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REVIEW

A Comprehensive Review on the Production, Cultural, and Medicinal Applications of Cannabis Plant for Sustainable Economic Development

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ABSTRACT

Cannabis sativa is a versatile plant which is recognized as an exceptional carbon sink and sustainable biofuel that addresses economic, environmental, and social dimensions. Its cultivation has historically been prohibited in many countries due to its psychoactive effects. However, the global movement towards the legalisation and decriminalisation for its medicinal and industrial uses has recently intensified, prompting new research into its botanical, ecological, and agronomic aspects. This review explored the available scientific information for a holistic and understanding of the Cannabis' medicinal and industrial applications. The review applied a

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systematic literature review guided by PRISMA principles to synthesize published work on *Cannabis sativa*. Peer-reviewed and grey literature were sourced from multiple databases and repositories using defined keywords. No lower time limit was applied, and literature coverage published work up to December 2023. After screening 625 records, 180 studies were retained and thematically grouped into six areas: historical or cultural significance, legality, botanical and chemical characterization, agronomic practices, medicinal potential, and economic contributions. A narrative synthesis highlighted key findings, contradictions, and knowledge gaps, while noting potential biases such as English-only sources and uneven geographic representation. The study further discussed the historical overview of cannabis, current global scenarios and legality issues, classification concerning botany and cannabinoid contents, agronomic and ecological practices, chemical composition, its biological activities, and economic importance. The study concludes that by balancing economic growth with environmental stewardship and cultural preservation, cannabis can be a promising cornerstone crop for sustainable development in South Africa and globally in the 21st century.

Keywords: *Cannabis sativa*; Medicinal; Industrial; Economy; Classification; Ecology; Legality Status; Cannabinoids

1. Introduction

Despite cannabis's extensive potential as a multifaceted crop with significant agricultural, medicinal, and economic value, its historical illegality has resulted in a critical gap in scientific knowledge regarding its cultivation, production, and long-term sustainability. Cannabis has been utilized in medicinal and recreational applications for centuries across the globe [1]. Medicinal cannabis is defined as the *Cannabis sativa* strains with a tetrahydrocannabinol (THC) concentration exceeding 0.3% [2]. According to Zheng et al. [1], the THC compound is psychoactive, and it creates a psychogenic effect when consumed by humans. In addition, THC has painkilling, anti-inflammatory, and antioxidant properties [3,4]. Cannabis also has a non-psychoactive compound called cannabidiol (CBD), which is known for its medicinal values [5]. CBD possesses anti-convulsive properties that suppress certain psychoactive effects of THC [4]. Medicines derived from cannabis have a significant role in the treatment of cancer, Alzheimer's, multiple sclerosis, and chronic pain, and function as safer alternatives to anaesthetics for relaxation [6]. Cannabis also holds a diverse cultural significance globally, serving as a sacred plant, traditional medicine, stimulant, and symbol of counterculture. In India, it is associated with the god Shiva and various spiritual practices. In Africa, it was used for labour, although policies have often marginalised its users [7]. The Rastafari movement uses it as a sacrament [7], while in the West, it has been tied to the 1960s counterculture, art, and music [8].

According to the Global Cannabis Report, September 2021, more than 70 countries have legalized cannabis for medicinal application, including Morocco, Portugal, Germany, and Australia. However, in South Africa, Canada, Uruguay, Mexico, the Netherlands, Spain, and parts of the United States, it has been legalized for adult use only [9]. The global cannabis market value is predicted at USD 214–344 billion and is likely to expand in the next few years [10]. In South Africa, the cannabis market value is estimated at R5 billion per year [11]. This global legalization of cannabis for its medicinal and economic value has prompted interest in the cultivation and distribution of products containing cannabidiol (CBD) extracted from cannabis flowers [12]. Hence, the current amendments in relaxing the legislation prohibiting the cultivation of medicinal cannabis in South Africa [11]. Cannabis is still a poorly understood agricultural plant despite its rich cultural, medicinal, and economic capability [13,14], with relatively limited available scientific information on its agronomy and socio-economic potential [15]. This is attributed to its previous legal position as a Schedule 1 drug category by the United States Drug Enforcement Administration [4]. Furthermore, limited agronomic information on cannabis challenges producers seeking to grow and produce high-quality crop yields [16]. Moreover, the systemic principles towards the sustainable cultivation and reproduction of cannabis remain unclear [17,18].

However, reproduction methods have an unavoidable influence on the yield and quality of the produce [19]. According to Small [20], Cannabis is an annual herbaceous and dioecious (bearing both female and male flowers) plant. The female flowers are rich in acidic forms of cannabinoid, namely, D9-tetrahydrocannabinolic (THCa) and cannabidiolic (CBDa) [16]. Owing to its dioecious reproductive nature, seed propagation is commonly practiced [9]. This results in the predominant emergence of male flowers, which have no commercial use except that of seed production and lack genetic uniformity among seedlings [21].

In contrast, the pollinated female flowers shift chemical properties from cannabinoid production to seed development [22]. To prevent this process, vegetative propagation from female plant material is commonly used. Hence, vegetative propagation methods such as stem cuttings become the primary method of propagation to maintain the genetic quality of cannabis cultivars for industrial cultivation [22,23]. Rooting success from stem cuttings depends on a series of factors such as the type of rooting media, temperatures, physiological state of the mother plant, as well as the position of the plant where the cutting is taken [24]. However, despite its growing legalization and multifaceted applications, cannabis remains poorly understood agronomically and culturally, leaving gaps in sustainable cultivation knowledge and economic integration. There is, therefore, a compelling need to study its full potential through an investigation into appropriate agronomic practices for increased yields and product sustainability.

This review is guided by the sustainable livelihood framework and the triple-bottom-line model of sustainability, which emphasizes the integration of economic, environmental, and social dimensions in agricultural development. Cannabis production is examined not only as an agronomic and botanical system but also as part of a broader value chain with cultural, medicinal, and industrial links. By applying these frameworks, the review fuses fragmented evidence into an overarching model, highlighting how cannabis can simultaneously contribute to sustainable rural livelihoods, environmental resilience, and global economic growth.

