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Review

Industrial Hemp (*Cannabis sativa* L.) Agronomy and Utilization: A Review

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Abstract: Currently, there are increased interests in growing grain and fiber hemp (*Cannabis sativa* L.) as well as in large-scale hemp products. Cannabis has been grown/utilized for thousands of years as a fiber, grain, and drug/medicinal plant. However, the strict control of cannabis cultivation to combat illegal use, the spread of new yarns and oilseeds, and the advent of cheap synthetic fibers caused a decreased/eliminated hemp production. Hemp has been banned in most of the world for more than seven decades; it missed out on the Green Revolution and the adoption of new technologies and varieties, creating a knowledge gap. After the 2014 and 2018 Farm Bill in the USA, hemp became legal and the land grand universities launched research programs. The ability to utilize the entire plant for multiple purposes creates opportunity for the market to value hemp products. Hemp production technology varies depending on the type of hemp cultivated (grain, fiber, or cannabinoids), soil characteristics, and environmental factors. Hemp has the potential to be a very sustainable and ecologically benign crop. Hemp roots have a significant potential for absorbing and storing heavy metals such as lead, nickel, cadmium, and other harmful substances. In addition, hemp has been proven to be an excellent carbon trap and biofuel crop. Hemp has the ability to successfully suppress weeds, and it is generally regarded a pesticide-free crop. The purpose of this paper is to examine historic and recent industrial hemp (grain and fiber) literature, with a focus on hemp agronomy and utilization.

Keywords: hemp cultivation; prohibition; renewal

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1. Introduction

The multifunctional hemp's abundance of beneficial ecological, agronomical, and pharmaceutical properties qualifies it as a useful raw material for a variety of conventional (fiber, food, oil, medicine) and advanced industrial products [1]. Hemp is unusual in that it may be used to produce a wide range of products. It has traditionally been grown for fiber or as a crop with two uses (both grain and fiber) [2]. It is widely regarded as a crop with various uses and a wide range of current and future applications, including those for nutrition, energy, textiles, healthcare, and a wide range of industrial goods [3]. The cannabis plant (*Cannabis sativa* L.) is one of the world's oldest crops, which has been widely cultivated due to its industrial [4], nutritional [5], medicinal, and psychotropic [6] products. Regulatory perspectives and terminology vary in different countries based on the concentration of Δ^9-tetrahydrocannabinol (THC). In most countries, the grain and fiber hemp varieties are classified as 'industrial hemp', while the Farm Bills of 2014 and 2018 in the United States describe 'hemp' as "the plant *Cannabis sativa* L. and any part of such plant, whether growing or not, with a delta-9 tetrahydrocannabinol (THC) concentration of not more than 0.3% on a dry weight basis" [7]. The aim of this review is to recognize hemp as a multipurpose plant that deserves its place in crop production systems.

1.1. Hemp's Environmental Advantages

Hemp has the possibility to be a very sustainable and ecologically benign crop, if correctly handled [8]. Hemp's roots have a significant potential for absorbing and storing toxic elements such as lead (Pb), nickel (Ni), cadmium (Cd), and other harmful elements and substances, allowing the hemp plant to be utilized for phytoremediation of polluted soils [9]. The morphological features of hemp, such as faster growth, beautiful, green leaves, as well as aromatic flowers, make it suitable for use as a landscaping plant. According to the findings, cannabis has a high ornamental potential and high viability for sustainable exploitation in the horticultural and ornamental industry [10]. Densely sown, it is generally regarded as a pesticide-free crop [11]. It has the ability to successfully suppress weed growth, so it could be easily included into existing crop rotations [12]. Additionally, some hemp residues and products may be used in organic farming pest management programs as botanical pesticides, miticides, or repellants [13]. Due to its rapid growth and production, it is one of the most effective CO_2 biomass converters. Hemp has been proven to be an excellent carbon trap, absorbing more CO_2 per hectare than most agricultural commodity crops and perhaps even woodlands. Each hemp hectare has the capacity for absorption of up to 22 tons of CO_2 per hectare. Crops having a lot of biomass, such as hemp, can sequester more carbon through photosynthesis and then deposit this in the body and roots of the plant via bio-sequestration [9]. Another potential application for hemp biomass is the creation of biochar for use in soil, which could lead to significant increases in C capture, as well as mitigate soil emissions of other greenhouse gases including methane, along with improving soil physical, chemical, and biological properties important for crop production [9,14]. Hemp production has the capacity of producing more than 13,000 kg of biochar/ha, per year [15]. Hemp plants are also more energy effective because of their capacity to control weeds, reduced pesticide usage requirements, and soil-health-enhancing characteristics [16]. The fuel qualities of hemp are comparable to or better than those of other solid biofuels such as wheat straw and wood [17].

1.2. Environmental Requirements

Hemp grows in a wide range of environments, although different hemp ecotypes perform better in particular areas of growth [18]. It is a temperate-zone crop that thrives in latitudes between the 42nd and 45th parallels [19]. Photoperiod sensitivity is a crucial feature of hemp adaptation to a certain region [20]. The flowering period is a determining factor in the yield of hemp both in terms of quantity [21] and quality aspects [22]. Previously, researchers proposed a standardized hemp phenology scale based on the decimal codes [23,24]. Therefore, the hemp period is categorized into four stages of growth: germinating seeds and emergence, plant growth stage, blooming and seed forming, and ageing/maturity of the plant [25]. The phenological model proposed by other authors [20,26] further divides the vegetative stage into three stages: juvenile stage, photosensitive stage, and flower development stage.

Hemp is regarded as a thermophilic plant, and research suggests that it has high heat requirements that are equivalent to its high water requirements [27,28]. According to Zadrożniak et al. [29], at latitudes between 51° and 58°, the total heat supply for the 120–150 day hemp vegetation phase should be between 2000 and 2600 °C. This temperature range is ideal for seed maturation. When the soil temperature is 8–10 °C or warmer, seed germination is normal [30]. The plant can tolerate brief frost periods down to −7 °C when it has 4–5 pairs of leaves, but growth ceases until warmer weather conditions return. Temperatures between 16 and 27 °C are considered optimal for hemp growth [9]. Earlier research [31] has shown that hemp grows best on soils rich in clay or silt and neutral in pH value. The proper amount of moisture is crucial during critical crop growth stages, such as germination and plant establishment [32], and water requirements will of course be affected by the ambient temperature. Wet soils do not support the growth of hemp because they can limit germination, development of the roots and shoots, decrease the quality of the fiber produced, and result in inconsistent plant heights, making harvesting

more challenging [33]. Overall, hemp needs deep, well-drained soils to produce high grain or fiber yields because the plant does poorly under anaerobic soil conditions. Soils with high salinity, acidity, and compaction should be avoided [27]. Optimal soil pH is 6.0–7.5; fertile soils with good drainage, adequate air movement, and the ability to store sufficient water reserves are suitable for this crop [2].

2. Hemp Taxonomy

Cannabis, *Humulus*, and eight other genera (*Celtis*, *Pteroceltis*, *Aphananthe*, *Chaetachme*, *Gironniera*, *Lozanella*, *Trema*, and *Parasponia*) previously classified as Celtidaceae have been reclassified as the Cannabaceae family [34]. Due to the different expression of gender in individual plants and the significant influence of the environment on the phenotypic characteristics, hemp taxonomy has been hotly debated at the genus level and has passed through several taxonomic revision stages throughout history [35]. The wide variability of quantitative traits and the unlimited ability of hemp plants for intercrossing are the basis for taxonomy of *Cannabis* as a monotypic genus containing the one species, *Cannabis sativa* [36]. Since the psychoactive potential when growing hemp is represented by a legal limit, the division into types and varieties is based on the THC plant content. The weakly intoxicant (THC < 0.3%) *Cannabis sativa* ssp. *sativa* includes cultivated (var. *sativa*) and naturalized weedy or wild hemp (var. *spontanea*), while strongly intoxicant (THC > 0.3%) *Cannabis sativa* ssp. *indica* includes domesticated (var. *indica*) and wild (var. *kafiristanica*) varieties [37].

