law, cultivation should be done in an enclosed setting (indoor or greenhouse), the propagating material (seed) must be below 30 kg/ha, and the entire cultivation area should be fenced. Furthermore, the greenhouse position in the field should be at least 1000 meters away from schools, archaeological sites, and other sensitive locations (Bilalis et al., 2019).

**Table 2.** List of some countries and their legal and production status of cannabis

| Country | Legal status | Production status | References |
|---|---|---|---|
| Canada | Legal | Large-scale commercial production for both medical and recreational use. | Government of Canada (2023) |
| Colombia | Legal | Rapidly growing industry, with companies focused on export to global markets. | Lamers (2022) |
| Israel | Legal | Leading producer of medical cannabis, with growing focus on research and development. | Israeli Ministry of Economy and Industry (2021) |
| Jamaica | Legal | Small-scale cultivation for medical and scientific research purposes. | Jamaica Information Service (2022) |
| Lesotho | Legal | Growing number of licenses issued for medical cannabis cultivation and export. | Uwakonye (2020) |
| Netherlands | Legal | Small-scale cultivation for medical and scientific research purposes. | Dutch Ministry of Health, Welfare and Sports (2023) |
| Portugal | Legal | Growing number of licenses issued for medical cannabis cultivation and export. | Infarmed (2021) |
| South Africa | Legal | Small-scale cultivation for medical and scientific research purposes. | SAHPRA (2017) |
| Uruguay | Legal | Large-scale commercial production for both medical and recreational use. | UIRCC (2020) |

Today, there are signs of recent growth in indoor cultivation, notably in the United States, Canada, Chile, Uruguay, Colombia, and Ecuador. While precise estimations of growing area and output volumes are impossible because of a lack of empirical data, cannabis cultivation has been recorded in 151 countries between 2010 and 2018, demonstrating the enormous geographical extent of production activities (Wartenberg et al., 2021). As a result, in nations such as the United States (US), authorized pharmaceutical cannabis usage is becoming more prevalent in 29 states (Gonçalves et al., 2020). While elaborating, only eight states and the District of Columbia have authorized medical utilization. It is legally allowed in several nations; for instance, it is legally allowed in several countries, including Germany, Spain, Austria, Denmark, the Czech Republic, Sweden, and the United Kingdom (UK), legalizing the medicinal utilization of *Cannabis sativa* and cannabis-based products (Table 3) (Gonçalves et al., 2020; Papastylianou et al., 2018). Similarly, Canada has become the world's second country to decriminalize the utility of both medical and recreational cannabis. Such complete legalization lets businesses and researchers collaborate to discover the hitherto unknown science of this once-forbidden plant (Bilodeau et al., 2019; Specchio et al., 2020; Żuk-Gołaszewska et al., 2018). Furthermore, the Minister of Health in France and Greece declared in 2017 that the inclusion of CBD in products for public consumption is up to a maximum of 0.2 per cent THC (Bilalis et al., 2019; Folina et al., 2019; Specchio et al., 2020). Almost hundreds of cannabis social clubs are spread within Spain, for which legislative Initiative law has been enacted, regulating consumption, production, a transit of cannabis by individuals and clubs (Papaseit et al., 2018). However, unlike in the United States, Canada, France, and Greece, the medicinal utilization of cannabis is authorized only in Germany, Italy, and the Netherlands (Table 3) (Papaseit et al., 2018; Specchio et al., 2020). As a result, worldwide authorization of medicinal and recreational cannabis production and usage has increased during the last two decades. Cannabis is legal for recreational utilization in 12 states in the United States, Uruguay, and Canada as of October 2020 and medical use in 36 nations (Wartenberg et al., 2021).

# 3 Botanical descriptions

## 3.1 General descriptions

Cannabis (*Cannabis sativa* L.: Cannabinaceae) is a dioecious and dimorphic annual crop that is sexually differentiated and has an anemophilous pollination process (Amaducci et al., 2015; Edwards and Whittington, 1992; Islam et al., 2021; Small et al., 2003; Strzelczyk et al., 2021). They are herbaceous (non-woody plants with aerial portions that die after fruiting) and have apetalous blossoms (no corolla) (Andre et al., 2016; El-Sohly et al., 2017; Stambouli et al., 2005). Cannabis is a tall, erected plant with erected stems, an extremely quickly, short-day plant with a deep, fibrous tap root

