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(Review Article)

Exploring the potentialities of industrial hemp for sustainable rural development

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Abstract

This literature review paper explores the potential sustainable applications of industrial hemp, contextualizing it within the UN Agenda 2030 Sustainable Development Goals (SDGs). Hemp is a dioecious, herbaceous, anemophilous (wind-pollinated) annual crop that grows from one to five meters in height. However, monoecious varieties have been developed through breeding and selection. Historically versatile, Cannabis sativa L. has faced stigmatization and unfounded prohibitions, having played crucial roles in different civilizations, including during World War I. A member of the Cannabaceae family, it is a versatile non-psychoactive crop, with low concentrations of THC. Recently, the global market for hemp has grown. It is an eco-friendly option in the food, textile, pharmaceutical, and energy sectors. This study is based on bibliographic research covering primary and secondary sources, including technical reports, academic journals, and scientific repositories. The origin, characteristics and cultivation methods of industrial hemp are discussed, besides its practical applications, including the production of fibers, health food grains, medicinal phytocannabinoids, biofuels, sustainable biomass energy, and carbon offsetting. Its potential to contribute to sustainable agriculture and achieve SDG targets stands out, considering environmental benefits, product diversification, resistance, and integration into agroforestry systems. Regenerative agriculture is explored as a promising approach, aligned with the principles of sustainable agriculture and the SDGs, aiming to restore agricultural ecosystems, promote soil health, and improve climate resilience. The research highlights the importance of reforming cannabis-related policies to achieve goals relating to health, justice, and global partnerships, emphasizing the need for sustainable approaches to exploiting this natural resource.

Keywords: *Cannabis sativa* L.; Latin America; Industrial hemp production; Sustainable rural development; Tropical regenerative agriculture

1. Introduction

As we progress towards development patterns dictated by late-stage capitalist production in the modern world, various events have shaped how we interact with the environment and meet human needs. Among .these transformative socio-environmental processes crucial for human population development, the creation and modernization of agriculture stand out [1]. Through human labor and its intensive material exchange with nature [2], many plants have been domesticated and improved to meet the needs of cultivators. Additionally, numerous plants have been discovered and optimized not only for human consumption but also for the production of medicines, clothing, and beverages.

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At this point, it is important to reflect on the ancient and versatile commodity known as Cannabis sativa, which has served as an alternative solution for various sectors of humanity for thousands of years, providing benefits to health, the environment, and the economy. However, it has not escaped the unfounded stigmatization and prohibition directed towards this entire plant family [3].

Cannabis is one of the plants that has accompanied humans since the domestication of plants in general [4]. Belonging to the Cannabaceae family, Cannabis sativa sp is a versatile plant that, through cultivation, yields various products, primarily the psychoactive substance THC (tetrahydrocannabinol). This substance is present in the form of secretory glands in its female inflorescences, and these flowers produce phytocannabinoids used and extracted for the production of medications for the treatment of various pathologies [5, 26-55].

Hemp (Cannabis sativa L.) originates from the Himalayan region in Asia, where it was initially cultivated with the primary goal of providing durable fibers and producing highly nutritious oilseeds [5, 26-55]. This versatile plant resource played a pivotal role throughout history, being cultivated by major empires over the centuries. Its roots extend to ancient Egypt, where it was highly valued for its multifunctional properties, and its presence endured through ancient Greek and Roman civilizations.

During World War II, hemp experienced a remarkable resurgence in importance due to the exceptionally high demand for durable fibers and food sources. In this critical period of history, hemp played a crucial role in supplying essential resources to the Allied forces and strategically contributed to the production of war materials.

However, the technical distinction between Cannabis sp. and industrial hemp lies in the low concentrations of THC in hemp, earning it the label of non-psychoactive cannabis. Its composition and THC production are generally low or nonexistent, ranging from 0.1 to 1% THC. Therefore, it does not induce psychoactive effects when consumed by humans.

Due to the significant development, particularly in the U.S. market in the years following the regulation of hemp and cannabis promoted by the 2018 Farm Bill , enabling the cultivation and utilization of hemp, many countries have embraced them as a key alternative crop in sustainable rural development projects. This trend aligns with the goals of sustainable and regenerative agriculture, as endorsed by organizations such as the United Nations (UN) [6], linked to the development of sustainable and regenerative agriculture. This is reflected in some of the Sustainable Development Goals (SDGs).