Hemp is predominantly a dioecious and infrequently monoecious annual herb. The height of the erect hollow stem varies, depending on the variety and environment, from 0.2 to 6 m and measures 1–3 cm in diameter at its base. Female plants are characterized by greater robustness compared to males, which are taller and slenderer. The plant's leaves have palmar composite morphology, with alternate or opposite leaf patterns on the stem and 3 to 13 leaflets basally and 1 to 3 leaflets apically [38]. On the end of a central stem, male flowers develop as a loose floral bunch with very few leaves. The female plants form flowers that are borne on racemes at the apex of the stem. Male flowers have five green-yellow sepals that enclose five closely packed stamens, which access to tiny anthers, while female flowers have two pistils and a single seed compartment. Hemp seeds are spherical or ovoid in shape and, depending on the cultivar, measure 3–5 mm in length [37].

3. Hemp Semantics

Although all *Cannabis sativa* plants are related in a certain way, the basic differences in appearance, chemical composition, method of production, and use are covered in semantics (Table 1). The term "hemp" (also referred to as "industrial hemp") describes an industrial crop grown primarily for its stems and seeds as raw materials for various industries. The term "marijuana" (also known as "cannabis") refers to all components of the *Cannabis sativa* plant, cultivated or not: organic compounds extracted from any part of said plants and any compound produced in accordance with the Code of the United States (USC), salts, derivatives, mixtures or preparations of such plants, and their seeds or resins [39]. Most of the marijuana is produced for its flowers, and the THC and CBD content of these products can range widely.

According to the National Institute of Drug Abuse (NIDA) and the National Center for Natural Products Research (NCNPR), samples of marijuana contained a range of THC from 3.96 to 15.34% [40], and the average THC content increased from 9.8% in 2009 to 14.9% in 2018 and 13.9% in 2019. According to the Canadian Government, the average THC concentration of illicit dried cannabis has increased from about 3% in the 1980s to 15–30% today. The THC potency of herbal materials, fresh or dried flowers, and leaves is up to 30%, in cannabis oil up to 3%, and THC in some chemical extracts can reach up to 90% [41].

Previous studies have shown that products with 0% CBD may be extremely potent in terms of THC, with most products containing more than 15% THC. These products, particularly those containing more than 15% THC, are clinically contraindicated and thus

should not be advertised as medical cannabis. As a result, products with a high THC content are likely to contain little CBD. The average THC:CBD ratio increased significantly from 24.81 to 103.48 from 2009 to 2017, but this trend reversed in 2018 and 2019 to 54.39 and 24.58, respectively. This reversal could be caused by the increasing legalization of marijuana and the CBD product industry [42].

Table 1. The main characteristics that distinguish hemp from marijuana [43].

Characteristic	Industrial Hemp	Marijuana
Phenotype	Tall, nearly tree-like, with relatively thin leaf and fiber stems that have fewer branches and blooms/buds.	Shortened, bushier, with broadening leaf and numerous branches bearing an abundance of buds high in THC.
Psychoactivity	No—whole plant; Yes—some concentrated extracts.	Yes.
Production	Field crop with fully mechanized commercial large-scale production. Whole populations with male and female plants are used.	Mostly manual and infrastructurally demanding indoors production under controlled conditions of lighting, humidity, and nutrition. Only female plants are grown.
Usage	Fiber and hurd for industrial application: textile production, papermaking, construction industry, biocomposites, and animal bedding; biomass: fuel, heat and electricity, hemp mulch, ropes, and twines. Hempseed for hemp oil, hemp oil products: body care and cosmetic products, industrial oil uses, source of feed additives, fuel feedstock, source of human food additives, and medicines. Herb parts that include leaves, flowers, and bracts: essential oil as a source of human food additives, medicines, and nutritional supplements.	The psychoactive effect determines the use for recreational purposes as well as the application as medicinal products.

4. Hemp Production through the Ages

The geographical origin of hemp is considered to be a wide region within Central, East, and South Asia, from where it spread to all temperate regions around the globe. The primary route for dispersal was probably transport via moving streams, birds, and mammals including humans. As one of the first domesticated plants, humans and hemp have been linked very early on, and hemp's spread was accelerated over time by human migrations [31,35,44,45]. Palynological research indicates the presence of hemp in East Asia from about 7000 BCE in Japan to 4500 BCE in China [34,44]. Hemp most likely reached Europe via the northern and southern routes, and after 500 BCE, cultivation became widespread from east to west [36,46]. The crop was brought to South America in 1545, in what is now Chile [39,47], and to North America in 1606 at Port Royal, Acadia in Canada. For the majority of its existence, hemp has been viewed primarily as a fiber plant, significantly less as a psychoactive plant, and to a lesser degree as an oilseed crop [47,48].

In 1998, hemp farming was allowed to resume in Canada due to federal legislation. Since then, commercial production has increased gradually as growers have overcome agronomic difficulties, and processors have worked to create hemp products and markets for the hemp products. The Canadian hemp business had been driven by the food and nutrition market since it was first reintroduced for fiber production, but the 2018 Cannabis Act opened up new prospects by extending the value chain. Hempseed yields on dry land fields are normally 1120 kg/ha and up to 3362 kg/ha in irrigated areas. Industry estimates indicate that the production of hemp that is certified as organic is increasing and now accounts for nearly half of the entire crop grown in Canada [49].

The Marijuana Tax Act, established by the U.S. Congress in 1937, subjected all aspects of cannabis culture to the U.S. Treasury Department's regulatory authority. In 1943 and 1944, production peaked. As imports resumed and legal limits were reinstated after the Second World War, production quickly decreased. In 2014, the Federal Agricultural Act

of 2014, also known as the 2014 U.S. Farm Bill, allowed for state pilot programs to begin cultivation of industrial hemp by both commercial growers and universities [19].

The U.S. Congress enacted the 2018 Federal Farm Bill, commonly known as the Agriculture Improvement Act of 2018, in December 2018. After an almost 45-year break in production, only four States—Colorado, Indiana, Kentucky, and Vermont—reported planting hemp in 2014, totaling 755 ha. Approximately 36,400 ha of hemp was planted nationwide in 22 U.S. States by 2018. Between 2017 and 2018, the number of issued permits more than doubled, demonstrating a rising interest in hemp production [50].

A number of land-grant universities in the U.S. have established research and extension programs in hemp as of 2023. For example, in 2018, Oregon State University established the Global Hemp Innovation Center (GHIC) to provide research, teaching, and outreach and engagement associated with hemp, building on its established network of statewide agricultural experiment stations and Extension service locations (Figure 1). The center has more than 65 faculty representing 19 academic disciplines engaged in research, teaching, and extension services. This mechanism of support for hemp research through statewide community-centric participation offers access to the research, knowledge, and connections necessary for Oregon's social, economic, and environmental requirements.