**Table 3.** Legal status of cannabis for medical utilization across many nations

| Nations | Cannabinoid based medicines | Raw herbal cannabis | Extemporaneous preparation |
|---|---|---|---|
| Uruguay | Legalized | Legalized | Legalized |
| United Kingdom | Nabiximols and Nabilone | Illicit | Illicit |
| Switzerland | Nabiximols | Illicit | Legalized |
| Sweden | Nabiximols | Illicit | Illicit |
| Spain | Nabiximols | Illicit | Illicit |
| Slovenia | Illicit | Illicit | Legalized |
| Slovakia | Nabiximols | Illicit | Illicit |
| Portugal | Nabiximols | Illicit | Illicit |
| Poland | Nabiximols | Illicit | Legalized |
| Philippines | Legalized | Illicit | Illicit |
| Peru | Legalized | Illicit | Illicit |
| Norway | Nabiximols | Illicit | Legalized |
| New Zealand | Legalized | Legalized | Legalized |
| Netherlands | Nabiximols and Dronabinol | Legalized | Legalized |
| Nepal | Illicit | Illicit | Illicit |
| Mexico | Legalized | Illicit | Illicit |
| Malta | Nabiximols | Illicit | Legalized |
| Luxembourg | Nabiximols | Illicit | Illicit |
| Lithuania | Nabiximols | Illicit | Illicit |
| Jamaica | Legalized | Illicit | Illicit |
| Italy | Nabiximols | Illicit | Legalized |
| Israel | Nabiximols | Legalized | Illicit |
| Ireland | Nabiximols | Partially Legalized | Illicit |
| Iceland | Nabiximols | Illicit | Illicit |
| Germany | Nabiximols and Nabilone | Legalized | Legalized |
| France | Nabiximols | Illicit | Illicit |
| Finland | Nabiximols | Partially Legalized | Illicit |
| Estonia | Illicit | Partially Legalized | Illicit |
| Denmark | Nabiximols | Illicit | Legalized |
| Czech Republic | Nabiximols | Illicit | Legalized |
| Croatia | Nabilone and Dronabinol | Illicit | Legalized |
| Canada | Legalized | Legalized | Legalized |
| Cambodia | Legalized | Illicit | Illicit |
| Brazil | Legalized | Illicit | Illicit |
| Belgium | Nabiximols | Illicit | Illicit |
| Austria | Nabiximols, Nabilone, and Dronabinol | Illicit | Legalized |
| Australia | Legalized | Legalized | Legalized |
| Argentina | Legalized | Illicit | Illicit |

Source: Aguilar et al. (2018); Bilalis et al. (2019); Bilodeau et al. (2019); ElSohly et al. (2017); Folina et al. (2019); Gonçalves et al. (2020); Johnson (2019); Kumar et al. (2021); Papastylianou et al. (2018); Specchio et al. (2020); Wartenberg et al. (2021)

system that thrives on fertile, well-drained terrain with neutral to slightly alkaline clay loam or silt loam soils (Bonini et al., 2018; Farag and Kayser, 2017). The plant's height typically ranges between 60 cm for the minor kinds and 7 m for the tallest, and male plants outnumber female plants in most populations (Edwards and Whittington, 1992; Farag and Kayser, 2017; Stambouli et al., 2005). Furthermore, male plants are less branching and taller than female plants and have a dark green hue (Stambouli et al., 2005; Strzelczyk et al., 2021).

The stem is green, upright, covered with hair, and branched in the top section, producing a panicle, and has diverse morphological areas and in a transverse fraction, from the exterior to the inside of the stem (Small et al., 2003; Strzelczyk et al., 2021). They are often angular, furrowed, with a woody core, occasionally hollow in the internodes, with branches positioned on opposite or alternating sides (Amaducci et al., 2015; Farag and Kayser, 2017). The leaves are intersectant on the lower portion of the stem (opposing pairs are twisted at 180°), and the leaflets are 6 to 11 cm long and 2 to 15 mm wide, with coarsely serrated leaf edges (Farag and Kayser, 2017; Small et al., 2003; Stambouli et al., 2005). Each leaf comprises multiple lanceolate finger-like leaves coated with secretory hairs and visible on both sides (Strzelczyk et al., 2021). Similarly, the Cannabis root is of the tap kind, with lengths ranging from 30 cm to 2 m in deep soils, up to 2.5 m in loam soils, remarkably closer to the surface and more branching in moist soils (Farag and Kayser, 2017; Small et al., 2003; Strzelczyk et al., 2021). The lateral roots can grow 20 to 100 cm long (Small et al., 2003). *Cannabis sativa* L. development phases are classified as follows: germination and emergence, vegetation, flowering and seed production, and senescence (Mediavilla et al., 1998; Strzelczyk et al., 2021). Furthermore, the fruit is an achene (commonly known as seeds), and it is elliptical (oval), somewhat compacted, smooth, roughly 2 to 5 mm long, often caramel and spotted, and it contains a solitary seed with a hard shell safely covered by the dainty mass of the ovary (Fig. 1) (Farag and Kayser, 2017; Small et al., 2003). *Cannabis sativa* is anemophilous, and microspore production is prolific; a solitary bloom generates over 350K microspores, and male plants often die after pollen grain production (Amaducci et al., 2015; Government of Canada, 2022; Small et al., 2003; Stambouli et al., 2005). The plant's leaves, bracts, and stems were coated with epidermal glandular trichomes, encapsulating secondary metabolites like phytocannabinoids and terpenoids (Fig. 2) (Bonini et al., 2018). Morphologically, identifying the gender of plants at the early stage is difficult since sexual dimorphism occurs in the later stage of plant advancement; nevertheless, males may be distinguished from females after blooming (Fig. 1) (Bilodeau et al., 2019; ElSohly et al., 2017). Nowadays, molecular approaches are currently used to distinguish the gender of plants at a young stage (ElSohly et al., 2017).