The development perspectives and paradigms present in the SDGs align with the conception, strategies, and goals of sustainable rural development. In this context, it is important to note that the theoretical and practical perspective of this article is grounded in the concept of sustainable rural development. This concept encompasses approaches and practices aimed at improving the quality of life in rural populations, promoting economic growth, social equity, and environmental preservation in an integrated and lasting manner. This approach seeks to balance economic development with the conservation of natural resources and the well-being of rural communities, considering not only present but also future generations [7].

This work represents one of the partial outcomes of a theoretical and empirical research conducted in Paraguay, a Latin American country that, pioneering in the region, decriminalized, legalized, and supported the implementation of a pilot project for industrial hemp cultivation as a rural development strategy in impoverished areas.

2. Methodology

The items of data for this research were gathered through a bibliographic search, seeking scientific literature and information in scientific articles on platforms such as Google Scholar, Elsevier, and SpringerLink. The applied descriptors included “industrial hemp,” “hemp sustainable crop,” and “Hemp and sustainable development.” Additionally, a narrative bibliographic research was conducted, utilizing classical theoretical sources to develop the theoretical framework. This framework is based on concepts such as sustainable rural development and categories like State, politics, and social reproduction. As this is a naturalistic research without control over variables and since it focuses on an ongoing rural development research/project, apart from the narrative bibliographic research and scientific databases, technical reports, grey literature, scientific repositories, and digital archives related to the theme were consulted. Thematic content analysis was performed with the data.

The adoption of this methodology aims to directly engage the researcher with what has been written, spoken, or filmed about a particular subject for the construction and approach of a theme that is still in its early stages in the scientific and political realms [8]. The analysis of the research object required studies primarily from the perspectives of agriculture, economics, and the environmental field.

3. Industrial Hemp: Origin, Characteristics, and Stigmatization

Hemp originates in Asia, in the Indian Himalayan region, China, Bhutan, Nepal, Afghanistan, Pakistan, and Bangladesh, where it was initially cultivated with the primary goal of providing durable fibers and producing highly nutritious oilseeds. India and China have a long, ancient history of cultivating and using hemp [9, 10, 11, 1, 26-55]. The earliest evidence of hemp use in Asian countries dates back to 10,000 years ago [9, 10, 11, 12, 13, 26-55]. However, for the past 6,000 years, it has been cultivated in almost all temperate and tropical countries worldwide, making it potentially one of the oldest non-food crops known. Throughout much of human evolution, this versatile plant resource played a pivotal role throughout history, being cultivated by major empires over the centuries [9, 10, 11, 12, 13]. Its roots extend to ancient Egypt, where it was highly valued for its multifunctional properties, and its presence endured through ancient Greek and Roman civilizations. Globally, it is estimated that at least 47 countries grow hemp for commercial or research purposes [9, 10, 11, 12, 13]. The global market size estimates for industrial hemp for 2025 vary greatly, with some estimates as high as USD 26.6 billion.

Although hemp can be grown as a dual-purpose crop, production systems are usually geared to producing either fiber or seed, and generally not both. There are established hemp breeding programs for fiber and seed – many of them in the commercial sector, with a general lack of knowledge across the industry about the type of germplasm available [9, 10, 11, 12]. There is limited information about the availability of elite breeding lines for improved seed size and quality [9, 10, 11, 12, 13].

Industrial hemp has been valued for its adaptability and versatile uses. During World War II, the United States government took significant interest in hemp cultivation due to its versatile applications in meeting various demands [9, 10, 11, 12, 13, 26-55]. Hemp was extensively used for the production of ropes, canvas, and military uniforms due to its strength and durability. Additionally, hemp oil was employed in manufacturing lubricants and aircraft paints. This emphasis on hemp cultivation aimed to ensure the supply of essential materials during the conflict [9, 10, 11, 12, 13].

However, after World War II, several factors led to the decline of the hemp industry in the United States. Competition from synthetic fibers – such as nylon, which became widely available and economical – influenced the demand for hemp fibers [9, 10, 11, 12, 13]. Furthermore, the Marihuana Tax Act of 1937 imposed high taxes and stringent regulations on hemp and marijuana, making the economic viability of hemp production challenging. The growing anti-drug public sentiment and the unfounded association between hemp and marijuana also contributed to the decline in hemp cultivation in the United States [9, 10, 11, 12, 13].