2. Materials and Methods

This review followed a systematic literature review approach guided by the PRISMA principles to identify published work on the Cannabis plant. Peer-reviewed scholarly and grey literature were identified and sourced using several search engines such as Google Scholar, PubMed, Research Gate, Scopus, Science Direct, institutional repositories, and other relevant websites to source secondary data. Access to these databases was provided by Walter Sisulu University's and Dohne Agricultural Research Institute's online library. The following search strings were applied using keywords such as: "*Cannabis sativa*" OR hemp OR marijuana AND (cultivation OR propagation OR agronomy OR medicinal OR industrial OR economic OR legality). No lower time limit was applied, and studies published up to December 2023 were included. Only English-language sources were considered due to feasibility. Only peer-reviewed articles, theses, dissertations, and government documents, including non-government organisation reports addressing cannabis history, legality, botanical classification, agronomic or ecological practices, medicinal or industrial applications, and economic contributions were included. Additionally, popular media articles, opinion pieces, and publications without sufficient methodological details were not considered for this review. This initial search returned 625 published articles (outcomes), with 58 duplicates. The duplicates were removed, and the remaining (n = 567) were further screened by their topics, keywords, and abstracts, and their relevance; 387 documents were further omitted at this stage. From the remaining 216 full-text articles that were reviewed, 36 did not meet the inclusion criteria and were excluded. The main reasons for exclusion were: (i) studies that were outside the thematic scope of this review (for example, papers focused solely on recreational use or criminal justice aspects), (ii) publications with insufficient methodological detail or weak evidence, (iii) duplicate or overlapping data across different sources, and (iv) works where the primary focus was unrelated to the agronomic, medicinal, cultural, or economic dimensions of cannabis. After applying these criteria, 180 studies were retained for the final synthesis and were mentioned in the article bibliography. From the 180 publications, the author(s), year, country or region, key research focus (agronomic, medicinal, cultural, legal, or economic), and major findings were extracted. The extracted information was grouped thematically into six domains: historical or cultural significance, legality, botanical and chemical characterization, ecological or agronomic practices, medicinal potential, and economic contributions. A narrative synthesis approach was applied to compare findings, highlight contradictions, and identify knowledge gaps. Potential biases include restricting the review to English-language studies, which may have excluded relevant works published in other languages. Along with geographic representation may also be uneven, with greater emphasis on North American and European literature compared to African or Asian contexts. The flow diagram in **Figure 1** illustrates the screening and selection process for studies included in this review.

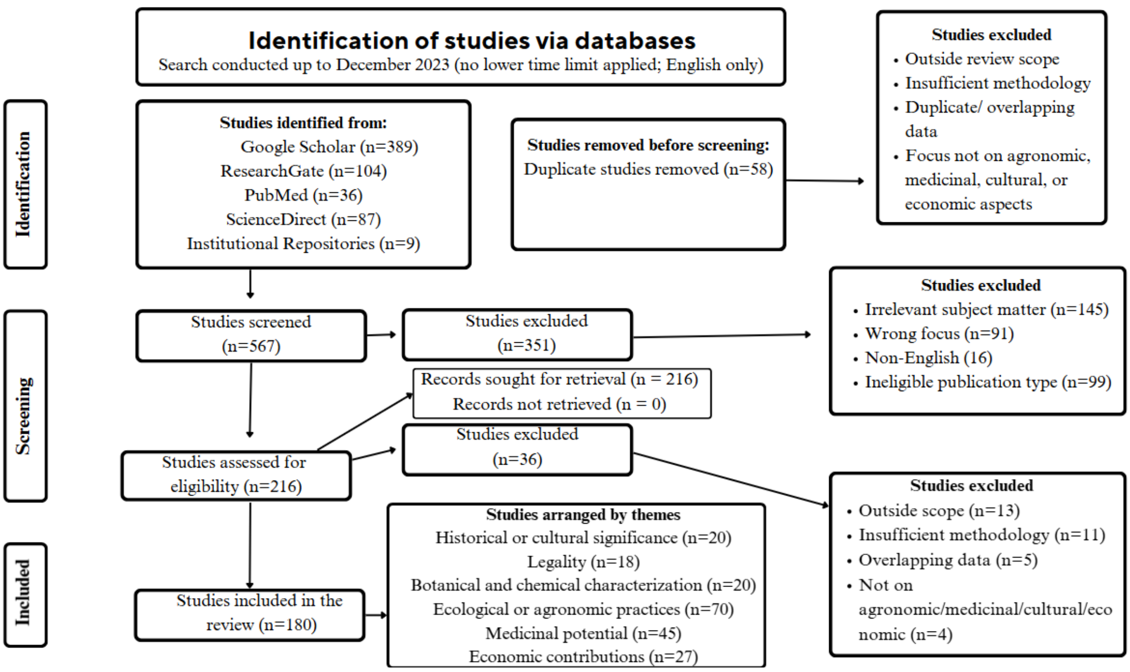


Figure 1. PRISMA style flow diagram.

3. Results and Discussion

This review explored available literature for a holistic, comprehensive understanding of the Cannabis plant, its medicinal and industrial applications, ecological or environmental factors affecting growth and development, as well as the economic potential. This study provides a historical overview of cannabis, examines current global scenarios and legal issues, discusses classification based on botany and cannabinoid content, and explores agronomic and ecological practices (propagation), chemical composition, biological activities, and economic importance. The reviewed studies suggest that cannabis holds promise for addressing sustainable health, economic, environmental, and climatic challenges, particularly in countries confronting poverty, although the evidence remains uneven across regions and contexts.

3.1. Historical Overview of Cannabis Landraces

Climate changes and variability have amplified a great concern regarding the state of existing plans to protect Plant Genetic Material for human use [25]. To address the current and future agricultural challenges, it is essential to classify, conserve, and understand the multiplication of landraces [26]. Plant genetic materials can change in response to changing environmental conditions and various selective pressures [27]. Hence, thoughtfully studied and maintained landrace populations are crucial for establishing a gene bank with adaptive features vital to safeguard the future of agriculture [25].

Cannabis sativa comprises both the drug or medicinal type (marijuana) and the industrial type (hemp) [28]. It is said to have originated in Central Asia [29]; however, its distribution is now global [30]. It has been widely cultivated as a medicinal plant since 2800 BC [31]. As a result, information on cannabis cultivation for medicinal purposes dates to the Pyramid texts from 2350 BC in Egypt [29]. The crop demonstrated its usefulness in the Roman Empire, where it was cultivated for fiber and medicinal purposes [32].

In Canada, cannabis is commercially cultivated for fiber and seed [33]. It is among the oldest non-food crops recognized globally [34]. Its cultivation was documented in the nineteenth century across Europe, especially in countries such as Germany, France, the Netherlands, the United Kingdom, Spain, Italy, and various other regions worldwide [34]. In Africa, archaeological evidence of the plant's arrival is limited. However, the continent-wide documentary record mainly dates to the nineteenth century [7]. Early trading routes in southern Africa brought the plant from the shores of the Indian Ocean into Mozambique and further into the heart of the continent [35]. Consequently, cannabis gardens were documented in South Africa, Mozambique, Egypt, Angola, Gabon, Sierra Leone, Kenya, Tunisia, and the Democratic Republic of Congo (DRC) during the nineteenth century [7].