## 3.2 Species classifications

*Cannabis sativa* L. botanical variations vary in chemical and genetic makeup, plant propensity, agricultural requirements, and handling suitability and include over 100s of recognized organic chemical components known as cannabinoids (Żuk-Gołaszewska et al., 2018). *Cannabis sativa* var. *ruderalis*, *Cannabis sativa* var. *indica*, and *Cannabis sativa* var. *sativa* are usually considered three distinct species (Table 4) (Bilodeau et al., 2019; ElSohly et al., 2017; Żuk-Gołaszewska et al., 2018). There was a historical, geographical distinction between *Cannabis sativa* var. *ruderalis* (Central Asiatic), *Cannabis sativa* var. *indica* (South Asiatic-African), and *Cannabis sativa* var. *sativa* (European), according to Bonini et al. (2018). The sativa and indica variants are the dominant cannabis plant species of recreational and medical interest (Bilodeau et al., 2019; ElSohly et al., 2017). In contrast, ruderalis is viewed as a vigorous variety growing in the northern Himalayas, described by a scanty, 'weedy' development, and is only sometimes developed for its medication content (ElSohly et al., 2017). Indica plants are typically shorter (average 1.8 m) with more extensive, bushier, and darker leaves and a higher THC to CBD ratio than sativa, which has an average plant height of 2.5-3.5 m and a lower THC to CBD ratio (Table 4) (Bilodeau et al., 2019; ElSohly et al., 2017).

## 3.3 Genetics

Cannabis' genome is heterogametic (2n = 18 + XY) in males and homogametic (2n = 18 + XX) in females, with a karyotype comprising of 9 autosomal plus a couple of sex chromosomes (X and Y) (ElSohly et al., 2017; Farag and Kayser, 2017; Schilling et al., 2020a; Small et al., 2003). By flow cytometry, Cannabis' sex chromosomes are the biggest in the chromosomal complements, comprising male cannabis's genome size to be 1683 Mbp, and that of the female is anticipated to be 1636 Mbp (Schilling et al., 2020a). Many dioecious plants have sex chromosomal alterations during embryonic phases as a survival strategy (Farag and Kayser, 2017; Schilling et al., 2020a). In dioecious strains, the inheritance of sexual expression, i.e., sexual specialization, is reliant on a couple of allosomes, the male heterogametic (XY), with a roughly 50:50 sex ratio. Conversely, sexual assertion appears to be autosomal and changeable by various ecological circumstances (ElSohly et al., 2017; Small et al., 2003).

## 3.4 Floral characteristics

Male flowers are naturally formed before female flowers in cannabis (usually two weeks sooner), although transitional hermaphroditic blooms may be found (Figure 1) (Amaducci et al., 2015; ElSohly et al., 2017; Government of Canada, 2022; Small et al., 2003). Floral organs often begin in the middle of summer and develop from the base to the inflorescence apex (Small et al., 2003). Inflorescences are made of multiple flower heads that grow from each leaf axil on long, leafy stalks (Fig. 2) (Farag and Kayser, 2017). As a result, the flower hangs while blossoming, making it more straightforward for the breeze to discharge pollen (Fig. 1)(Strzelczyk et al., 2021).

Female flowers sprout in the axils irredeemably with a single ovule ideological purist perianth (Fig. 2) (Bonini et al., 2018; Small et al., 2003). Pistillate (female flowers) have one or two pistils and are practically sessile (Farag and Kayser, 2017; Strzelczyk et al., 2021). The flowers, which take the shape of small spikes and have no petioles, are situated 2-4 in each leaf angle (Strzelczyk et al., 2021). The female perianth is hazy, comprising a slim unified layer that sticks to the ovary (Fig. 2) (Small et al., 2003). Female flowers have distinctive hairs called trichomes, which


**Figure 1.** (A) Male cannabis plant; (B) Female cannabis plant; (C) Male inflorescence; (D) Female inflorescence; (E) Hermaphrodite inflorescence; (F) Seed/achene