In contrast, in recent years, there has been a renewed interest in industrial hemp production in the United States, especially since 2018 with the Farm Bill. This interest is particularly evident in regions of the country heavily dependent on a single crop, such as tobacco or wheat. Farmers have shown interest in the potential of hemp as a high-value alternative crop [9, 10, 11, 12]. So far, economic studies show optimistic results in terms of the profitability of hemp production [9, 10, 11, 12, 13].

4. Hemp (Industrial Cannabis sativa): Commercial Importance

Hemp is a dioecious (male and female plants are separate), herbaceous, anemophilous (wind-pollinated) annual crop that grows from one to five meters in height [9, 10, 11, 12, 26-55]. However, monoecious varieties have been developed through breeding and selection.

The biotypic connection of hemp to marijuana (medical Cannabis sativa L. ssp. indica), a related species with a high psychoactive Λ9-tetrahydrocannabinol (THC) (from 0.3 to 40% dry weight), led to the banning of hemp in several countries, including the USA [9, 10, 11, 12]. Meanwhile, a higher non-toxic cannabidiol (CBD) content and a lower Λ9-tetrahydrocannabinol (THC) content are two of the advantages of hemp over marijuana for agricultural production. Cannabis plants produce between 80 and 144 identified cannabinoids, including THC, and approximately 300 non-cannabinoids. Among the cannabinoids, Cannabidol (CBD) may have multiple medicinal properties [5, 26-55].

Increasing demand for organic, eco-friendly , environmentally sustainable products opens the doors for hemp products in the global market. About 25,000 potential hemp products are currently available in markets [9, 10, 11, 12], ranging from textiles, clothing, rope, home furnishings, industrial oils, and cosmetics, to food and pharmaceuticals. Hemp has regained its potential as an important agricultural crop due to its versatile contributions as a source of CBD, fiber, oil, and grain. Its weed suppression potential is well suited to crop rotation [9, 10, 11, 13]. Hemp oil and crop residues can be used in organic farming as eco-friendly organic insecticides and pesticides. Advances in modern technology have expanded the use of hemp in the production of nanosheets, biodegradable plastics, and construction concrete (known as hempcrete), biochar and textiles [9, 10, 11, 12, 13, 26-55].

The cultivation of fiber-type industrial hemp is more efficient and less environmentally degrading than that of many other crops. Hemp can be grown under a variety of agro-ecological conditions and has a capacity to grow quickly, especially after the first 4–5 weeks after emergence, making it an excellent candidate for carbon sequestration [9, 10, 11, 13]. Hemp is currently considered as a niche crop and is grown in temperate regions. Products manufactured from hemp are eco-friendly, renewable, and associated with less harmful methods of preparation [9, 10, 11, 12, 13, 26-55].

Hemp grain and its derivatives have also gained popularity among consumers and have multiple uses. The durability and high strength properties of the cellulose-rich fiber from the stalk make it a valuable product for rope, paper, building construction materials (hempcrete), and reinforcement materials. Moreover, currently, the utility of fiber-type industrial hemp as a functional food ingredient has been leading to a revival of old medicinal applications, as its metabolites have shown potent biological activities [9, 10, 11, 12]. The market is driven by the growing demand for fiber-type industrial hemp from several sectors, such as food and beverage, personal care, and animal care industries, across the globe. Growing awareness regarding the dietary advantages of hempseed and hempseed oil, along with rising demand from the cosmetics and personal care industries, will stimulate market growth. Increasing production of soaps, shampoos, bath gels, hand and body lotions, UV skin protectors, massage oils, and a range of other hemp-based products is expected to have a positive impact on the market [9, 10, 11, 12]. The high nutritional values and beneficial fatty acid and protein profile of fiber-type industrial hemp have been driving the demand for hemp products [9, 10, 11, 12, 13]. The high absorbency of hemp fiber is beneficial for livestock bedding, oil and gas cleanup, and personal hygiene applications. In addition, increasing product demand from the textile, paper, and building materials markets, owing to favorable acoustic and aesthetic properties, will also support market growth [9, 10, 11, 12].

Hemp fibers are used in paper, carpeting, home furnishing, construction materials, insulation materials, and auto parts and composites. Insulation materials and biocomposites consume a significant product amount because of their low weight, superior strength, biodegradability, and thermodynamic properties [9, 10, 11, 12, 26-55]. Hemp shives cost half as much as fibers and have several applications in different industries, which is expected to drive growth due to regulation [9, 10, 11, 12]. They are majorly used in animal bedding materials on account of their high absorbance ability – around four times their own dry weight [9, 10, 11, 12]. Paper produced from hemp fibers requires fewer chemicals for processing as compared to paper produced from wood pulps. Hemp oil is widely used in the manufacturing of food and beverages due to its high nutritional content, including fatty acids, proteins, and several other ingredients [9, 10, 11, 12]. Several food manufacturing processes make use of hemp seeds and oil, which is expected to propel market growth [9, 10, 11, 12, 13].