In South Africa, it was found growing in isolated patches in the wild, where the individuals harvested the flowers for smoking [7]. It was first adopted by the Khoikhoi people, who used it as a chewed or boiled intoxicant and herbal remedy, and it was distributed to the Xhosa communities residing in the Eastern regions of South Africa [36]. In the Eastern Cape, the plant grows predominantly in Pondoland, in valleys and undercliff forests that are inaccessible to the law enforcement authorities [7]. Whereas the Eastern Pondoland, the Lusikisiki area in the Ingquza Hill region, has been known for decades to produce the best dagga in the country [11]. The historical trajectory of cannabis demonstrates its resilience as both a cultural and economic crop, yet gaps remain in linking traditional uses with modern applications. Future research could systematically compare indigenous knowledge systems with current industrial practices to identify sustainable innovations rooted in cultural heritage.

3.2. The Use, Cultural Application, and Historical Legality of Cannabis in South Africa

Cannabis is an important crop utilized by people for multiple purposes, ranging from recreational, medicinal, and industrial applications [37]. A medicinal plant refers to any plant that contains compounds with therapeutic potential to produce plant-based medications [38]. The long co-existence between human and cannabis resulted in its early domestication, which revealed a variety of possible uses such as a source for textile fiber, narcotic and psychoactive compounds [39]. North African farmers planted cannabis (industrial hemp) for fibre into the early 1900s, although it was a marginal crop [40]. The dagga plant has been utilized by most of the indigenous communities in Southern Africa for different reasons, including recreational, medicinal, and cultural applications [41].

The precise use and social norms regarding cannabis differed from one ethnicity to another [42]. Although there is limited substantial evidence on its cultural significance, it is documented that the Zulu warriors motivated their troops to smoke dagga to reduce fear and strengthen their fighting ability during their battles [43]. The white settlers used cannabis (dagga) to strengthen their economy [44]. Whereas the Nguni tribe smoked cannabis as a social custom [35]. Cannabis use as a mind-altering drug has gained increased public attention [11]. Smoking of dagga by labourers was associated with decreased efficiency, especially among those who were farm workers [35].

In 1925, cannabis was banned by international drug control measures under the Geneva Opium Convention, due to its psychoactive properties [7]. Making it a prominent focus of drug-policy reform [45]. Consequently, in the 1990's many countries, particularly in Europe, North America, and South America, relaxed regulations by permitting certain instances of production, sales, possession, and use [46].

In South Africa, the use, transportation, and sales of drugs such as cocaine, morphine, including cannabis were prohibited for the first time in 1922 under the Customs and Excise Duties Amendment Act 35 of 1922 [35]. In 1928, the cultivation and consumption of cannabis was outlawed under the Medical, Dental and Pharmacy Act No.13 [11]. Furthermore, the anti-cannabis legislation was intensified in 1971 through the passing of the Abuse of Dependence-producing Substances and Rehabilitation Centres Act (No. 41 of 1971, Schedule I). Followed by the installation of the Drugs and Drug Trafficking Act (No. 140 of 1992), which is still in effect and enforces a fine or imprisonment of not more than 15 years to those found in possession of cannabis [11,35]. Additionally, the Weeds Act (No. 42 of 1937) made provision for the combating of some weed plants, including cannabis. Moreover, the Conservation Agricultural Resource Act (No. 43 of 1983) (CARA), the amended act of 2001, declared cannabis a category 1 weed and invasive plant, which states that the plants may not occur on any land or inland water surface other than in biological control reserves [47].

Currently, decriminalization policies and new scientific evidence have increased the interest in the medicinal potential of cannabis and have paved the way for the release of marketing authorizations for cannabis-based products [48]. South Africa is participating in this global wave of cannabis liberalization [7]. As a result, some studies have reported that the South African Constitutional Court (Con-Court) ruling by the Deputy Chief Justice Zondo in September 2018, found the criminalisation of home use and cultivation of cannabis by adults, as specified in the Drugs Act of 1992 and the Medicines Act of 1965, unconstitutional [49,50]. However, it was emphasised that cannabis may not be consumed in public, distributed, sold, or used by minors [51]. To date, the draft *Cannabis for Private Purposes Bill*, which proposed the limits on personal and private adult use, possession, and cultivation as well as sales, has yet to be approved and signed into law by parliament [52]. Cultural practices surrounding cannabis reflect its role in identity, spirituality, and social structures. However, these dimensions are underrepresented in current economic and agronomic analyses. Comparative ethnographic studies across regions could provide valuable insights into how cultural acceptance influences legalization, consumption patterns, and market development.

3.3. Classification and Botanical Description of the Cannabis Plant

The genus *Cannabis* is an annual herbaceous plant and a member of the Cannabaceae family [53,54]. This genus was subdivided by 'Baptise de Lamarck' into two main species, namely *sativa* and *indica*, using the morphological and chemical characteristics [55]. Cannabis is a cosmopolitan species with a global distribution, and the term "Cannabis" is collectively used to represent various strains [56]. The plant has two distinct growth phases, namely, the vegetative and the flowering phases [29]. The vegetative phase is characterized by leafy, vegetative growth [57]. It has branched taproot roots that grow about 30–60 cm deep [58]. Cannabis has an upright growth habit with upright stems growing up to 2 and 4 meters, slightly branched with greyish-green hairs [54]. The plant has palmate leaves, comprised of five to seven leaflets, on long, thin petioles with acute stipules at the base, linear-lanceolate, tapering at both ends with sharply serrated leaf margins (**Figure 2**) [59].

Cannabis is a dioecious wind-pollinated species in which the male and the female flowers develop in separate plants [39,59]. However, it seldom displays a monoecious (hermaphroditic) nature [22], meaning that male and female flowers develop on the same plant [56]. Although this phenomenon is occasionally observed in successive generations [60]. The flowering male and female plants are easily differentiated based on their distinct inflorescence [61]. The flowers are unisexual; the male flowers develop in axillary and terminal panicles, apetalous, with five yellowish petals and five poricidal stamens, while the female flowers develop in the axils and terminals, with one single-ovulate ovary [29,57].

At flowering, each leaf axil has several flower heads on long, leafy stalks that make up the inflorescence. The female flower accumulates essential oils known as cannabinoids, which are mostly synthesized and stored in glandular trichomes [62]. A single light brownish grey small fruit about 2–5 mm long is produced per flower, containing a single seed tightly enclosed within a hard shell [63]. These fruits are elliptic, smooth, and filled with seed [54]. However, its phenotypic traits are influenced by genetic code (genotype) and the ecological factors [64].