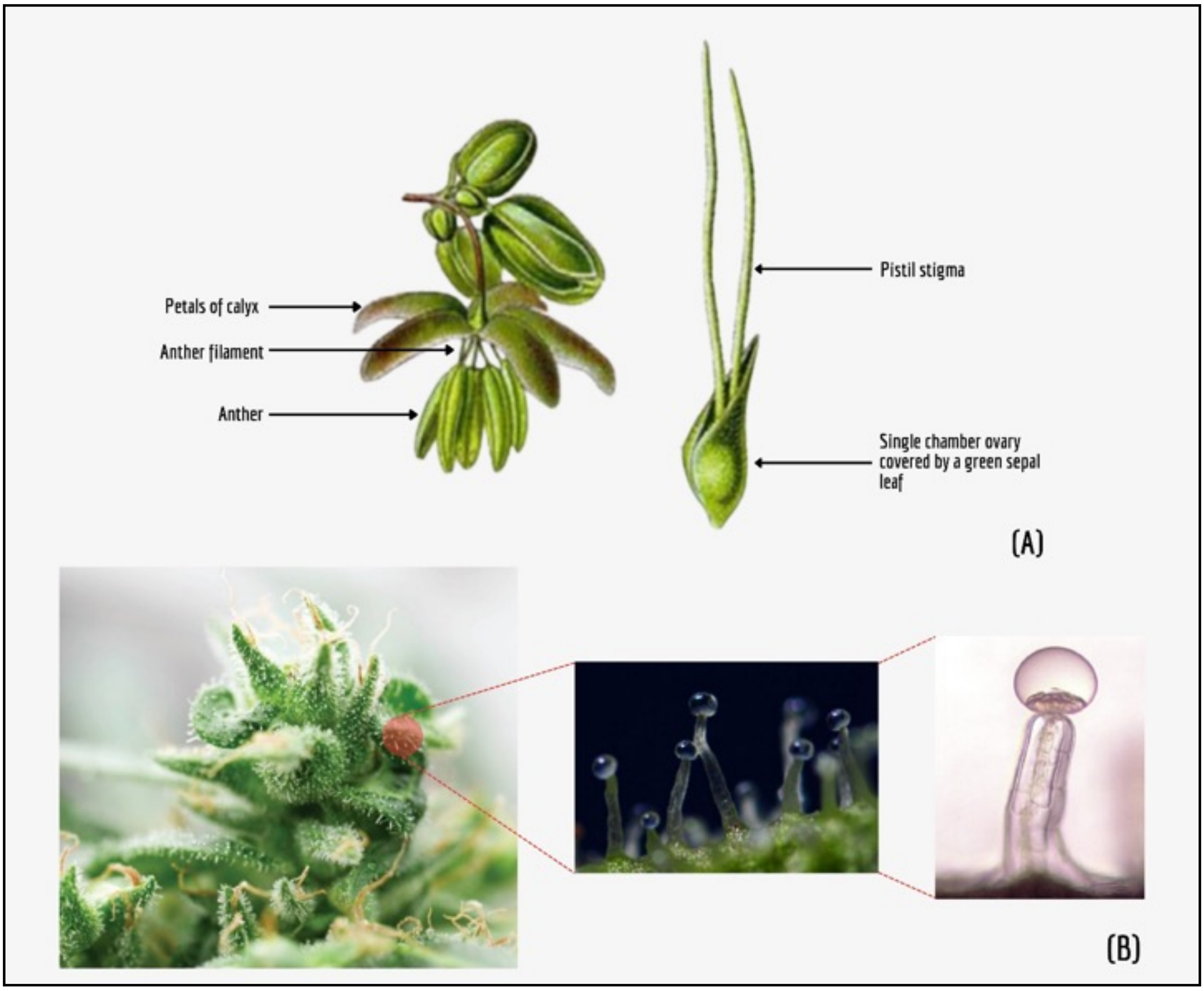


**Figure 2.** (A) Morphological structure of flowers of cannabis (Left: male) and (Right: female). [Retrieved from (Strzelczyk et al., 2021)]. (B) Exemplifying miniatures, trichomes on the cannabis inflorescence and a magnified solitary trichome containing sequestered cannabinoids at the apex of the trichome stalk [Modified from Chandra et al. (2017a)]

generate resin containing the hallucinogenic chemical tetrahydrocannabinol - 9 THC (Fig. 2) (Strzelczyk et al., 2021). The carpellate blooms have a superior and short apical style and two long filiform stigmatic branches. They develop a dense inflorescence and a compact panicle (Small et al., 2003; Strzelczyk et al., 2021). On the other hand, the male inflorescences are slender and pedicellate, with five hairy tepals around 2.5 to 4 mm long and five stamens with flaccid filaments opposite the tepals (Fig. 2) (Bonini et al., 2018; Farag and Kayser, 2017; Small et al., 2003; Strzelczyk et al., 2021). The males develop a loose and branching panicle, a broomstick (cymose) panicle (Small et al., 2003; Strzelczyk et al., 2021). After anthesis (flower opening), a male specimen slips away and dies (Strzelczyk et al., 2021).

## 4 Cultivation technology

Cannabis is an annual plant that may be cultivated effectively indoors and outdoors, with both benefits and drawbacks. Though indoor culture allows for photoperiod regulation to initiate blooming and maturity (3-4 crops per year), outdoor cultivation is often restricted to one crop per year (5-7 months depending on the cultivar) (ElSohly et al., 2017; Żuk-Gołaszewska et al., 2018). Commercial cannabis cultivation is primarily done indoors and necessitates environmental standards, including humidity and lighting for vegetative and blooming growth stages (Bilodeau et al., 2019). More crucially, medicinal cannabis is produced using the sinsemilla methodology, which harvests only uninoculated female flowers with a high THC concentration and eliminates male plants during production (Żuk-Gołaszewska et al., 2018). Cannabis plant production and medicinal quality are affected mainly by plant type and agricultural practices, namely sowing date, fertilizer, seeding rate, and watering (Schilling et al., 2020a; Żuk-Gołaszewska et al., 2018).

## 4.1 Growing conditions

### 4.1.1 Soil conditions

Cannabis may be grown in a diverse range of soil types, even though it thrives best in well-drained, loose, loam soils rich in organic content, followed by clay loam, whereas sandy and clayey soil are unsuitable (Adesina et al., 2020; Amaducci et al., 2015). Cannabis growing requires soil that is near neutral or slightly alkaline (Żuk-Gołaszewska et al., 2018). An appropriate soil for cannabis development, according to Amaducci et al. (2015), should possess a pH of 6.0 to 7.5, high water holding capacity, high nutrient content, and high aeration. Thus, according to Small et al. (2003), wild cannabis on sandy soils appeared to be able to endure dry circumstances, but *C. sativa* favours moist soils and does not withstand waterlogging.