Hemp seeds and oil contain an amino acid known as arginine, which is extremely good for the heart as it dilates and relaxes blood vessels. Hemp oil fights inflammation and lowers blood pressure, hence helping to prevent the formation of blood clots. Hemp seeds are a good source of gamma-linolenic acid (GLA), which is known for its strong anti-inflammatory properties [9, 10, 11, 12]. Foods rich in GLA are extensively used to fight inflammation in the joints (arthritis), nerve damage, and inflamed skin conditions such as acne, and eczema [9, 10, 11, 12]. Hemp seed oil is currently advertised primarily as a natural health product for body care purposes, as oil for salad dressings, or to be taken directly as a dietary supplement. Its susceptibility to rancidity with heat and prolonged storage is strong, reducing its use as cooking oil [9, 10, 11, 12, 13, 26-55].

Hemp is used to making cloth, cosmetics, rope, printer's ink, wood preservatives, detergents, soaps, and lighting oil. Hemp fibers are used in the preparation of artificial hair wigs. Hemp seeds, which are rich in protein, fiber, and fatty acids, including omega-3 and omega-6, are used to produce a variety of food products [9, 10, 11, 12]. It is said that they have antioxidant effects and may reduce symptoms of numerous ailments, improving the health of the heart, skin, and joints. Hemp seeds have been commonly claimed as one of the most nutritionally complete food sources due to its high nutritive traits [9, 10, 11, 12, 13].

As a result of the significant development of the U.S. market in the years following the regulation of hemp and Cannabis promoted by the 2018 Farm Bill, which enabled the cultivation and utilization of hemp, many countries have embraced it as a key alternative crop in sustainable rural development projects [9, 10, 11, 12, 13]. This trend aligns with the goals of sustainable and regenerative agriculture, as endorsed by organizations such as the United Nations (UN), linked to the development of sustainable and regenerative agriculture. This is reflected in some of the Sustainable Development Goals

(SDGs) [9, 10, 11, 13]. The development perspectives and paradigms present in the SDGs align with the conception, strategies, and goals of sustainable rural development [9, 10, 11, 12]. In this context, it is important to note that the theoretical and practical perspective of this article is grounded in the concept of sustainable rural development [9, 10, 11]. This concept encompasses approaches and practices aimed at improving the quality of life in rural populations, promoting economic growth, social equity, and environmental preservation in an integrated, lasting manner [9, 10, 11, 14]. This approach seeks to balance economic development with the conservation of natural resources and the well-being of rural communities, considering not only present but also future generations [9, 10, 11, 12, 14].

This paper represents one of the partial outcomes of a theoretical and empirical research conducted in Paraguay, a Latin American country that, pioneering in the region, decriminalized, legalized, and supported the implementation of a pilot project for industrial hemp cultivation as a rural development strategy in impoverished areas. In light of the above, this article aims to analyze the culture of industrial hemp, reporting its origin, general characteristics, and its relation to the SDGs agenda, especially SDG 2 – Zero Hunger and Sustainable Agriculture.

5. New Sustainable Raw Materials as a Solution to an Economic Need

This raw material appears at an economic turning point. The economic trend after COVID-19 requires Latin American countries to be more resourceful in local economies, translating into greater government spending and private investment in the agricultural sector and greater pressure for sustainable industrial development. According to the International Monetary Fund (IMF), the risks arising from geopolitical conflicts in Latin America may lead to tightened financial conditions, disrupt supply chains and, at the same time, cause inflationary damage by raising the prices of food and raw materials; besides, the El Niño and Niña phenomena affect annual production in the agricultural sector [15, 16].