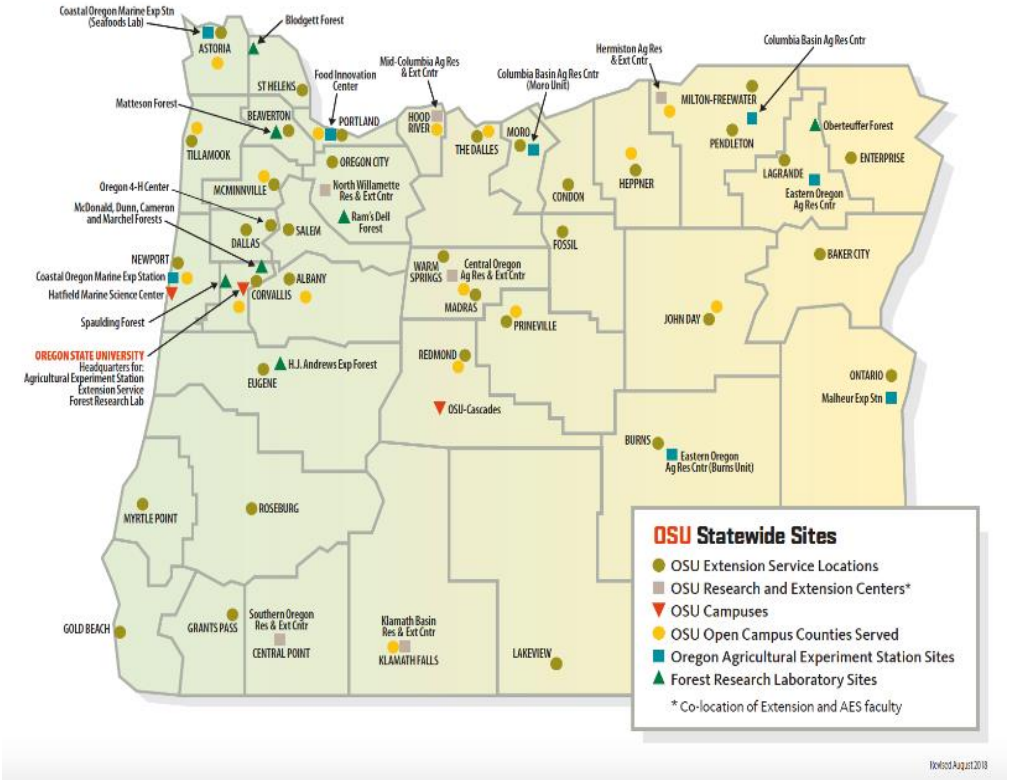

Figure 1. Oregon State University's statewide presence includes agricultural experiment stations and re-search centers at 14 locations and an Extension Service presence in all 36 counties. (Image credit: Oregon State University; Source https://ourimpact.oregonstate.edu/) (accessed on 10 March 2023).

During the twentieth century, while hemp was banned in most countries across the globe, Europe was a major hemp-producing region because hemp cultivation and processing continued mostly in Southern and Southeastern Europe (Ukraine, Russia, and other parts of the former Soviet Union), Romania, Hungary, and the former Yugoslavia (Figure 2), and in some Western European countries (France and Italy), as well as in Poland. The end of the last century and the beginning of this century marked the "renaissance" of hemp, which, thanks to recent changes in legal regulations, is grown on ever larger areas.

Figure 2. Wetting of hemp in Serbia in the first half of the 20th century. Source: http://www.zdravasrbija.com/lat/Zdrava%20Srbija/2002-Konoplja-nas-podigla,.php (accessed on 10 March 2023).

In the EU, hemp production has recently seen a considerable rise in area, growing by 75% from 19,970 ha in 2015 to 34,960 ha in 2019 (Figure 3). Hemp production is up 62.4% during that time, from 94,120 tons to 152,820 tons. More than 70% of the EU's production is coming from France, the Netherlands (10% of production), and Austria (4%), and the rest from other EU-member countries [51]. However, the area under hemp in the EU remained the same in 2020, and then decreased slightly to 32,000 ha in 2021 [51].

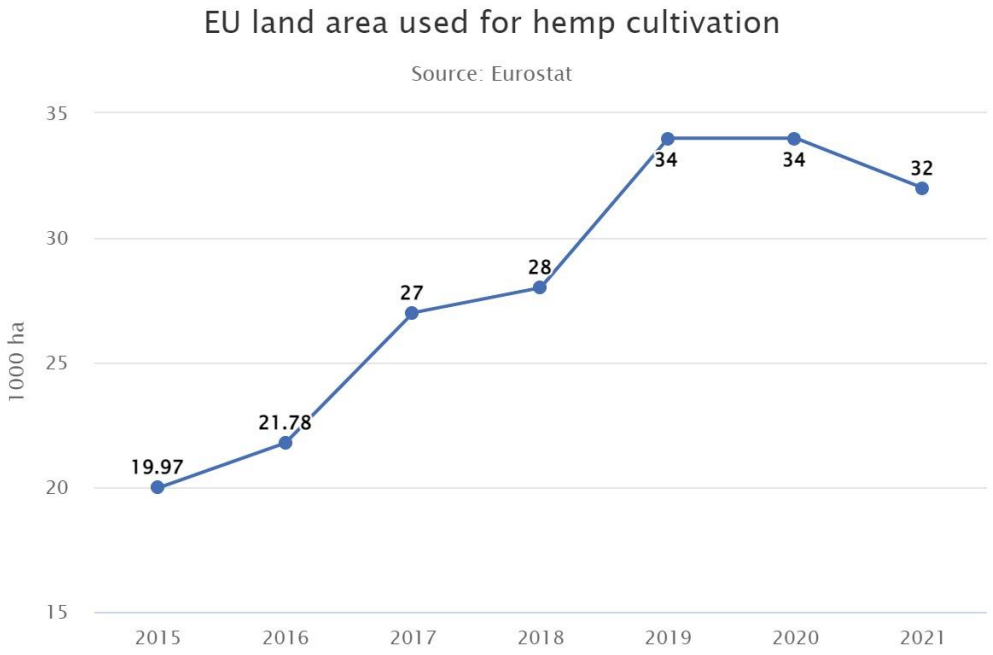

Figure 3. EU Land area used for hemp cultivation (Source: EUROSTAT https://agriculture.ec.europa.eu/farming/crop-productions-and-plant-based-products/hemp_en (accessed on 10 March 2023).

Currently, according to the EU Plant variety database, there are 96 registered hemp varieties (cultivars), for fiber, grain, and dual-purpose. Most of these cultivars have been originally developed in Hungary, Italy, France, Latvia, Lithuania, Romania, Holland, Poland, Spain, Russia, Slovenia, Czech Republic, and Serbia [52].

5. Hemp Agronomy

5.1. Hemp in Crop Rotations

Hemp fits best in a crop rotation with cereals or, preferably, a legume, as an oilseed crop, but it can be grown as a fiber crop after any other crop [31]. Monoculture hemp ought to be avoided for a variety of reasons, such as pathogen build-up, reduced fertility, and risks of reduced quality. Hemp plants have been shown to reduce the quantity of a limited number of nematode species and certain fungi in soils, and hemp may be grown without chemical pesticides [53]. Hemp was found to suppress three infectious agents (*Verticillium dahlia* and the root-knot nematodes, *Meloidogyne chitwoodi*, and *Meloidogyne hapla*), suggesting that incorporating hemp into a cycle of crops could improve soil health properties [54]. However, research into nematodes and plant pathogens is relatively limited at this point in time compared to other crops, and the understanding of hemp's suppressiveness may evolve as additional research is conducted and published. Hemp grown at dense plant populations can quickly cover the soil surface as plants can rapidly develop following emergence, particularly fiber-yielding types, making it a strong competitor against weeds. This is possibly among the most significant impacts of rotating hemp with other crops [9]. The production of hemp is frequently followed by the planting of winter cereals, and for this reason, harvesting must be completed as soon as possible, especially on heavy soils that are high in clay content, since these become quickly unworkable with late summer or fall rains. This is in accordance with some authors' recommendations that early sowing times and early harvests be used to optimize fiber output in order to prevent unfavorable retting (post-harvest fiber handling) (Figure 2) and stem-drying conditions [2].