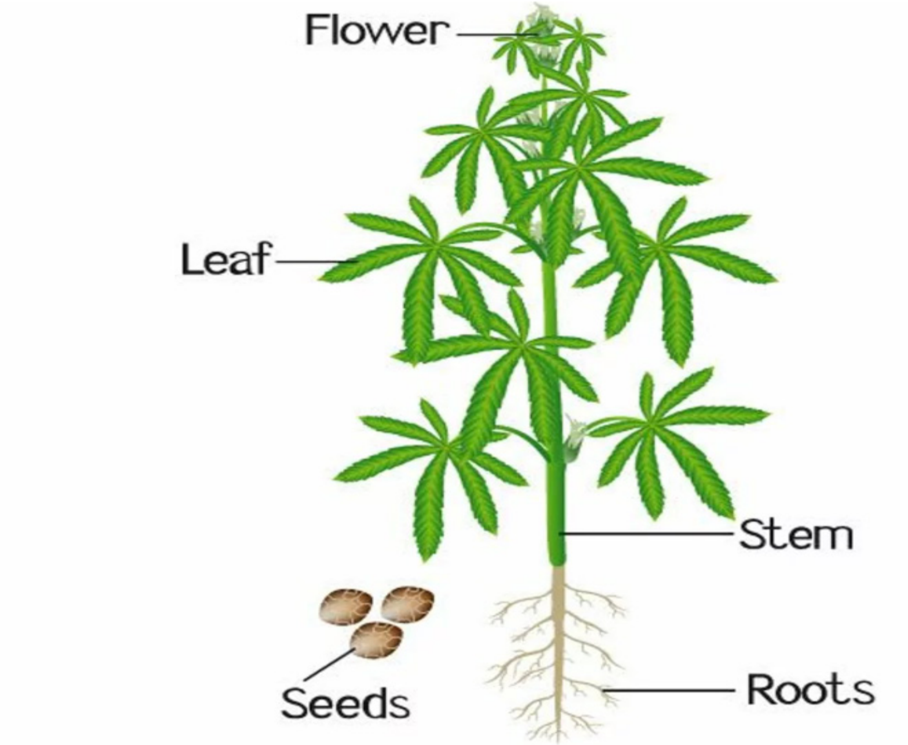


Figure 2. Schematic representation of a cannabis plant.

Source: Hesami *et al*., 2023.

3.4. Ecological Factors Affecting the Growth and Development of the Cannabis Plant

Plant growth productivity may be influenced by both environmental and agronomic factors as well as their interaction, and Cannabis is not an exception to these [65]. Cannabis is a rapidly growing, annual plant whose development and yield are affected by different ecological factors [66]. These factors include both abiotic elements, including temperature, water, light, and nutrients, as well as biotic components, including pests, microorganisms, and plant competition, which collectively influence cannabis physiology and morphology [67].

Cannabis grows well in well-aerated, slightly acidic soils with a pH value of 5.8–6.5 [68]. Soil texture, organic matter content, temperature, and available water influence nutrient availability and root development [69]. When soil encompasses these properties, it promotes the adsorption and exchange of mineral components, resulting in humus containing macro and micronutrients that aid plant growth [70]. These macronutrients (NPK) and micronutrients such as magnesium, calcium, and iron are important for plant growth and cannabinoid biosynthesis [71]. Moreover, microbial interactions, including mycorrhizal fungi, can enhance nutrient uptake and stress tolerance [69]. However, the activities of these beneficial bacteria may be restricted by the low pH, except for fungi, which may thrive in a wide range of soil pH levels [69].

Temperature is a critical ecological variable that significantly affects metabolic processes, cannabinoid synthesis, and plant structure [64,72]. Numerous studies suggest that the ideal temperature range for cannabis cultivation is 20–30 °C [73–75]. However, excessive temperatures, above 35 °C, and cold below 15 °C may induce stress, which may lead to reduced photosynthetic efficiency and impaired plant development [76]. Prolonged plant exposure to temperatures below 15 °C may cause slow growth [72].

Water use efficiency and effective irrigation strategies are crucial in both indoor and on-field cannabis production [77]. Water stress can severely impact cannabis growth and development, particularly at its flowering stage [78]. Overwatering can lead to rot diseases such as root and stem rot, post-emergence damping off, and nutrient leaching [79], whereas drought stress reduces leaf turgor, photosynthesis, and cannabinoid synthesis [80]. Relative humidity (RH) impacts transpiration and disease susceptibility [81]. Cannabis vegetative growth is favoured by higher RH ranging between 60–70% [82]. However, the flowering stage requires lower RH (40–50%) due to its susceptibility to diseases such as rust and mold [83]. Hence, the area planted must be well aerated to prevent fungal diseases and maintain strong plant structure.

Cannabis is naturally a photoperiod-sensitive plant; therefore, its growth and development are primarily influenced by light and period (day length) [84]. Numerous studies suggest that long photoperiods of 14$^+$ hours result in vegetatively grown cannabis plants, while short daylight of below 12 hours induces and encourages flowering [67,85,86]. Additionally, light intensity influences cannabinoid concentration by encouraging more photosynthesis and biomass accumulation, improving productivity [87]. Numerous studies that highlighted the interactive effect of ecological factors on plant growth and development are listed in **Table 1** below.

Table 1. Summary of previous studies.

Ecological Factor	Possible Explanation	Primary Effects on Plant Growth & Development	References
Light intensity	Higher light intensity increased photosynthesis; quality effects on cannabinoids were minor or varied with cultivar.	Higher light intensity resulted in photosynthesis that improved plant growth and flower yield. However, the response of secondary metabolites to light were differed based on cultivar.	Rodriguez-Morrison et al. [87]
Photoperiod (flowering)	Cannabis is generally a short-day plant. Photoperiod controls the transition to the reproductive stage; longer days can increase yield in some cultivars without reducing potency, but may delay the flowering.	Cannabis flowers robustly at 12 hours or less of light exposure. Although responses are genotype-specific, some cultivars initiate and bulk above at 13 to 14 hours with yield gains due to higher daylight intensity.	Ahrens et al.; Peterswald et al. [84,88]
Light spectrum & UV	Blue-enriched and UV-A exposures can shift cannabinoid/terpene profiles; classic work shows UV-B can increase Δ^9-THC in some genotypes, though modern results are mixed.	Spectrum tweaks chemistry more than biomass; UV can up-regulate certain secondary metabolites but may depress growth at high doses.	Park et al. [71]
Temperature	Photosynthesis is often optimal at 25–30 °C, and that is variety-dependent. Thus, some drug-type cannabis showed optimal growth between 25–30 °C.	Cannabis germination occurred at 5 °C however, the 12 °C was the optimal temperature for germination. Excessive heat above 30 °C can inhibit growth and development, and at flowering. Lower cannabinoid concentration was found when plants were subjected to 35 °C.	Chandra et al.; Dumani et al.; Holweg et al. [74,89,90]
Carbon dioxide (CO_2)	With sufficient light intensity and nutrients, CO_2 enrichment improves whole-plant yield.	Elevated CO_2 (700–1000 + ppm) increased leaf photosynthesis by about 40–50%. Moreover, it enhanced plant growth and flower yields. However, the effects on potency were inconsistent.	Chandra et al.; Chandra et al. [74,91]
Relative humidity (RH)	High RH (>70%) and cool-moderate temperatures (17–24 °C) favour Botrytis development in cannabis inflorescences.	Excessive RH increases bud-rot risk, and too low RH can result in stunted plant growth and quality.	Mahmoud et al.; Chandra et al. [82,91]
Airflow microclimate	Poor ventilation and stagnant air raise temperature and RH around buds, increasing powdery mildew and Botrytis risk; moderate air movement reduces the duration of leaf wetness.	Adequate airflow reduces disease pressure and supports gas exchange. Whilst the excessive wind can mechanically stress plants.	Punja et al. [92]
Water availability	Chronic deficit lowers biomass and harvest index; brief stress may alter phyto-cannabinoid profiles, but it is risky and genotype-dependent.	Severe drought noticeably reduces the floral hemp yield and cannabinoids. However, the induced short drought in late flowering has been reported to increase THCA/CBDA concentrations.	Morgan et al.; Fusaro et al. [93,94]
Irrigation strategy	Higher irrigation frequency in high-porosity media is associated with higher plant growth and yield.	Frequent, small irrigations maintain root-zone O_2 and nutrient delivery; although over- or under-watering suppresses plant growth.	Caplan et al. [16]