In its latest economic outlook report for the Americas, dated October 13, 2023, the IMF establishes a growth projection for Latin America at 2.3% for the year 2024. With respect to the average of the previous 10 years – 3.8% – it is a setback [14, 16]. The economic slowdown for the Americas in 2024 puts pressure on the internal development variables within each Latin American country. Countries such as Brazil, Paraguay, Colombia, Ecuador, Argentina, Mexico, Uruguay and Chile – which have legislation or mechanisms for the production of new raw materials such as hemp – are the same economies with agro-industrial platforms that are capable of incorporating the country's industrial structure strategies that positively impact all current challenges, such as poverty, unemployment, migratory crisis, education, climate change, green growth, and digitalization. In turn, this may give rise to international competition; the countries may be able to enter markets with the highest quality standards – the ones that require compliance with the sustainable development objectives within the UN Agenda 2030 Sustainable Development Goals.

6. Industrial Hemp and Its Characteristics

Hemp, an annual herbaceous plant, has been cultivated agriculturally for many centuries for its fibers and oilseeds. Botanically, hemp (Cannabis sativa L.) is an advanced plant. It is dioecious, meaning the same plant has male, female, and sometimes both (hermaphrodite) reproductive organs [9, 10, 11, 12, 13, 26-55]. Hemp grows as a woody plant that lives only one year and efficiently harnesses sunlight, even more so than most other C3 plants. Being a C3 plant means that the plant uses the C3 carbon fixation cycle, absorbing carbon dioxide directly from the atmosphere for the production of sugars and other organic compounds [9, 10, 11, 12, 13]. Generally, hemp is a fast-growing plant, efficient in absorbing carbon dioxide, allowing it to reach an impressive height of four to seven meters in a short period [9, 10, 11, 12, 13].

Hemp is not only a standout crop among various agricultural options, complementing fiber and paper production, but it also brings environmental benefits and shows lucrative potential. It fits into sustainable agricultural systems, due to its distinct characteristics that make it a promising crop in the context of sustainable rural development [9, 10, 11, 12, 13]. Besides rapid growth, the crop easily adapts to different climatic conditions and soil types. Additionally, industrial hemp is known for its low incidence and resistance to pests and diseases, reducing the reliance on pesticides and promoting more sustainable agricultural practices when integrated into production systems [9, 10, 11, 12].

The use of this crop is seen as a sustainable alternative for various industries, sectors, and communities as a means of improving sustainable rural development indicators (IEJ, 2023) [9, 10, 11, 12]. As highlighted by Russo et al. [17], hemp can contribute to a greener and circular economy, with more responsible production and consumption and less environmental impact. Furthermore, hemp cultivation may provide social and economic benefits to local, rural, and developing communities [9, 10, 11, 12].

Even though Cannabis has more than 500 mapped cannabinoids in its composition, the factor that distinguishes industrial hemp from medicinal Cannabis is the THC (Λ9-tetrahydrocannabinol) content present in the female plant inflorescences [9, 10, 11, 12, 13, 18]. Industrial hemp has very low or almost negligible psychoactive THC levels, which distinguishes it from Cannabis, prohibited in Brazilian territory under Law No. 11,343, of August 23, 2006, known as the Drug Law [9, 10, 11, 12, 13].

Each part of the hemp plant has a specific use in the industry. Due to their high nutritional value, the seeds are used in food production, animal feed, and even in cosmetic products [9, 10, 11, 12]. The hemp stem, in turn, is a valuable source of fibers and hurd (the inner part of the stem), used in paper manufacturing, various textile products, construction materials, and as bedding for animals. Additionally, the robust root system of hemp plays a crucial role in phytoremediation of heavy metals and soil structure improvement, making it particularly suitable for cover crops [9, 10, 11, 12, 13]. Its inflorescences are the basis for the production of oils and cosmetics, such as essential oils composed of Cannabidiol (CBD) and pure extracts and terpenes [9, 10, 11, 12, 19, 20].

The crop presents diversified production and viability as an off-season crop in other countries, and can be used in sectors such as animal and human nutrition. Some companies in Brazil, as well as startups, have already been developing products and research projects to study the crop, create technology, adapt genetics to Brazilian production regions, fostering the necessary expansion for the market [9, 10, 11, 12, 13].

The use of industrial hemp can bring significant environmental benefits compared to other crops and materials [9, 10, 11, 12]. Hemp cultivation may help reduce soil erosion and air and water pollution, as well as improve local biodiversity. Moreover, the plant is highly renewable and can be used as a more sustainable alternative to materials such as plastic and cotton [9, 10, 11, 12, 13, 26-55].