### 4.1.2 Temperature

Temperature is an essential factor in cannabis cultivation at all stages of development. Cannabis plants are widely dispersed geographically and grow in various conditions (Small et al., 2003). Even though cannabis thrives optimally in standard daily air temperatures ranging from 16 to 27 °C, it can also survive in low and high temperatures. For instance, at a low temperature of 8 to 10°C, the seed requires 8 to 10 days to sprout. Young seedlings with 8 to 10 leaves may withstand minor cold exposure, often up to 5 °C (Adesina et al., 2020; Werf, 1994). Furthermore, according to Potter (2013), cannabis plants from various agroclimatic zones worldwide have diverse optimal photosynthesis temperatures ranging from 25 °C to 35 °C. However, the optimal GDD requirements for high-producing CBD cannabis require further exploration (Adesina et al., 2020).

### 4.1.3 Light requirements

High light intensity is required throughout the vegetative development stage to maximize cannabis growth, and appropriate photoperiodicity management is required to induce budding (Adesina et al., 2020; Bilodeau et al., 2019). Natural light is insufficient for medicinal cannabis production, and artificial light is frequently required to supplement lighting up to 20 hours per day at a density of 120 mol $m^{-2}$ $s^{-1}$ and higher, particularly in indoor culture for continuous and consistent cannabinoid output (Bilodeau et al., 2019; Folina et al., 2019). According to Potter (2013), cannabis must have access to numerous light energies to attain adequate photosynthesis. This has been accomplished by deploying a supplemental lighting system capable of producing 55 W $m^{-2}$ of photosynthetically active radiation.

## 4.2 Propagation techniques

### 4.2.1 Propagation through seeds

Cannabis seeds constitute the most often used technique of multiplication. After 4-5 days, seed germination begins. The seedlings are initially subjected to 6 M.A. fluorescent light (18-h photoperiod), then transferred to larger containers (30 cm × 30 cm) and subjected to multispectral development light settings (18 hours of photoperiod) for vegetative development (ElSohly et al., 2017). Because feminized and non-feminized seeds produce non-uniform plants with variances in cannabinoid composition and yield in the final product, culling is required (Dreger and Szalata, 2021; Government of Canada, 2022).

### 4.2.2 Vegetative propagation

There are various methods for propagating cannabis plants vegetatively. The primary methods are air-layering, grafting, and cuttings (ElSohly et al., 2017). After screening and choosing a clone with a specific composition, a healthy node section of roughly 6 to 10 cm in length with a minimum pair of nodes from the parent plant may be utilized for vegetative purposes. Cannabis may be efficiently propagated vegetatively by utilizing either a solid (soil) or a liquid media (hydroponics) (Chandra et al., 2017a; ElSohly et al., 2017). For soil propagation, a terminal limb is clipped at an angle of 45 degrees underneath a node and instantly submerged in filtered water. The cutting's bottom (2 cm) is then drenched in rooting hormones before being implanted in containers (5 cm × 5 cm) composed of a coco natural growing medium and a sterilized potting mix (1:1) mixture. Rooting begins in 2-3 weeks, accompanied by transplanting to larger pots (e.g., 30 cm × 30 cm) after six weeks of indoor culture (ElSohly et al., 2017). Plants are grown underneath 18 hours of photoperiod for vegetative development unless they reach a specific size, at which the light cycle is switched to a 12-hour photoperiod for flowering and maturity (Government of Canada, 2022).

### 4.2.3 *In vitro* micropropagation

The callus phase has been used in most *in vitro* regeneration methods produced for cannabis thus far. Young leaves are used as the source of indirect organogenesis established for cannabis. Cannabis propagation by nodal explants, as opposed to callus, allows for the development of hereditarily stabilized and true-to-type offspring (ElSohly et al., 2017; Farag and Kayser, 2017). Despite the numerous ways for plant propagation, direct organogenesis is a prominent *in vitro* propagation method that involves the tissue development of arboreal organs or axillary buds from plantlets, either explicitly or implicitly. Direct organogenesis is a two different Cannabis methodology developed at UM that employs nodal segments (Chandra et al., 2017a; Government of Canada, 2022). However, a novel aromatic cytokinin has been employed to generate a one-step regeneration strategy based on adventitious shoot stimulation and effective rooting (Chandra et al., 2017a). Gas chromatography-flame ionization detection (GC-FID) is utilized initially to analyze alchemical profiling and determine cannabinoids in micro propagated plants to assess the long-term stability of the phytochemical composition (ElSohly et al., 2017).

## 4.3 Plant spacing

Plant spacing varies according to the species of cannabis growing. Typically, the maximum yield of flowers or buds is produced when cannabis is cultivated for CBD at a plant population of 10-15 plants $m^{-2}$, which eliminates unwanted self-thinning owing to interspecific competitiveness (Adesina et al., 2020; Campiglia et al., 2017).

## 4.4 Water requirements

Cannabis requires substantial water throughout the growth periods, particularly during the initial six weeks when the young plants are entrenched (Schilling et al., 2020a,b; Small et al., 2003). Cannabis necessitates a rainfall of 63 to 75 cm. According to other research, cannabis demands 2500-3500 mm of moisture during the vegetative stage and 5000-7000 mm of accessible moisture for optimal yield (Adesina et al., 2020). According to Folina et al. (2019), drip irrigation is the best approach for controlling the amount of water used in indoor farming. Drippers are commonly fitted on black plastic tubes 12-20 mm in diameter placed on the ground surface, one for each plant line or one for two.