Table 1. *Cont.*

Ecological Factor	Possible Explanation	Primary Effects on Plant Growth & Development	References
Nutrients	Adequate, balanced nutrition increases vegetative vigour and floral yield.	Optimal Nitrogen (N) supply in the vegetative stage maximizes growth and yield. Whereas excessive fertilization doesn't necessarily increase cannabinoids. Phosphorus (P) and overall "ionome" changes alter biomass and chemistry.	Caplan et al.; Velechovský et al. [16,95]
pH (root zone)	Cannabis is commonly managed near pH 5.8–6.5 based on fertilization studies; lower acidic pH impairs the nutrient availability.	Outside the optimal pH, nutrient lockout and deficiencies occur, reducing growth and quality.	Wielgusz et al. [96]
Disease pressure	Botrytis: RH >70% and 17–24 °C in dense inflorescences are highly conducive; free moisture 8–12 h greatly increases infection. Powdery mildew thrives under moderate temperatures with high RH and poor airflow.	Direct losses of buds and their quality dictate conservative RH in flower, pruning, spacing, and sanitation are reported to prevent disease pressure.	Mahmoud et al.; Punja et al.; Romanazzi et al. [82,92,97]
Elevation and sunlight(UV)	Higher UV at higher altitude has been linked historically with higher THC in some accessions; however, responses are genotype dependent.	Potential THC up-regulation at high altitudes and high light exposure; excessive UV can reduce growth.	Bevan et al. [98]

Damping-off, Fusarium, and Pythium root and crown rot, powdery mildew, and bud rots are common diseases that affect cannabis growth and yield potential [24]. Therefore, understanding these environmental variables is essential for optimizing plant growth, development, health, yield, and cannabinoid content.

3.5. Characterization and Importance in Plant Improvement

The term "characterisation" in the context of gene banks and germplasm collection management refers to the description of features that are highly transmissible, physically visible (seen with the naked eye), and similarly expressed in all contexts [99,100,101]. Characterization is a systematic documentation of traits that define and differentiate plant genotypes [102]. It is a critical step in plant breeding and crop improvement involving detailed assessment and documentation of morphological, physiological, biochemical, and molecular traits of plant genetic resources (PGR) [103]. There are various types of characterization employed to achieve specific interests in crop improvement programmes. Each type contributes to a more complete understanding of the genetic potential and diversity of plant germplasm. Thus, morphological refers to observation of external traits such as plant height, leaf shape, flower colour, and fruit size [104]. Agronomic characterization: Evaluation of traits related to yield, stress tolerance, and adaptability [105]. Biochemical Characterization: Analysis of biochemical markers, such as protein or enzyme profiles [106]. Molecular characterization: Use of DNA-based markers, namely, Random amplified polymorphic DNA (RAPD), Inter simple sequence repeat (ISSR), and single-nucleotide polymorphism (SNP) to study genetic diversity [107]. Plant genetic material is critical for crop production, maintenance, and improvement. Morphological features are commonly used in the characterization of genetic diversity [108]. However, its trait expression is subject to ecological variability [109]. Characterization and evaluation of germplasm are important aspects in species conservation [110]. Without proper characterization, valuable genetic variation cannot be effectively used for plant improvement [111]. Hence, understanding variation in plant populations is vital for enabling breeders to select desirable features to develop plants with improved traits concerning growth performance, yield, and resilience to ecological stresses (drought and or diseases) to ensure economic gains [112,113].

3.6. Propagation Methods and Techniques of the Cannabis Plant

The best agronomic practices to produce quality medicinal cannabis are necessary to ensure efficiency and improved phyto-cannabinoid yields for sustainable product development [22]. Moreover, it is imperative to establish the propagation protocols for medicinal cannabis landraces that impose no differences in morphological, physiological, biochemical, as well as genetic profiles to that of the mother plant [9]. Generally, plant propagation is performed to multiply, reproduce, and preserve species' genetic material and is realized through sexual (seed) and asexual (vegetative) reproduction [114]. Due to high market demand for specific plant species, it is deemed essential to use suitable propagation techniques for a specific plant species [115]. Consequently, Cannabis is propagated sexually by seed [29], asexually by vegetative cuttings [116], and through micro-propagation using an in vitro technique [117]. Although agronomic guides and online information are available for growers, very limited are based on peer-reviewed scientific research [16]. However, these propagation techniques are critical to maximize the cannabis yields and quality for the development of high-value products [118].

3.6.1. Propagation of the Cannabis Plant through a Sexual Propagation Technique

The sexual propagation method involves the production of new plants from seeds [119]. The process of sexual propagation in plants includes the meiosis cell division, which is the process that creates natural genetic variability [120]. Agricultural plants are widely propagated by seed for the development of seedlings [114]. Hence, the seed propagation method is considered a basis for the production of valuable agronomic plants [119]. Thus, increases genetic variability and develops hybrids with superior qualities [121].