5.2. Seed Bed Preparation and Sowing

Traditionally, hemp has been planted in the same way as other break crops in terms of soil preparation. Tillage techniques for hemp, especially on soils rich in clay, include plowing at a 30–40 cm depth in fall or winter. Final preparation is done in the spring as a shallow cultivation for creating a thin seedbed [11].

The most significant consideration when growing hemp in a new area is determining the ideal planting date that will enable optimum stand establishment and high yields of grain and/or fiber. For hemp, sufficient moisture is crucial during key stages of crop development, such as germination and emergence. Young, freshly germinated hemp plants are vulnerable to a variety of biotic, physical, and environmental stresses. Therefore, hemp sowing time and seed layer preparations are significant in terms of stand establishment. It is also important to consider thinking about the expected weather forecasted soon after planting in case of low seedling vigor. This is particularly important when using traditional tillage methods with direct seeding [31].

Seeding dates are mostly determined by climatic factors. Hemp germinates at temperatures as low as 1–2 °C; however, it should not be planted early in the season. Sowing should be delayed till the soil temperature reaches 10–12 °C so to ensure hemp's quick development that enhances its capacity to surpass weeds [45]. Most hemp types will sprout in 3 to 5 days when sown in warm soils (>10 °C) with sufficient soil moisture. To ensure rapid germination and plant development, seeding dates are typically determined by soil temperature and moisture accessibility, as well as the photoperiod, which determines the duration of the vegetative process and, eventually, stalk and grain yield [11].

Plant spacing in hemp is determined by the type of hemp grown, such as fiber, seed, or cannabinoids. In general, densely planted hemp encourages greater plant height and restricts flowering. Hemp grown primarily for fiber is planted closely together to promote stalk elongation while reducing branching, yielding longer and stronger fibers. Particularly when it is produced for fiber or seed products, hemp is frequently planted using seed drills with row spacing ranging from 7.6 to 17.8 cm. However, the recommended seeding rates differ significantly, with the ideal sowing depth varying from 1.9 to 3.2 cm depending on soil type, soil preparation, available water, and seeding date [5]. According to another study, the spacing between hemp plants grown for fiber ranges from 20 to 40 cm [45,55]. It was

suggested that similar planting densities would be necessary for the best hemp oil output for varieties produced for seed. Research has shown that 120 plants per square meter with an interrow spacing of 0.5 m produced high yields of the stem, seed, and inflorescence combined [5]. Another study suggested hemp seed drills for sowing at depths of 2–3 cm and row spacing of 9–17 cm [46,56]. The quantity of seed for sowing varies and ranges from 40 to 150 kg ha^{-1} [13]. According to other authors, seeding rate recommendations vary from 40 to 65 kg ha^{-1} for fiber hemp to reach 200–300 plant m^{-2} and 20 kg ha^{-1} for seed hemp [2].

5.3. Fertilization

5.3.1. Nitrogen

For the cultivation of hemp grain, nitrogen (N) is a crucial nutrient. Hemp has a low tolerance for fertilizer applied at the seedling stage, and therefore, N fertilizers must be either band applied before seeding or injected (placed) at a given distance from the seed. Nitrogen suggestions for total N range from 112 to 168 kg ha^{-1} for dry land and up to 224 kg ha^{-1} for irrigated hemp grain crops (Table 2). Additional research is needed in the fields on the timing of plant N requirements and supply needed during the growing period. Hemp has been observed to develop up to 7.6 cm per day as it begins its lengthening stage in early July in the northern latitudes. Faster cell elongation rates lead to thinner cell walls and, subsequently, to weaker bast fibers. For this purpose, just 56 kg ha^{-1} of N is suggested for fiber hemp (Table 2), and this is typically provided pre-planting. Farmers face a challenge in determining the optimal N fertilization rate in order to maximize their financial gain because research studies have shown variable findings concerning stem and seed yields in response to N fertilization in soils with wide differences in soil N availability [57].

Table 2. Macronutrient requirements for industrial hemp (adapted from Kostuik and Williams, 2019) [31].

	Grain/Dual Purpose Hemp (kg ha^{-1})	**Fiber Hemp (kg ha^{-1})**
Available N	112–224	56
Available P	56	67
Available K	336	336

Previous research indicated that high N rates increased grain protein and grain oil content [58], and a study determined that 150 kg N ha^{-1} was adequate for the production of grain hemp [59]. Further research has shown that N fertilization at rates of up to 200 kg N kg ha^{-1} can increase stem diameter, plant height, seed yields, and biomass yields of dual-purpose cultivars [60]. Another study found that 60 kg N ha^{-1} was adequate for dual-purpose hemp production and that there was no increase in seed yield as N rate increased [4], while yet another study found that applying 100 kg N ha^{-1} provided the tallest plants and the greatest seed and inflorescence yields [61].

5.3.2. Phosphorus

Hemp is particularly responsive to seed-placed phosphorus (P), according to studies conducted by the Canadian Parkland Crop Diversification Fund. Hemp seed mortality increased significantly when P_2O_5 applications exceeded 22.4 kg ha^{-1} of actual P [52,62]. Hemp can compensate for the loss of plants and sustain yield through enhanced branching, which can counteract the effects of higher seedling mortality. At the same time, thinner plant stands will increase the time till harvest. Temperature, soil physical characteristics, soil moisture conditions, and seeder or planter opener all play a role in the suggestions for hemp-seed-placed P. It is advised to use no more than 22.4 kg ha^{-1} of real P_2O_5 when seeding on loamy-clay soils with narrow openings. The amount of available P_2O_5 soil and applied fertilizer recommended for a hemp's grain crop is 56 kg ha^{-1}. For the fiber crops, 67 kg ha^{-1} of phosphorus is recommended (Table 2) [31].

5.3.3. Potassium

Hemp needs a large amount of potassium (K). For the grain/dual-purpose hemp, and fiber crops, 336 kg ha^{-1} of K is recommended (Table 2). Potassium absorption follows a similar path to P uptake as the plant develops [63]. Fiber hemp cultivars absorb the most K throughout the fiber developmental stages. Fiber quality has been demonstrated to be more affected by K than by P [64]. A certain amount of K, however, also exits the field as grain. The majority of it is left in the field, and considering its mobility in soil, a significant amount of K will leach into the soil when mineralized. Growers should be aware that if the fiber is baled fresh or if the entire plant biomass is taken out of the field before the retting process, significant amounts of nutrients, especially K, will be lost. To sustain soil nutrient levels over for an extended period of time, nutrient losses and removals from fields with the grain or stems must be managed [31].

5.4. Water Management

Irrigation can have an important effect on the yield of fiber hemp, according to studies performed in a variety of environments [65]. One of the most restricting factors for fiber production and quality is soil moisture deficiencies. Drought and hot weather have been shown to enhance bloom production but slow plant growth and fiber maturation [66]. In a 2-year experiment, stem size and height were reduced accompanied by increasingly thinner stems during the drier months of the year [67]. According to European research, hemp needs 500–700 mm of available water, and 250–300 mm of water is required during the vegetative development period [55]. A study by Cosentino et al. [68] using varying periods of sowing and rates of water availability, has shown that when seeding was delayed, the crop used less water since vegetative growth was significantly slowed by unfavorable photoperiodic conditions. Bari et al. [69] analyzed four irrigation treatments (ranging from 680 mm to 262 mm) in a setting similar to Southern Europe and reported that the hemp crops produced good stem and dried bark yields when 66% of the available water was recovered, which corresponded to a seasonal water usage of 410–460 mm [2].