Hemp has already been cultivated in about 50 countries and has great potential for agricultural and economic expansion in Brazil. The legal cultivation of Cannabis sp. generated around USD 600 million in 2017 in the United States alone, where plants of the Cannabis genus are already considered an agricultural commodity [9, 10, 11, 12, 26-55]. One study on agroclimatic zoning for C. sativa varieties provided information and data on the immense potential for crop production in Brazil, especially in the Northeast and Central-South regions of the country. The author further states that a significant part of Northeastern Brazil, as well as the region near the border with Paraguay, have the highest aptitude for hemp cultivation in Brazil.

7. Practical Applications of Industrial Hemp Fibers

In recent years, there has been a resurgence of interest in hemp as a sustainable and versatile textile fiber in the fashion and textile industry [9, 10, 11, 12]. Hemp is a sustainable and environmental friendly crop that can provide valuable raw materials to a large number of industrial applications. Hemp fiber is very strong compared with other natural fibers such as cotton, flax and nettle. The cultivation of hemp has significantly less environmental impact compared to cotton. Industrial hemp contains primary and secondary fibers – the primary fibers may be used for textiles [9, 10, 11, 12, 13]. Hemp has been mostly blended with cotton and synthetic fibers due to barriers in the industrial process of the production of full hemp-based textiles [9, 10, 11, 12]. Hemp clothing is stronger and more durable than cotton clothing and does not deform as easily [9, 10, 11, 12]. Apparel made from hemp merges easily with dyes and does not discolor easily [9, 10, 11, 12]. Hemp has outstanding antibacterial properties that surpass those of cotton and also any other natural fiber. Hemp textile fiber is hypoallergenic and has natural antimicrobial properties, making it an excellent choice for individuals with sensitive skin [9, 10, 11, 12]. However, despite its many benefits, hemp is still relatively expensive in India compared to other cellulosic fibers such as cotton, linen, rayon, etc. [9, 10, 11, 12]. Hemp has a great cultural and historical value in India because it has been grown and used there for thousands of years. This cultural history can be conserved and honored by using hemp in the fashion and textile business [9, 10, 11, 12, 13, 26-55].

The benefits of using hemp fiber for the production hemp plastic is one of the hot topics in cannabis science [9, 10, 11, 12]. Traditional fossil-fuel based plastic production emits massive levels of greenhouse gasses, and the material can take hundreds of years to break down [9, 10, 11, 12]. Traditionally, plastics are made from petroleum-based compounds, which release toxic gases into the atmosphere [9, 10, 11, 12, 13]. Petroleum-based plastics and its by-products have a devastating effect on land, water, and wildlife. Just like conventional plastics, biodegradable plastics are produced using petrochemicals; however, some additives are included in their manufacturing, assisting in their fast degradation [9, 10, 11, 12]. Hemp plastic is a type of biodegradable plastic made from hemp fibers, which have a sufficiently high cellulose concentration in manufacturing polymers. The resulting material is fully biodegradable and recyclable [9, 10, 11, 12]. It can then be processed into various products, including packaging, consumer goods, automotive parts, and more conventional plastics. Hemp plastic, which is completely biodegradable, can be a better alternative to synthetic plastic.

Hemp plastic is also lightweight, with an impressively high density-to-weight ratio [9, 10, 11, 12]. This makes hemp plastic a potentially good material for making lightweight components in the car and aerospace industries. Conversely, hemp plastic helps minimize the greenhouse effect. Hemp plastic offers great thermal, UV, and dimensional stability [9, 10, 11, 12, 13]. Some types of hemp plastic are also resistant to flames. Hemp plastic is solely produced using the cellulose extracted from hemp plants; therefore, there is no toxicity during its production [9, 10, 11, 12, 13, 26-55].

One of the oldest and primary applications of industrial hemp is the production of high-quality fibers. Hemp fibers are strong, durable, and versatile, finding use in the textile industry for making clothing, fabrics, and ropes [9, 10, 11, 12]. Moreover, these fibers are less susceptible to mold and have antimicrobial properties, making them suitable for applications in sectors such as construction and automotive industries and in the production of biocomposites used in biodegradable materials [9, 10, 11, 12, 14].