Conversely, Cannabis is a plant that is predominantly dioecious, and its reproductive nature is cross-pollinated [20]. Furthermore, when cultivated from seed, Cannabis produces approximately 50% male plants and 50% female [22]. Owing to its dioeciousness, seed propagation is commonly practiced [9], which results in the emergence of predominantly male flowers that have no economic importance other than the seed production [21]. According to Chandra *et al.* [22], male plants release pollen grains that set seeds in female plants, which negatively affects cannabinoid yield and quality. Thus, female plants are preferred for maximum cannabinoid production and to sustain uniformity in biomass [92]. As a result, the male plants are uprooted and discarded from the field as soon as they show up to circumvent cross-pollination [122]. Male flowers (**Figure 3a**) are morphologically different and appear earlier than female flowers (**Figure 3b**), making it easily determined and detached from the growing area.

(**a**) Male flower. (**b**) Female flower.

Figure 3. Visual illustrations of cannabis flower gender.

Source: Raman et al. [122]

3.6.2. Cannabis Propagation through an Asexual Propagation Technique

Asexual propagation, also known as vegetative propagation, is the plant reproductive technique that does not use the seed but involves the use of stems and leaf cuttings, the separation of suckers and rhizomes, as well as micro-propagation [114,119]. Asexual propagation is based on the principle of totipotency [119], which is defined as the capacity of a single cell to form an entire organism [124,125]. It is the most important means of plant regeneration for several horticultural crops such as fruits, nuts, vegetables, as well as industrial plants [119]. In this reproduction technique, adventitious organs development is the primary regenerative process required [125]. Adventitious organs are defined as organs that arise from the dedifferentiation [114], which is defined as the early stage of new root and shoot formation [119]. Asexually propagated plants are successively pure with a true-to-type genetic identity [126]. Therefore, traditional methods of cuttings technique (stem cuttings) in cannabis became the primary method to maintain and propagate superior cultivars for industrial cultivation [92].

3.6.3. Cannabis Propagation Using the Stem Cuttings

Propagation of a plant by cutting refers to the horticultural technique that surgically uses a vegetative fragment or part of a parent plant to reproduce new plants that are true to type [127]. This technique of propagation is necessary to maintain the lines of genetically identical plant material [23]. Various techniques of cuttings have been designed and used for plant multiplication based on the grower's needs and market requirements [128]. The plant parts that are often involved in propagation by cuttings are mostly the stems, herbaceous roots, and terminal bud, due to their simplicity and convenience; however, stem cutting usually presents a very low success rate [129]. The ability of stem cuttings to form roots varies according to the plant species; some root easily while others are stubborn even when growth regulators are applied [127]. Moreover, the herbaceous technique involves propagation through shoots, aided by the presence of intercalary meristematic activity with a high rooting success rate [130].

Plants propagated through the cutting techniques usually produce uniform yield, fruit size, and quality that fetch a good return in the market [131]. Many of the seed plants do not produce seedlings that are true-to-type [127]. With regards to cuttings' success, cuttings are plant fragments that have no root system and are prone to die from dehydration when the proper rooting conditions are not met [128].

Cutting requires a humid environment and rooting medium that is not too wet to avoid the cutting rot [131]. For this reason, several rooting mediums are used in this process, including but not limited to soil, perlite, vermiculite, coir, rock wool, expanded clay pellets, coarse river sand, and peat [132]. Although not essential, numerous plant hormone compounds, particularly the auxins, are applied to promote root formation [127]. Moreover, sustainable production with optimized propagation protocols for a stable source of biomass material is crucial for ensuring a consistent cannabinoid content in sustainable pharmaceutical drug development [22].

3.7. Biological Potentials of Medicinal Cannabis (*Cannabis sativa*)

Although Cannabis has numerous plant varieties, only two of them have economic significance, namely, *Cannabis sativa* and *Cannabis indica,* as described by Lamarck [55,56]. These two cultivars are usually referred to as medicinal cannabis [28]. A range of varieties and hybrids of *Cannabis sativa* L. has been developed and are suitable for both industrial and medicinal processing [56]. These varieties have different biological potentials, chemical composition, plant growth habits, and agronomic requirements [133].

Cannabis encompasses more than a hundred identified phytochemical constituents, collectively known as cannabinoids [134,135], which are primarily concentrated in glandular trichomes of unfertilized female flowers [57]. The medicinal properties of cannabis are attributed to a group of secondary metabolites (cannabinoids, flavonoids, stilbenoids, terpenoids, alkaloids, and lignans) that are beneficial for humans with multiple applications such as aromatherapy, cosmetics, and pharmacotherapy [67,136–138]. However, two major and well-studied cannabinoids have economic significance, namely, D-9-tetrahydrocannabinol (THC) and cannabidiol (CBD), which have historical use as recreational and medicinal agents [58,139]. THC is a psychoactive compound that is abundantly found in female inflorescences of the cannabis plant [140]. As such, growers harvest the female flower tops, and other plant parts, including male flowers, are discarded [141]. Whilst the CBD is found in all plant tissues and is non-psychoactive [142]. There are studies that suggest that the concentration and composition of these two cannabinoids determine whether a plant is classified as an industrial or medicinal species [140].

The medicinal cannabis contains a tetrahydrocannabinol (THC) concentration exceeding 0.3% [2]. In contrast, the industrial-type has a prevailing concentration of the CBD [133]. Despite being psychoactive, THC contains two synthetic analogues, namely, Marinol(dronabinol) and Cesamet (nabilone), that are medically approved and utilized to manage nausea and vomiting associated with cancer chemotherapy [48]. Apart from Δ9-THC and CBD cannabis compounds, such as cannabinol (CBN), cannabigerol (CBG), and cannabichromene (CBC), have healing effects when used in traditional remedies [31,143]. Subsequently, THC and CBN are active in lowering intraocular pressure and can be used in cases of glaucoma that are resistant to other therapies [144]. Terpenoids may directly stimulate physiological effects and or control cannabinoid responses [145]. In addition, flavonoids, cannabinoids, and terpenoids have biological effects, including anti-inflammatory, anti-cancer, and neuroprotective properties [146].

As an ancient medicine, cannabis contributes to healing several ailments, with separate plant parts used for a specific application [147]. Thus, the flowers were used in remedies prepared for the management of acute pain, insomnia, coughing, and wounds. While the leaves were used in remedies for malaria, panting, roundworm, and hair loss [137]. Roots were used in management of ailments such as fever, inflammation, gout, arthritis, and joint pain, skin burns, maternity (birth) complications, vaginal discharge as well as physical injuries [147]. In addition, cannabis is reported a key ingredient in the homemade remedies for asthma, epilepsy, fatigue, glaucoma, insomnia, nausea, pain, and rheumatism, and to stimulate appetite and digestion [148].