5.5. Hemp Insects, Diseases, and Weeds

Hemp seems to do more "good for the environment" compared to various other crops, depending on a range of resources and standards for the environment, and it has been utilized as a rotation to disrupt weeds and insect lifecycles [8]. There are a limited number of pesticides registered for use in hemp [70,71]. So management of yield-limiting pests and diseases that occur in hemp depends on incorporation of sound cultural management strategies.

5.5.1. Insects and Nematodes

Hemp's native protection against many pests is attributed to trichomes releasing terpenes and cannabinoids that are considered repellents to herbivores. Aphids are common in the heads of hemp seeds, but very little is defined about how aphid feeding affects grain yields economically [72]. Field observations have noted that few species of insects have exceeded economic criteria that would require management. Grasshoppers and army worms, which devour leaves, have been discovered in large numbers in certain hemp farms with minimal to no influence on hemp productivity. Hemp can tolerate harm from significant populations of leaf-feeding insects thanks to its robust growth and an abundance of leaf tissue. Farmers that commonly utilize corn in their crop rotation may be concerned upon finding the European corn borer in hemp fields [31]. Hemp may be effective for soil nematode control, according to published albeit limited research, as trichome phytochemicals can have nematicidal impacts on root-knot nematodes [73]. A higher yield (10%) was associated with fewer cyst nematodes in soybeans cultivated after a hemp harvest [74]. Recently, the root-lesion nematode (*Pratylenchus penetrans*) has been reported as parasitizing hemp in the U.S. [75]. Additional research is needed on plant pathogenic nematodes in industrial hemp, especially in the U.S., as information is limited.

5.5.2. Diseases

Multiple diseases can affect hemp. Many of the reported hemp pathogens do not result in significant economic impacts on hemp, at least at this point in time. Since the registration of fungicides for hemp is extremely limited, it is important that cultural and occasionally biological methods of control are exercised. Results from earlier research and field observations point to the use of timing and rates of seeding to manage hemp diseases such as those caused by *Sclerotinia sclerotiorum* (white mold) and *Botrytis cinerea* (gray mold), as these are among the fungal diseases that can negatively affect hemp production. Both of these diseases can cause stem cankers or rot of seed-bearing buds. The presence of sclerotic produced by *Sclerotinia* in hempseed can be challenging to remove, lowering the quality and value of the final product. Controlling *Sclerotinia* and *Botrytis* involves reducing the environmental conditions that contribute to successful infection by spores or release of ascospores via apothecial production through the timing of planting and plant density to avoid wetter conditions during late stages of hemp maturation. Beet curly top virus is another pathogen that can cause significant losses in industrial hemp. This virus is vectored by leafhoppers and severe outbreaks with 100% yield losses have been reported in the U.S. in Arizona [76]; curly top has also been reported in industrial hemp planted in other western U.S. states including Colorado [77], Oregon, and Washington [78]. Control of curly top is difficult and primarily focuses on the monitoring and management of the leafhopper vector. Certain soil-borne pathogens can impact plant stand through causing die-out at the seedling or later plant stages. *Fusarium* and *Pythium* are among the more important soil-borne pathogens. Both genera can cause root rot and die-out of seedlings; Fusarium can also incite crown rot, stem rot, and wilt disease. *Pythium* is of greater importance when soils are overly wet during the early stages of plant growth. For control of these diseases, it is also generally advised to properly rotate crops with non-host crops and to choose cultivars that are less vulnerable [31]. The use of pathogen-free seed or seed treatments with effective materials will become increasingly important for managing *Fusarium* diseases as the hemp industry matures over the upcoming decades.

5.5.3. Weeds

The best approach for weed management in hemp is to facilitate the rapid emergence and growth of a sufficiently dense plant population. To encourage hemp to germinate and grow quickly, it is essential to sow seeds shallowly into a warm, moist, and well-prepared seed bed. The fast growth and high biomass output of hemp will outcompete the majority of weed species once hemp plants are between 0.15 and 0.20 m in height. Hemp can suppress late-germinating weeds with the use of mechanical weed management methods, such as cultivation right before seeding. With broader row spacing, interrow cultivation may be an alternative. For instance, in hemp seed production, by far the biggest problem is ragweed in the crop because ragweed and hemp seeds are very difficult to separate [31].

5.6. Harvest

5.6.1. Hemp Fiber

The timing of the harvest of hemp plants grown for fiber has a major effect on fiber quality. Hemp grown for fiber is harvested when male plants are at 100% bloom [65], as that is when the primary bast fiber output peaks [79]. During reproductive development, an increase in lignin among fiber bundles occurs, which complicates the separation of fiber bundles. Additionally, if plants (fibers) are left to reach full maturity, the strength of the fibers is decreased in comparison to fibers that are less mature. These factors lead to the harvesting of specialized fiber crops when no more than 20% of the plants have female flower development. Use of typical hay-making machines for harvesting specialized fiber crops is the most common method. Typically, the plant is often cut utilizing a hay-cutting tool or sickle-bar that produces a constant covering of stalks on the field. After that, the stems are left to ret, undergoing microbial degradation under moist conditions, and stems are rotated at least once during retting, usually with a rotational hay fork. After being

retted, the stalks are arranged into windrows and left to dry. When the stems are dry, they are collected using rectangular or circular bailing hay machinery and placed indoors where the stems are well protected to avoid any additional retting [31].

5.6.2. Hemp Grain

Hemp seed matures about three to four months after planting, depending on many factors including sowing time, latitude, ambient temperature, amount of rain or irrigation during the growth period, genetics of the hemp variety, and availability of soil nutrients. When stressed by environmental or edaphic factors, hemp plants may bloom earlier. Harvesting should begin when most of the seeds (90%) have matured. The benefit of collecting grain at this water content is that the pectin that retains the stem fiber around each other is still present and functioning. This results in less wrapping inside the combine harvesting and threshing parts [26].

5.6.3. Hemp Flowers

Though grown mostly for its grain and/or fiber and stem, hemp is also grown often for its flowers. Hemp essential oil, as a secondary product of hemp, is now regarded as a product with a high additional value and a promising marketing possibility because of its potential applications in the cosmetic industry, medicine, and crop protection. The harvest date varies depending on each hemp variety's flowering timing and flowering behavior [80]. The optimal moment to achieve maximum production of hemp essential oil is when there is the highest number of intact glandular trichomes in the inflorescence, which corresponds to when approximately 50% of the seeds are mature [81]. Furthermore, monoecious varieties are favored because they yield more inflorescences per hectare, despite the fact that dioecious varieties have higher essential oil concentration levels [81]. For these reasons, monoecious varieties are unquestionably favored because they respond by producing new inflorescences that can produce enough seeds if the inflorescences are harvested at full female flowering, increasing the plant's sustainable development and ability to be used for a variety of purposes [82].

6. Fiber and Grain Uses

6.1. Hemp Stems (Fiber and Hurd)

6.1.1. Hemp Use in Textiles

Humanity has used hemp fibers to make fabrics, cordage, yarns, carpets, and cloth for a very long time. To create a variety of materials suited for long-lasting and cozy apparel, the fibers can be spun, followed by weaving or knitting. Due to its strength and adaptability, hemp fiber was a widely used fabric for garments until the cotton industry became more established on a global scale [48,83]. Comparing hemp fibers to other natural fibers like cotton, linen, and nettle, hemp fibers are far stronger. Their adaptability, sturdiness, and water-resistance are additional benefits. Christopher Columbus sent hemp-equipped ships to the Americas [83]. Hemp was used to create the earliest known woven cloth, the first American flag, and Levi Strauss' original denim trousers. It is currently being utilized to create a variety of fabrics that are similar to cotton but far more durable [83,84]. In order to support the acceptance of hemp as a fabric or accessory, several consumer companies, including Patagonia, Adidas, and other major networks, have incorporated hemp products in their line of products. Hemp fibers have many uses in the textile industry, and hemp fabrics have a wide range of uses, including clothing, jeans, sportswear, bags, hats, pillowcases, blankets, shoes, and socks. It is also used to make hemp jewelry, and other ornaments [85–87]. Another study [88] has noted that there are no differences between hemp and cotton materials in terms of color fastness to breaking, oil stain discharge, ignitability, rip power, breaking power, and lengthening. To make hybrid fabrics for clothing, fibers can also be blended with other materials. For example, cotton or linen can be used to provide particular textures and functions. Hemp is a sustainable fabric for upholstery and furniture, including textiles for chairs, tables, fashion accessories, mirrors,

wall decor, and ornamental items. Due to the numerous potential uses of hemp materials, some European businesses and cooperatives, particularly in France, are launching new research and development programs to return European hemp into the textile sector [89].