## 4.5 Fertility requirements

The principal soil macronutrient that affects THC in cannabis plants is nitrogen. According to a study, soil nitrogen levels are directly tied to the THC concentration of cannabis leaves and their location on the plant (Government of Canada, 2022; Żuk-Gołaszewska et al., 2018). As a result, cannabis is less susceptible to potassium (K) fertilization than N and P fertilization; it is recommended that cannabis get 120 kg, 52-67 kg, and 65 kg NPK/ha (Adesina et al., 2020; Amaducci et al., 2015). Organic additives, such as mammalian excrement, such as horse manure, can be an excellent fertilizer for cannabis development, according to Adesina et al. (2020) and Small et al. (2003), followed by the cow and poultry manure.

## 4.6 Current varieties

Selecting a cultivar that is ideal for a particular utility and adaptable to a dynamic environment is essential for cannabis cultivation (Amaducci et al., 2015). Cultivars cultivated in northern settings produce less biomass when grown in the South, owing to shorter growth length and early blooming. Cultivars developed in low latitudes; on the other hand, they exhibit prolonged blooming and substantial biomass outputs when cultivated at high elevations (Amaducci et al., 2015; Laursen, 2015; McPartland, 2018). Nowadays, up to 20 Cannabis hybrid cultivars exist that are more or less well-defined variants for indoor or exterior growing (Farag and Kayser, 2017). Marijuana strains generally have greater total THC levels and develop a lot of flowers and side branches, giving them a bushy look (Table 4) (Schilling et al., 2020b).

In the Netherlands, Bedrocan BV studies and registers three *Cannabis sativa* varieties: Bedrocan, Bedrobinol, and Bediol, as well as one Cannabis indica variety, Bedica (Farag and Kayser, 2017). Amaducci et al. (2015) recommended the YunMa cultivar series for Southern China (YunMa 1, YunMa 2, YunMa 3, and YunMa 4) bred in Yunnan Province, Southwest China. Similarly, in Europe, cannabis production and psychoactive tetrahydrocannabinol (THC) levels are officially limited to 0.2 per cent. Some cultivars mentioned in the European Union Cultivar Catalog are Futura 75, Ferimon 12, Felina 32, Fibrol, KC dora, Kc Zuzana, Lovrin 110, Santhica 23, Santhica 27, Santhica morcna, Santhica 70, KC Virtus, Lipko, Monoica, Cannakomp, Finola, Tygra, Bialobrzeskie, Beniko, Kompolti, Tibors (Table 5) (Baldini et al., 2018; Fernandez et al., 2019; García-Tejero et al., 2019; Islam et al., 2021; Laursen, 2015; McPartland, 2018; Schilling et al., 2020a; Tang et al., 2016). Furthermore, Schilling et al. (2020a) stated that trichomes may be abundantly present in the female *Cannabis sativa* plant epidermises of the varieties Finola and Felina 32.

## 4.7 Method of cultivation

### 4.7.1 Outdoor cultivation

Outdoor cannabis cultivation often begins in early April or the last week of March or with the advent of warmer weather and continues around early December or November, based on the kind (Government of Canada, 2022). The seeds are planted in little disposable pots, and healthy seedlings are transported onto the field. Seeds can also be sown directly on the field (ElSohly et al., 2017). Male blooms, followed by female flowers, occur two to three months after

**Table 4.** Varieties within subspecies according to the domestication of *Cannabis sativa*

| Subspecies | Varieties | THC content | Traits |
|---|---|---|---|
| Indica | Indica | High | Domestication |
| Indica | Kafiristanica | High | Wild-type |
| Sativa | Sativa | Low | Domestication |
| Sativa | Spontanea | Low | Wild-type |

Source: Bonini et al. (2018); Bilodeau et al. (2019); ElSohly et al. (2017); McPartland (2018)

seeding/transplanting (around the middle of July. Male plants are typically culled because they produce less D9 -tetrahydrocannabinol (D9 -THC) than female plants, preventing cross-pollination between various types and within that variety (Government of Canada, 2022; Wartenberg et al., 2021). It is tough to sustain a consistent chemical composition in outdoor settings if cultivated from seeds, depending on the weather and available area (Fig. 3) (ElSohly et al., 2017; Farag and Kayser, 2017). Vegetative cuttings of specific parent plants with certain molecular patterns (CBD-THC type or high CBD type) are favoured for producing cannabis with different chemical profiles (Chandra et al., 2017b).

#### 4.7.2 Indoor cultivation

Indoor growing of cannabis under-regulated ecological parameters enables comprehensive monitoring of the plant's life cycle, culminating in the administration of biomass quality and quantity (Stambouli et al., 2005). Cannabis growth and photosynthetic processes necessitate a higher photosynthetic photon flux density (PPFD). It can employ moderate PPFD and humidity for gas and water vapour exchange activities. It performs considerably better when grown at an optimal light intensity of 1500 mol.m2s1 and a temperature of 25-30 degree Celsius (Government of Canada, 2022). For indoor propagation; many light sources can be employed, such as fluorescent light bulbs for juvenile cuttings and high-intensity discharge (HID), high-pressure sodium (HPS), or metal halide (MH) bulbs for mature plants (Fig. 3) (Máthé, 2015).