In modern science and pharmacology, female flowers are basically orally administered through use of vaporizers such as Micro Vape, G Pen Herbal Vaporizer, Volcano, buccal sprays, oral capsules and oils that are commercially available [149]. However, its pharmacological action is dose-dependent and may have negative effects, mostly associated to THC, due to unintended overdosing [137]. Dizziness, confusion, hypotension, panic depression, hallucinations, allergic reactions, vomiting, and diarrhoea have been reported to be the representative symptoms of cannabis over-dose [150–152]. Burning and smoking cannabis reduces the availability of bioactive ingredients by 40%, leading to lung diseases and breathing impediments [153,154]. Therefore, starting with low amounts and gradually increasing the quantities after a satisfactory period of clinical evaluation, depending on the pharmacological effects, is recommended [155,156]. An overview of the major cannabinoid constituents, their molecular structures, distribution in different plant parts, and associated bioactivities in humans is summarized in **Table 2.**

Table 2. Major cannabinoid constituents, molecular structure, distribution in plant parts, and their bioactivity in humans.

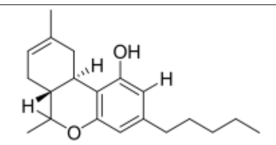
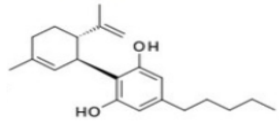
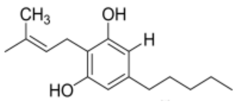
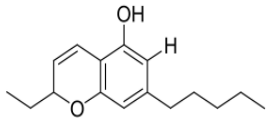
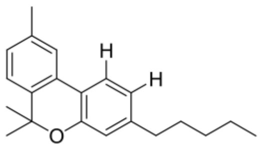
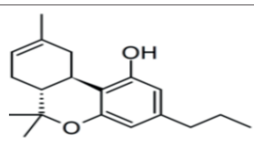
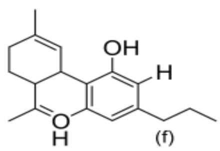
Cannabinoid Type	Molecular Structure	Main Plant Part	Bioactivity	Reference
Δ9-tetrahydrocannabinol (THC)		Flowers (mainly trichomes)	Analgesic, anti-nausea, appetite stimulant, Chronic pain, nausea (chemo), glaucoma, PTSD.	Blebea et al. [156]
Cannabidiol (CBD)		Flowers, leaves, some in stems	Anti-inflammatory, anxiolytic, anti-seizure, Epilepsy (e.g. dravet syndrome), anxiety, inflammation, arthritis.	Gonçalves et al. [157]

Table 2. *Cont.*

Cannabinoid Type	Molecular Structure	Main Plant Part	Bioactivity	Reference
Cannabigerol (CBG)		Early flowering buds, leaves	Antibacterial, neuroprotective, anti-inflammatory, glaucoma, inflammatory bowel disease, MRSA.	Odieka et al. [136]
Cannabichromene (CBC)		Flowers	Antidepressant, anti-inflammatory, pain, mood disorders, inflammation	Sepulveda et al.; Hong et al. [158,159]
Cannabinol (CBN)		Aged plant material	Sedative, anti-inflammatory, insomnia, pain, inflammation	Baron [160]
Tetrahydrocannabivarin (THCV)		Flowers	Appetite suppressant, anti-seizure, obesity, diabetes, epilepsy	Oultram et al.; Li et al.[161,162]
Cannabidivarin (CBDV)		Flowers	Anti-epileptic, anti-inflammatory, autism spectrum disorders, epilepsy	Zamberletti et al.; Alves et al. [163,164]

Cannabis pharmacology is rapidly expanding, but much of the evidence remains fragmented across small-scale or pre-clinical studies. Future directions should focus on standardized clinical trials, pharmacovigilance systems, and harmonized quality controls to validate efficacy and ensure safe integration into health systems. Such rigorous validation is essential to bridge the gap between traditional use and modern, evidence-based medicine. Additionally, by prioritizing these measures, researchers and policymakers can protect patient well-being and provide healthcare professionals with the robust data needed to make informed treatment decisions.

3.8. Economic Contribution of Cannabis

According to the Global Cannabis Report of September 2021, Cannabis has emerged as a significant economic enterprise in more than 70 countries that have legalized its medicinal use. African countries, including Lesotho, South Africa, Rwanda, Zambia, Malawi, Ghana, Eswatini, Zimbabwe, Uganda, and Morocco, are currently moving towards legalizing medicinal cannabis as part of economic diversification initiatives aimed at creating jobs and business opportunities [165,166]. Its economic contributions mainly comprised agriculture, pharmaceuticals, wellness, textiles (including hemp), and tourism (**Figure 4**) [167]. Hence, some African countries, such as Zimbabwe, Lesotho, and Malawi, propose to explore the potential of medicinal cannabis for industrial usage as a part of economic growth [168].

The cannabis market is subdivided into concentrates and flowers [168]. Flower contains approximately 15% to 30 % of THC, about 0.1% to 1% of CBD, and presumed levels of other cannabinoids, making it the dominant type in the market (**Figure 5**) [169]. The global market value for cannabis production was valued at USD 43.72 billion in 2022 and is predicted to grow to USD 444.34 billion by 2030 [10,170]. The market is likely to expand in the next few years with a projected annual growth anticipated to be the average 34.03% [166]. North America contributes 81.79% to the global cannabis market, with mainly Canada at 65% in 2024, benefiting from export opportunities to Germany and Israel, followed by Asia at 21.1% with Thailand dominating the production [171]. This is attributed to the increasing legalization of medical and recreational cannabis in the U.S [170]. South America and some African countries demonstrate opportunities for cost-effective outdoor production due to favourable climatic conditions. Thus, the Morocco's first legal harvest of 294 metric tons in 2023 showed its capabilities for export market [172]. While South Africa's 2024 Cannabis for Private Purposes Act newly regulates private cannabis use by adults, established the regional development [172].

Figure 4. Potential industries that could use the Cannabis plant as their main raw material for economic improvement.
Source: Raihan, and Bijoy [166].