6.1.2. Hemp Use in Papermaking

Paper has been made from hemp for a long time. The majority of its fiber produced in ancient China was used to make paper scrolls [90]. Hemp paper was used to write the U.S. Constitution and the earliest copies of the Bible [91]. In comparison to paper made from wood, hemp paper was stronger, more durable, and less likely to yellow [63]. The fibers are the world's strongest natural fibers, and the volume and quality of cellulose in hemp make it a perfect papermaking basic material [92,93].

Hemp fibers have been utilized to create specialty pulp and paper after hemp was "rediscovered" in Europe inside the 1990s. It is a non-wood fiber that, because of its good quality, pulp physical properties, and tensile strength, makes an excellent raw material for the creation of specialty paper [91,94,95].

Bast fibers of hemp have the largest percentage of cellulose (85%) of all botanical fibers, and the lowest percentage of lignin (3–5%); removing lignin, which ties the cellulose together, takes a lot of energy and chemicals. The short fibers from the heart have high cellulose content (70%) and higher lignin content (23%) than the long fibers. Wood, on the other hand, has a lignin content of up to 34% and a cellulose content of up to 50% [96].

Hemp paper has several advantages over other types of paper. It has a long shelf life and does not turn yellow with time [97]. Processing hemp to paper does not necessarily yield toxins such as dioxin, unlike paper made from wood pulp. A significant advantage of hemp-based paper is its recyclability; it can be reused 7–8 times more than regular pulpwood paper, which can be recycled only 3 times [93]. Specialized papers for writing and print of the finest quality, archive, protective, greasy papers, membrane filters for technological and professional research, coffee and tea bags, handcrafted papers, bible sheets, and a range of specialist artistic documents can be produced from hemp [83,89,98]. Hemp can contribute to the prevention of deforestation; over the course of a 20-year cycle, 0.4 ha of hemp may generate as much paper as 1.6 to 4 ha of trees [99].

6.1.3. Hemp Use in Construction

Hemp can produce two by-products for utility as various building materials: fiber and the wooden core of the hemp stalk, which is employed to make hurds. In the manufacture of insulation materials, hemp fibers are used in place of synthetic fibers. These materials benefit from hemp fiber's mechanical strength in addition to the ecological advantages of using plant matter. Construction jobs utilize two essential components of these particles: small density and the insulating qualities that emerge from their low mass-to-volume ratio. The building industry additionally values a material's flexibility and permeability as supplementary qualities. The manufacturing of light and ultra-light concrete and mortar, whose qualities are largely connected to their composition, is the main usage of cord particles in the modern world. Varying the amount of binder allows for the production of materials with a wide range of final applications, such as plastering, paving, wall building, and roof insulation. Hurds can also be stuffed into gaps and under floors to act as an insulating material that takes up space. Because of a shortage of hemp production, these uses are not yet fully developed [83].

A number of commercial items with varied densities that mimic concrete, wood, and even plastic can be created from hemp-based materials. In comparison to more well-known mineral and oil-based alternatives, hemp-based biomaterials also have a number of other benefits. These construction materials are strong, lightweight, cost-effective to produce, waterproof, fireproof, and possess excellent heating and cold tolerance in the winter and the summer, respectively. Furthermore, the substances are perfect for minimizing the consequences of earthquakes, flooding, and other natural disasters [100]. Additionally, it is

believed that the hemp construction materials are able to absorb CO_2, which makes their use desirable from an environmental perspective [101,102].

Hemp hurds are combined with a lime and water binder to make hempcrete, a substance that resembles concrete. Many existing environmental problems could be addressed by using hemp in construction. It is a fire-resistant material that is thermally stable. It is also an efficient pesticide and insect repellent, ensuring that the wood is less vulnerable to insect damage, resulting in a longer lifespan [89].

6.1.4. Bio-Composites

Composite materials are created when two or more separate materials are mixed to create a new technical material; this is referring to the fiber-reinforced matrix material [103]. Over a thousand years ago, hemp fibers were employed to strengthen materials [104]. Hemp fiber composites are currently generating more interest in both fundamental research and industrial applications because they have the potential to replace synthetic fibers as reinforcing materials at a cheaper cost and with a more ecologically friendly method of product creation [4].

Hemp biomaterials incorporate fibers to offer tensile strength, lightweightness, shatter strength, and elasticity. Short core fibers or hurds are often used because they are plentiful; however, if sliced, poor-grade bast fibers (or the entire plant) might be used. Hemp biocomposites, which can be in the form of a compound natural fiber, hemp cellulosic plastic composite materials, or hemp polymer resins, are used to make design and construction elements as well as plastic. Hemp may be used to substitute for fiberglass and wood particulates as well as other natural materials such as flax in composite materials [105].

Non-structural panels of fiber, insulating, fiberglass replacements, cement blocks, stucco, and plaster are all possible via hemp-based construction materials. Hemp hurds are combined with lime to create concrete blocks [105]. Hemp replaces fiber glass as a biofiber additive to plastics, allowing for greater versatility in the completed item [106]. Fibers made from hemp have been utilized in addition in snowboards, skiing, and canoeing. The bio-composite material provides benefits including biodegradability, mobility, and reduced consumption of energy but with equivalent strength capabilities when used as a component in a substrate produced from soybeans [107].

In the food packaging industry, hemp can be reinforced to manufacture insulating mats, as well as prolonged foams made of starch [108]. The use of automotive bio-composites in inner paneling for automobiles, doorway screens, trunk liners, spare tire covers, package boxes, headliners, and other items are increasing in popularity. Hemp bio-composites have excellent strength, longevity, and lightweight properties, as well as positive unintentional behavior [109].

6.1.5. Animal Bedding

Nowadays, hemp is widely used for specialized purposes, such as bedding for animals. Because of its hydrophilic characteristics and water absorption capacity, it is very good bedding for horses, chickens, and pets [48]. Animal bedding made from hemp is much less allergenic and better at controlling odors than bedding containing wood particles, straw, or hay. Additionally, when hemp is put out on the ground, it offers a solid base that doesn't frequently shift. The fact that the hurds are often cut into little pieces makes it more comfortable for horses. In livestock shelters, hemp straw is utilized as an option to barley or wheat straw. For smaller animals like hamsters, guinea pigs, and rodents, as well as for bunnies and snakes, small components serve as bedding [80,110]. Hemp's woody core is highly absorbing, so it provides excellent bedding for animals, and in fact, such use has been around for well over a century. Hurds may collect five times their mass in moisture (generally a 50% increase over wood shavings), are dust-free, and compost quickly [83,111].