If a photoperiod cycle of more than 18 hours of light and 6 hours of darkness is managed, these plants will persist in vegetative growth. Cannabis blooms when exposed to a 12-hour photoperiod (ElSohly et al., 2017; Farag and Kayser, 2017). The humidity in the indoor growing room is critical, including all phases of plant development, from seedling growth to blossoming and harvesting. When compared to fully established plants, juvenile plants demand higher humidity. Herbaceous cuttings require regular water spraying on the foliage to maintain the microclimate moist (70-75 per cent humidity) till the seedlings are well anchored, even though active vegetal and flowering periods require 55-60 per cent humidity (Máthé, 2015; Wartenberg et al., 2021). The quantity and periodicity of cannabis irrigation are determined by various factors, including growth stage, plant size and pot size, temperature, humidity, and other characteristics. Airflow over the surfaces of the leaves regulates water vapour and gas interaction between the foliage and the microclimate (Chandra et al., 2017a; El-Sohly et al., 2017; Wartenberg et al., 2021). It has been found that increasing the acoustic CO2 concentration in the atmosphere increases the photosynthetic activity and water usage efficiency (WUE) in cannabis by 50 and 111 per cent, respectively, leading to higher total growth (ElSohly et al., 2017; Farag and Kayser, 2017; Government of Canada, 2022; Máthé, 2015).

### 4.8 Flowering inducement

Flowering was produced after 12 hours of photoperiod in the presence of a suitable nutritional media. Female pistil flowers will blossom on the plant in 7-14 days, racemes will expand in volume, and cannabinoids will slowly accumulate throughout this time. After eight weeks of blossoming, the stigma and trichomes transfer and become an organ/brown colour, and the rate of THC production drops drastically (Máthé, 2015). Adesina et al. (2020) observed, however, that specific cultivars begin flowering regardless of day length, whilst others require fewer days to reach the flower development stage. Phytochromes are specialist photoreceptor proteins that initiate flowers produced in response to the seasonal increase in night length (Potter, 2013; Werf, 1994). Indoor cannabis farmers control this reaction by starting plant development with a long day duration of 18 to 24 hours daily. It is a common and well-documented strategy to stimulate and sustain bloom by changing the day duration to a 12-hour and 12-hour night cycle (Potter, 2013).

### 4.9 Harvesting, processing and storage

Addressing the optimal collecting stage is crucial in cannabis cultivation for achieving the desired biochemical content, such as the optimal D9 -THC concentration (Chandra et al., 2017b). This may be accomplished by daily analyses of the cannabinoid concentration in various plant areas. The concentration of D9-THC climbs with the age of the plant until it


**Figure 3.** Cannabis cultivation system and potential ecological impacts. (A) Outdoor cultivation generally applies to other farming systems in that energy is obtained from sunlight, and water is obtained locally through rainfall or storage. Plants are cultivated on either local or imported soil, and nutrients can be supplemented with fertilizers. (B) Indoor cultivation depends on synthetic water supply, soil media, nutrients, and energy. Indoor facilities are generally incorporated with local power/storage/water systems, which can help with waste management and resource surveillance. [Modified from Wartenberg et al. (2021)]

reaches a maximal point during the budding stage, following a linear progression for 1-2 weeks before decreasing with the start of senescence (Bonini et al., 2018). If D9-THC production is the primary goal, harvesting occurs when the crop is in the complete flowering stage or when 75 per cent of the hair-like structures become brown, indicating that the flowers are ready to harvest (Folina et al., 2019). The stems are clipped just at the roots (Potter, 2013), then dried in the shade for seven days with continual desiccant air, or a basic laboratory oven can be utilized for overnight drying at 40 °C (Chandra et al., 2017a), and then leaves and the inflorescence is manually removed (Máthé, 2015). It is generally advised that the drying temperature be kept between 40 and 45 °C since numerous terpenoids (molecules that are partially responsible for the psychoactive effects but are also highly responsive to plant odour) dissipate at temperatures over 45 °C (Amaducci et al., 2015; Folina et al., 2019).

Furthermore, the elimination of the carboxyl group is required for the conversion of cannabinoid acids (THCA, CBDA, etc.) into neutral cannabinoids. This is accomplished by evenly heating the dried material (Potter, 2013). To preserve stability, the entire extract of cannabis is treated to eliminate undesired co-products of the extract for standardized improved Cannabis supplementary extract, which is maintained at 20 to 5 °C in closed chrome-plated cylinders (Amaducci et al., 2015; Máthé, 2015).

### 4.10 Yield

Dry flower yields can typically approach 400 g $m^{-2}$ each crop cycle under perfect climatic conditions and competent management. Total annual yields can exceed 2 kg of dried flowers $m^{-2}$ due to repeated cropping 4-5 times per year (Máthé, 2015).

### 4.11 Disease and pest control

The Good Agricultural Procedures, which govern quality requirements in medicinal crop cultivation and processing, allow for minimal pesticide usage and a preventive and curative approach (Potter, 2013). Some of the diseases seen in cannabis include grey mould (caused by *Botrytis cinerea*), cannabis canker (caused by *Sclerotinia sclerotiorum*, *Fusarium* species, and other genera), root rot (caused by *Fusarium solani*), and damping off (caused wide species of fungus, but primarily by oomycetes) (Máthé, 2015; Small et al., 2003). Furthermore, numerous bacteria, viruses, and parasitic plants are responsible for various disorders. Similarly, approximately 300 insect species have been discovered to attack cannabis, including stem borers, beetle larvae, flower beetle grubs, and cabbage or *Cannabis curculio*, which damage the stem, leaves, roots, and inflorescences (Maule, 2015; Small et al., 2003). To manage the aforementioned diseases, rigorous cleaning procedures are essential, and growth circumstances that encourage infections and infestations must be avoided. Furthermore, any pests that come can be controlled by beneficial insects and mites that consume or parasitize the invader (Máthé, 2015; Wartenberg et al., 2021).