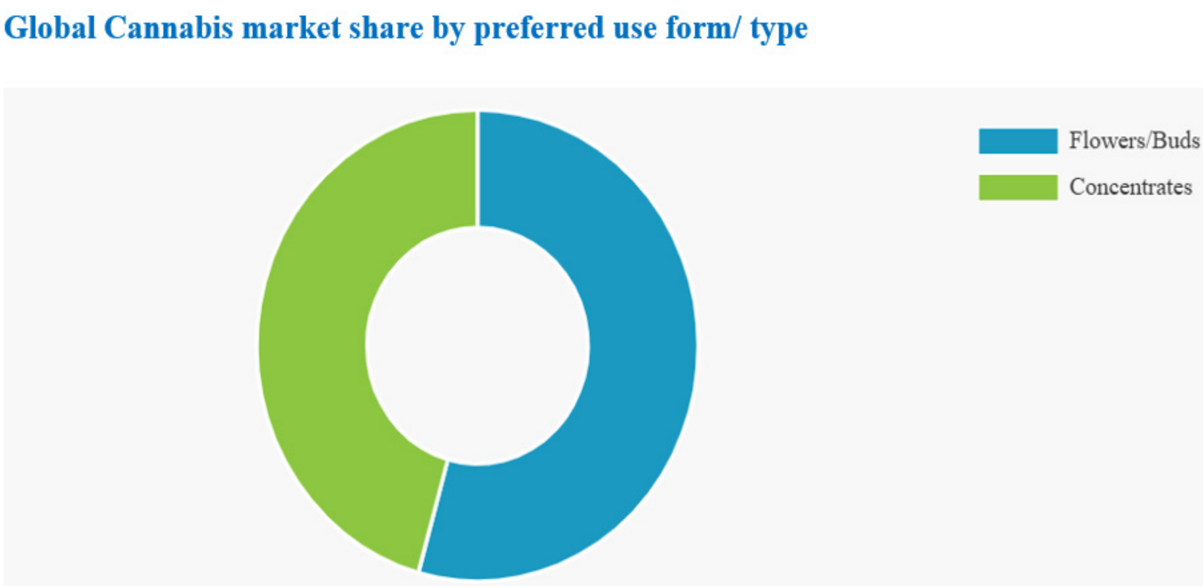


Figure 5. Widely consumed cannabis product in the global markets.
Source: Panchalingam et al. [168]

The South African cannabis industry is estimated to contribute R28 billion ($1.5 billion) and could potentially create approximately 10,000 to 25,000 jobs [165]. Furthermore, in South Africa, legal cannabis could add R107 billion (~USD 6 billion) to the economy and create over 130,000 jobs [173]. However, challenges such as ***a)*** regulatory uncertainty; lack of clear policies, particularly in developing countries, limits foreign investment and formal market development; ***b)*** Informal and illicit markets *viz* make it difficult to measure the true economic impact, particularly in countries where cannabis is still largely illegal; ***c)*** Banking and financing barriers *viz* businesses face limited access to banking and capital due to cannabis's classification as a controlled substance in many countries, and this impedes the contribution of cannabis to the economic growth and development. A global overview of cannabis production by region, including key producing countries, estimated production levels, and major trends, is presented in **Table 3**.

Table 3. Global overview of cannabis production by region, key countries, and production trends.

Region	Key Producing Countries	Global Production %	Estimated Productions (Tonnes/Year)	Brief Explanation of Production Trends	Source
North America	USA, Canada, and Mexico	72	1300	Commercial or large-scale production is driven by the legalization of cannabis. Thus Canada produced 600 and USA produces 700 tonnes in 2023, resulting in North America being the largest contributor to legal cannabis market.	Alpina; Market Growth Report [174,175]
South America	Colombia, Uruguay, and Brazil	5	28.6	Uruguay legalized cannabis in 2013 and has established a comprehensive regulatory framework for the cultivation, processing, and distribution of medical cannabis. Hence, their production is export-oriented; as such, in 2023, Uruguay was the only South American country among the top producers.	Malabadi et al.; Huseynova et al.; UNDC [176–178]
Europe	Netherlands, Spain, and Germany.	29	579	Production is driven by a strong medical market. However, the presented data is seizures as the is no available published data for Europe, especially considering the mix of illicit and newly legal or medicinal operations.	EUDA [179]
Africa	South Africa, Lesotho, and Morocco.	22–26%	Africa wide = 38,000; Morocco = 4200	Production is dominated by informal and traditional cultivation. This data estimate has likely incorporated both legal and illicit cultivation across the continent as the illicit cultivation is mostly dominant. Expect for Morocco, where cannabis production was legalised in 2022 for medical and industrial use.	Nabil et al. [180]
Asia-Pacific	China, India, and Thailand.	8.6%	n/a	Thailand legalized marijuana cultivation for domestic use in 2022. While South Korea, Japan, and Malaysia are paving the way for pharmaceutical applications. Hence, a rapid expansion in hemp cultivation for industrial and pharmaceutical applications is realized.	Malabadi et al.; UNDC; Niloy et al. [176,178,181]

Overall, the economic promise of cannabis is evident in textiles, construction, food, and bioenergy sectors. However, uneven market access and regulatory inconsistencies restrict its full potential. Cross-country comparisons of supply chain models and policy frameworks could help identify pathways for inclusive, sustainable economic scaling.

4. Conclusion

This review was limited by its restriction to English-language sources, which may have excluded relevant evidence from other linguistic regions. Furthermore, the geographic distribution of available studies was uneven, with greater emphasis on North American and European contexts compared to African or Asian ones. These limitations warrant cautious interpretation of the findings. The *Cannabis sativa* plant, with its multifaceted uses in industrial, cultural, and medicinal sectors, holds significant potential as a driver of sustainable economic development. Although the plant has been cultivated for ages in numerous places across the globe, it has been used as a medicinal herb. The advances in cultivation techniques, value-added processing, and scientific research on its therapeutic as well as pharmacological properties have expanded opportunities for emerging economic development. The study further revealed that the entire plant parts can be used for specific purposes (medicinal and industrial) and may be beneficial for economic growth initiatives, especially in poverty-stricken countries. Thus, integrating cannabis production into formal agricultural and industrial systems can generate employment, diversify rural incomes, and stimulate innovation in biotechnology, pharmaceuticals, textiles, and green construction. The literature suggested that the Cannabis plant provides a possible solution to the critical challenges of climate change, as an alternative, environmentally friendly, and sustainable raw material. However, the realization of its full potential depends on supportive regulatory frameworks, responsible cultivation practices, and continued investment in research and public awareness. This review, therefore, concluded that by balancing economic growth with environmental stewardship and cultural preservation, cannabis shows potential as a cornerstone crop for sustainable development, particularly in developing countries such as South Africa in the 21st century. However, an investigation into appropriate agronomic practices for increased yields and product sustainability may be necessary to explore the full potential of this highly promising multi-purpose crop. Furthermore, we identify research gaps for the policy-and-innovation agenda to align cannabis economies with public health, biodiversity conservation, and just transitions.

Author Contributions

A.D., Conceptualization, Writing—Initial Draft, Writing, Revisions, Data Curation, Investigation, Visualization; I.E., Conceptualization, Writing, Review and Editing, Supervision; T.T.S., Conceptualization, Writing Review and Editing; A.O.O., Data Curation and Reviewing; B.M., Conceptualization; O.A.S, Reviewing and editing, data curation and visualization, Review and Editing; H.A.S., Reviewing and Editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

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Informed Consent Statement

Not applicable.

Data Availability Statement

All data generated in this study are included in this article for publication.

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Conflicts of Interest

The authors declare no conflict of interest.

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