6.1.6. Biomass as a Source of Energy, Heat, and Fuel

As a whole plant, low-grade fibers or hurds of hemp can be utilized as a feedstock for heat, electricity, or fuel. Hemp biomass in pellet form can be burned directly in residential wood stoves to produce heat. This practice of exploiting the hemp as a crop for power generation can be applied on a bigger scale for the creation of "green" power from generators if the biomass is transformed into charcoal. This might be used to substitute coal combustion in the co-generation process, which currently depends on forestry and farm waste [112]. However, due to the industry's scale and valuation applications for hemp fibers, this form of application is not currently feasible. Fermentation, pyrolysis, and destructive distillation are other methods for processing biomass to produce methanol, ethanol, or gasoline [48].

6.1.7. Hemp Use as Mulch

Hemp is also used in the production of horticultural mulch. It is, like traditional mulch, mostly used as a garden surface treatment, including for vegetables, flowers, and ornamental plants grown in containers. Hemp mulch is lightweight and does not clump on the surface. It is very effective at retaining moisture, reducing soil erosion, and suppressing weeds. It does, in fact, eliminate the requirement for manual or chemical weed management and acts as a screening to prevent seed germination. Because bast retains soil moisture for longer periods of time, hemp mulch's water-absorbing capacity reduces the need for watering. Hemp mulching is more effective than other types of mulch at protecting soils from the heat of the sun and freezing winter temperatures. Hemp mulch also contributes humus to the soil, which means that as it decomposes, it helps enrich the soil, is pH neutral, entirely compatible with soil pH, and biodegradable [38,83]. Additionally, a number of producers purchase hemp-based fleece in the shape made from felt or mulch cloth, typically offered in a roll, such as the textiles produces in France by Geochanvre (Lézinnes, France). Hemp mulch cloth provides environmental protection while also serving as an herbicide substitute. These biodegradable felts can be utilized as weed-control mulching mats for green spaces, such as roadsides. They are an effective and environmentally acceptable substitute for plastic mulching. Additionally, embankments and irrigation can both benefit from the use of hemp fleece, for instance, to separate soil layers or prevent erosion. When compared to polypropylene fleece, these hemp products have a considerable potential for reducing energy use and greenhouse gas emissions [113,114].

6.1.8. Hemp Ropes and Twines

Hemp ropes and twine have long been used to make hemp fiber. Hemp rope still has uses, despite the marine industry generally replacing it with more affordable, durable, and lightweight synthetics. Hemp rope has a reputation for tying itself together for stronger knot stability because of its coarser texture. Due to its smoothness, toughness, strength, and comfort on the skin, hemp yarn is used to manufacture jewelry. It can also be used for crafts, gardening, and landscape design [89].

6.2. Hemp Grain

6.2.1. Nutritional Value of Hemp Grain

Hemp has been used as a food source since about 3000 years ago, when it was a major food source for humans in the area what is now China and Nepal [115]. Considering all of its nutritional benefits, hemp grain is frequently regarded as one of the most nutrient-dense dietary choices. Both the whole, unshelled seed and its processed counterparts, such as the flour, protein powder, and oil, can be consumed. Although a few studies [116–118] have emphasized the significant variation in hemp seed composition depending on varietal and environmental factors, hemp seeds typically contain 25–35% lipids with a distinct and optimal fatty acid composition, 20–25% easily digestible proteins rich in necessary amino acids, and 20–30% carbohydrates. Hemp seeds are a source of antioxidant compounds, as well as other bioactive components such as bioactive peptides, phenols, tocopherols, carotenoids, and phytosterols, which would seem to be mainly influenced by environmental

and agricultural variables and, to a smaller degree, genetic differences [116]. Edestin and albumin are the two major proteins in hemp seed. These quality storage proteins are digestible and include sufficient quantities among all important amino acids for proper nutrition. Arginine is particularly abundant in hemp seed. Oil, proteins, vitamins, and minerals are among the nutrients and compounds contained in hemp seeds. Chlorophyll is found naturally in mature seeds, so fresh hemp seed (fatty acid) oil is green [119].

Since hemp seed contains phytosterols, consuming it helps to decrease cholesterol by removing lipid development in the arteries. As the health benefits of these seeds has grown popular, a range of new hemp-seed-based products such as butter, oil, milk, and hemp flour are now available on the market. Similar to almonds and peanut butter, hemp butter is made from pulverized hempseed nuts that have been mashed into a smooth paste. Edible hempseed oil is increasingly popular as a nutritious additive in smoothies. It also can be drizzled on top of meals or used in salad dressings and sauces. Milk made from hemp, which could be manufactured in households by blending the hemp nuts with water in a ratio of 3:1 and filtering the liquid, is another new product that has received a lot of momentum. Hemp flour is used in baking products that contain other refined components [4].

6.2.2. Hempseed Oil and Hemp Oil Products

Hemp seed oil is high in polyunsaturated fatty acids, and especially linoleic acid and alpha-linoleic acid. The characteristics of hemp seed oil make it excellent for manufacturing light body oils and lipid-rich lotions that absorb quickly [120]. Hempseed oil is a good provider of tocopherols: γ -tocopherol (89.11%) was found to be the most prevalent compound in hempseed oil, followed by α-tocopherol, β-tocopherol, and δ-tocopherol [121]. Furthermore, it contains biological compounds of two essential fatty acids, stearidonic acid and gamma-linolenic acid. Hempseed oil's health benefits are linked to the high content of phytosterols and the high percentage of unsaturated fats (about 80%) in its fatty acid profile [122].

Typically, hemp seeds are cold pressed to produce hempseed oil at temperatures between 45 and 50 °C [103]. It is the same method and technique used to obtain oil from traditional oil seeds such as sunflower and linseed. Hemp oil may be used in food, cosmetics, drugs, and a variety of industrial applications.

6.2.3. Body Care Products and Cosmetics

Bars of soap and shower gels, as well as cosmetic products such as balm, massage oil, and oil beauty items, are all examples of hemp body care and cosmetics. Hemp is a popular ingredient in cosmetics for the skin because of its significant oil content and advantageous unsaturated fatty acid profile (linoleic, linolenic acids). The acids mentioned above are widely used in the skin-care sector, and they affect a range of cellular membrane operations as well as immune cell stimulus [123].

6.2.4. Industrial Grade Oil Uses

Hemp oil has been used for a long time in a variety of applications, including inks, polishes, paints, sealers, cleaning agents, and lubricants [37]. Because it has good surface penetration and drying properties, hemp oil is useful in these applications [124]. Hemp sealers are made by polymerizing hemp oil or transformation to polyurethane [90]. Hemp-based bioplastics have been proposed for applications including plumbing piping [90,125]. Interfacial compatibility with composite fibers, as well as the finished product's recyclability or biodegradability, are all technical challenges that will need to be addressed in the future [126].

6.2.5. Hemp Seeds as Feed Additives

Previous research found that cattle fed with hemp seed had both beneficial and detrimental impacts. One of the studies [127] suggests that cattle feed containing hemp seeds

and oil may benefit the human end user leading to enhanced nutritional characteristics. Human nourishment can be improved by including hemp in livestock diets.

Hempseed cake has also been given to dairy cows, with varying outcomes in terms of milk output and fat profile uniformity [128]. Since THC is mostly found in foliar tissues, feeding animals with this plant material could lead to health problems due to its higher level of THC. As a result, the European Food Safety Authority (EFSA) [129] proposed restricting or prohibiting the addition of hemp plants to animal feeds, as well as a maximal THC content of 10 mg kg^{-1} in seed-based feeding products.

According to a previous study [130], feeding cannabinoid-rich industrial hemp silage composed of leaves, flowers, and seeds reduces feed intake and milk produce in dairy cows. Heart rate, respiratory rate, and animal behavior were all affected negatively. Feeding cows reduced industrial hemp silage made from the entire hemp plant had no effect on their health or effectiveness. Other cannabinoids, particularly CBD, which was found in high concentrations in industrial hemp (and thus also in cow's milk after feeding), have insufficient data to evaluate potential health risks [130].