### 4.12 Production factors affecting yield and quality

Some of the production factors that influence cannabis yield and quality are as listed below:

**Genetics** The genetic makeup of the cannabis plant plays a significant role in determining yield and quality. Varieties with higher yields and better-quality traits can be selectively bred to enhance production (Chandra et al., 2017a).

**Light** Light is crucial for photosynthesis, growth, and flowering of the cannabis plant. The intensity, duration, and spectrum of light influence the yield and quality of the final product. Studies have shown that high-intensity LED lighting can significantly increase yield and potency (Magagnini et al., 2018).

**Nutrients** The cannabis plant requires a range of macronutrients, micronutrients, and trace elements for growth and development. Proper nutrient management is essential to maximize yield and quality. Studies have shown that nitrogen, phosphorus, and potassium are the most critical macronutrients for cannabis production (Yang et al., 2021).

**Temperature and humidity** Temperature and humidity play a critical role in the growth, development, and overall health of the cannabis plant. Studies have shown that optimal temperature ranges between 20-28°C during the day and 18-24°C at night, with humidity levels between 40-60% during the vegetative stage and 50-60% during the flowering stage (Andre et al., 2016).

**$CO_2$** Carbon dioxide is a critical factor in cannabis cultivation as it enhances photosynthesis and plant growth. Studies have shown that elevated $CO_2$ levels can increase yield and potency, with optimal levels between 800-1200 ppm during the vegetative stage and up to 1500 ppm during the flowering stage (Magagnini et al., 2018).

**Water** Proper water management is essential for cannabis production, as water stress can significantly reduce yield and quality. Studies have shown that irrigation systems with drip emitters or micro-sprinklers

**Table 5.** List of cannabis varieties, release year, and production capacity in different countries

| Country | Variety | Release year | Production capacity (MT $ha^{-1}$) |
|---|---|---|---|
| Canada | 'Finola' | 2003 | 0.5 - 1.5 |
| China | 'Yunma 1' | 2015 | 1.6 - 3.3 |
| Czech Republic | 'Kompolti' | 2010 | 0.7 - 1.2 |
| Denmark | 'Tycho' | 2012 | 1.2 - 1.7 |
| France | 'Fibrimon 24' | 1999 | 1.0 - 1.5 |
| Germany | 'Felina 34' | 2002 | 1.2 - 1.8 |
| Hungary | 'Kompolti' | 2011 | 0.7 - 1.0 |
| Italy | 'Carmagnola' | 1997 | 1.0 - 1.5 |
| Netherlands | 'Futura 75' | 2013 | 1.0 - 1.5 |
| Poland | 'Białobrzeskie' | 2016 | 0.8 - 1.2 |
| Romania | 'Tisza' | 2014 | 1.1 - 1.6 |
| Slovenia | 'USO-31' | 1998 | 1.1 - 1.4 |
| Switzerland | 'Fedora 17' | 2010 | 0.8 - 1.2 |
| UK | 'Futura 75' | 2002 | 0.8 - 1.3 |

Source: Karche and Singh (2019); Struik et al. (2000); Raman et al. (2017); Amaducci et al. (2015); Baldini et al. (2020); Deleuran and Flengmark (2006); Lisson and Mendham (2000)

can provide uniform water distribution and reduce water stress, leading to improved yield and quality (Bajić et al., 2022).

**Pest and disease management** Effective pest and disease management is important for maintaining plant health and maximizing yield and quality. Common pests and diseases that can affect cannabis include spider mites, aphids, powdery mildew, and bud rot (Magagnini et al., 2018).

## 5 Impacts on the environment

### 5.1 Positive impacts

**Carbon sequestration** Hemp plants have the ability to sequester large amounts of carbon dioxide from the atmosphere, thus helping to mitigate climate change (Pervaiz and Sain, 2003).

**Soil health** Hemp plants have deep taproots that can penetrate up to 2 meters into the soil, helping to break up compacted soil and improve soil health (Amaducci et al., 2015).

**Water conservation** Hemp plants require less water than many other crops, and their water use efficiency is high, meaning they can produce a greater amount of biomass per unit of water used (Gill et al., 2022).

### 5.2 Negative impacts

**Pesticide use** Hemp plants are susceptible to pests and diseases, and some farmers may use pesticides to protect their crops. This can lead to negative impacts on the environment and human health (Wartenberg et al., 2021).

**Soil contamination** Hemp plants have the ability to absorb contaminants from the soil, which can be a concern if the soil is contaminated with heavy metals or other pollutants (Husain et al., 2019).

**Water pollution** Hemp cultivation can potentially lead to water pollution if runoff from fields containing fertilizers or pesticides contaminates nearby water sources (Wartenberg et al., 2021).

## 6 Conclusion

Cannabis has the potential to be a valuable agricultural and medicinal crop if grown properly. The legalization of its production under controlled indoor conditions highlights its significance for mankind. It is important to recognize that all things have both benefits and drawbacks, and we should work to minimize the negatives while maximizing the positives. By taking appropriate precautions, we can effectively grow, process, and use cannabis for our benefit. Additionally, lifting the prohibition on its cultivation and use will allow researchers to further explore the potential of this crop and uncover its secrets.

## Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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