In the United States, as of March 2023, hemp and hemp-derived products are not permitted in pet food or animal feed. The right to utilize hemp and hemp-derived products in foods for people or animals was not included in the 2018 Farm Bill. Food products are regulated by the FDA [110].

The European Food Safety Authority (EFSA) states that hemp seed, hemp oil, hemp expeller, hemp flour, and hemp fiber can be used in various animal species' feed. This, however, depends on how much more food is consumed. The limit THC level was set at 0.2% in Commission Regulation (EU) 2017/1017 dated 15 June 2017 [131].

6.2.6. Hemp as Biofuel Feedstock

Henry Ford first used hemp in the production of biofuels in 1941. He was the first one to invent a machine powered by this biofuel. Biofuels based on hemp are widely regarded as among the most efficient instruments for diminishing reliance on imported oil and lowering emissions of greenhouse gases [4]. This type of biofuel can reduce reliance on fossil fuels while also contributing to a cleaner climate [132]. Hemp plants have a high density and fast growth rate, making them ideal for use as a biofuel crop. Hemp fiber has a higher digestible cellulose and hemicellulose content than any other energy crop. Furthermore, hemp has a higher ratio of digestible sugars to lignin than other biofuel crops with comparable yields. Hemp seed oil biofuels have high fuel efficiency and unusual kinetic viscosity and combustion stability variables, which can be overcome by including chemical additives such as antioxidants. Trans-esterification is used to make hemp biodiesel [4,89].

6.3. Hemp Herbae (Leaves and Flowers)

6.3.1. Hemp Essential Oil

Hemp essential oil (EO) is a compounded composition of numerous volatile chemicals, primarily monoterpenes, sesquiterpenes, and other terpenoid-like molecules which can be separated by distillation [133]. Myrcene, caryophyllene, limonene, pinene, terpinolene, and humulene are the most important chemical constituents. These volatile compounds have potential applications in cosmetics, food additives, aromatherapy, and the perfume industry [80]. The hemp EO has also been reported to have antibiotic and pest-controlling capabilities for bacteria [134], insects, and also weeds [135]. Hemp EO has shown to significantly inhibit microbial development, depending on the hemp variety and planting time [136]. Caryophyllene can be useful in the therapy of anxiety and depression [137]. Some authors discussed and promoted the "synergy and phytocannabinoid-terpenoid entourage effects" [138].

Hemp EO was found to be synthesized in the same structures as cannabinoids, in the epidermal glands or epidermal glandular hairs [139]. The bracts enclosing each female flower and the small leaves of the feminine inflorescence have the highest density of glandular hairs and, therefore, the highest EO content [140]. Because the quantitative

and qualitative content of hemp EO varies greatly depending on variety, pedoclimate characteristics, harvesting time, and extraction procedures [141], its terpene profile may change and may be difficult to standardize [82]. The best harvest time to obtain high EO yields is when the inflorescence has the most intact glandular trichomes, which is about the time when about half of the seeds have matured [80]. Furthermore, despite the fact that EO content seems to be correlated to individual inflorescence volume [81], monoecious cultivars may be favored because they produce more inflorescences per hectare [80] and could be harvested a little bit earlier, in full bloom, when the EO content would be highest [142].

6.3.2. Hempseed Oil and Essential Oil as Human Food Additives and Medicines

The potential importance of hemp to food, supplements, and cosmetic industries, which produce goods for human use or consumption, dwarfs its ability as an animal feed [89]. Hempseed oil exposed to high temperatures cause the development of trans-fatty acids, which limit the beneficial components and cause the oil to taste bitter and spoiled. For this reason, hempseed oil is not recommended for frying [143]. It is commonly used in salads and pasta sauces, as a margarine and butter alternative, and as a nutritional supplement [144].

While more research is required to back up claims about hemp's effectiveness for a variety of illnesses, substances extracted from inflorescences are used in therapies ranging from managing high blood pressure and oxidative stress to treating inflammation, cancer, and even as a source of therapeutic compounds to address COVID-19 [145,146]. Since hemp seeds are rich in important fatty acids, such as α-linolenic acid [145], hemp oil can be used to help with inflammatory diseases like arthritis, as well as to reduce blood pressure and cholesterol levels in the arteries [147]. Hemp oil, when applied topically, is used to treat open wounds, scalding injuries, and irritations of the skin including psoriasis and neurodermatosis [148]. In addition, hemp contains gamma-linolenic acid, a popular substance with many health advantages. So hemp oil is expected to have a high market value and be used mostly in foods for humans and dietary supplementation. Although the majority of research has focused on hemp seeds as a protein source and oil, studies show that hemp flowers from fiber varieties can also be a valuable component of EO, as well as various therapeutic components [149]. Additionally, the EO has antibacterial and insecticidal effects [150].

7. Innovative Domain

Currently, the increased interest in hemp research and cultivation worldwide has led to the development of research and projects about hemp and hemp organizations and associations, for the promotion and dissemination of research results and the importance of hemp in general [151]. Many new applications for hemp fiber and hemp hurd have emerged as technology advances, including the manufacture of carbon nanosheets, plastic materials, 3-dimensional filaments, oil absorbent components, and building concrete [152]. Super-capacitors made from hemp are one of the most revolutionary hemp applications. These superconducting materials are used in electric vehicle brake pads, machine power source, turbo-charging, and cordless devices. Hemp plastic materials are used to create a 3-dimensional filament constructed completely from hemp refuse, with the aim of producing consumer goods from natural raw materials. Hemp Bio Plastic (HBP) filaments are advantageous due to their low environmental impact and high weight-to-volume ratio. A novel device known as a vaporizer pen has been introduced, allowing patients to inconspicuously breathe managed dosages of hemp. This regulates the level of toxic effects caused by smoking in the body. Among the upcoming innovative hemp pieces are ink, soil amendment, tofu, floor coverings, nail varnish, denim, boogie boards, nappies, and hemp eyeglass backpacks [4].

8. Conclusions and Future Perspectives

Given the growing media and scientific interest in hemp's many benefits as a sustainable fiber crop, food supply, medicinal plant, and potential biofuel, it appears that hemp may soon enjoy an even greater resurgence in popularity. Hemp fibers make up a very minor fraction of the textiles produced in Europe and elsewhere today, with cotton still holding a prominent position on the market. In addition to being eco-friendly, hemp is a very adaptable plant, and a source of superfood that is gaining popularity in Europe and other regions. Subsequently, there is an increasing demand for the nutrient-dense hemp seeds. Although there is great potential for the hemp seed industry, restrictions on the industry's growth currently exist [152].

Hemp has received a lot of attention over the past ten years as a crop with great potential. That is driven by innovative techniques that allow hemp to be used for building materials, bioenergy, and industrial paper, as well as the use of hemp derivative products to replace petrochemical products. Advanced demands are emerging on the market, and there is more diversification in production technologies, harvesting, and processing equipment. Increasing the production area for industrial hemp requires the development of all these capacities. Another key factor is to identify market questions for which modern research needs to provide answers, develop guidelines, and scientific projections in view of the ban that lasted for many decades. Legislation should continue to progress in the service of hemp production. The development of legislation to remove the remaining hurdles will be critical to realize the fuller potential of industrial hemp. It is essential to clearly define and adapt the Law on Psychoactive Substances as well as the Law on Food Safety so as to not preclude hemp utilization. The U.S. should help industrial hemp producers in terms of subsidies already used by producers of other crops. The understanding and support of all these aspects would significantly contribute to the development of an increased wider breadth of research, bringing more robust knowledge, and overall significantly improve the position and utilization of hemp products by human societies.

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