Cultivating hemp for fiber production allows the creation of alternative planting and soil management systems, involving not only crop rotation but also plant diversification and integration, providing the opportunity to add value during soil fallow periods [9, 10, 11, 12]. Hemp fiber shows significant potential for the production of a wide range of value-added products. From textiles to construction materials and paper products, hemp demonstrates versatility in creating local and regional markets [9, 10, 11, 12, 13, 26-55]. This industrial diversification can stimulate rural economies, creating jobs across different sectors of the production chain, from cultivation to processing and marketing [9, 10, 11, 12]. The hemp plant has the potential to be a source of biomass with a high cellulose content, which can be converted into biofuels such as ethanol and biodiesel and sustainable biomass energy [9, 10, 11, 12, 13]. Additionally, the residual biomass of hemp, such as unused parts of the plant, can be transformed into thermal and electric energy through burning or anaerobic fermentation processes. These forms of renewable energy contribute to reducing greenhouse gas emissions and transitioning to a cleaner energy matrix [9, 10, 11, 12].

Hempcrete is a plant-based sustainable building construction material made with a low environmental impact that reduces waste production and decreases both energy use and the consumption of natural resources [9, 10, 11, 12, 13, 26-55]. It is a cost-effective building material made from industrial hemp fibers, lime and water [9, 10, 11, 12]. Its sustainable properties make it a promising material in both new projects and renovations [9, 10, 11, 12]. It is a breathable composite, with good thermal and acoustic-insulation properties. For building purposes, the hurds (inner woody core) of hemp are mixed with a lime-based binder forming a bioaggregate concrete, known as “hempcrete” [9, 10, 11, 12]. The hemp-lime composite material is mainly used to make walls, although floor slabs, ceiling, and roof insulation can be made. The relatively denser hempcrete mixture is poured above a base layer into the floor to make floor slabs [9, 10, 11, 12, 13]. Hempcrete is a biocomposite mixture of hemp shives, lime binder and water. A lightweight material, which is about one-eighth the weight of concrete. Furthermore, civil engineers confirmed that hempcrete blocks may also be used for roofs, as well as the more conventional wall applications, since their implementation is easier than other types of material [9, 10, 11, 12, 26-55].

One study demonstrated that hemp has eco-friendly attributes throughout its life cycle. Hemp biomass exerts the lowest environmental impact concerning various parameters such as nutrient depletion, pesticide application, soil compaction, and promotion of eco-biodiversity, even though low to medium impact results were observed concerning erosion, water consumption, and biodiversity [9, 10, 11, 12]. Apart from these advantages, hemp also excels as an excellent phytoremediation biomass, capable of decontaminating soils with high levels of heavy metals. These metals typically accumulate in the plant biomass and can be subsequently extracted from its ashes [9, 10, 11, 12, 13].

Another study reports that the residual biomass of hemp, obtained after bioenergy extraction, can be used for biochar production, which can be applied as a soil amendment [9, 10, 11, 12]. This recycling of hemp biomass allows for a high carbon sequestration rate, benefiting not only the soil and subsequent plants but also contributing to emission reduction, as hemp has a carbon-neutral footprint [9, 10, 11, 12, 13, 26-55].

8. Grains

Cannabis seeds, in general, typically contain around 30% oil and 25% protein, accompanied by significant amounts of dietary fibers, vitamins, and minerals [9, 10, 11, 12]. The oil extracted from hemp seeds, obtained through mechanical extraction, has over 80% polyunsaturated fatty acids, with a special emphasis on linoleic acid (omega-6) and alpha-linolenic acid (omega-3). The ratio between omega-6 and omega-3 in this oil is considered optimal for human health, as indicated in studies. The biological metabolites of two essential fatty acids, namely gamma-linolenic acid and stearic acid, are also present in this context [9, 10, 11, 12, 13, 26-55].

Hemp seeds are rich in protein content and majorly used as birdseed and animal feed. Bird and fish feed are important markets for hemp seeds in animal nutrition, as fish and birds need fatty acids with a high share of omega-3 and omega-6 fatty acids for optimum development [9, 10, 11, 12].

Hemp seeds are a balanced health product with bioactive components that have the capacity to aid health beyond basic nutrition [9, 10, 11, 12, 13]. The major constituents of hemp seed include easily digestible proteins (20–25%), polyunsaturated fatty acids (PUFA), abundant lipids (25–35%), and carbohydrates (20–30%) high in insoluble fiber. Hemp seed protein is well suited for human and animal consumption, consisting mainly of the high quality, easily digestible proteins edestin and albumin, which are abundant with essential amino acids [9, 10, 11, 12, 13]. The rich source of PUFA, linoleic acid (omega-6) and alpha-linolenic acid (omega-3), is favorable and regarded as balanced for human nutrition, as nutritional recommendations indicate that 15–20% of daily caloric intake should come from fats, and approximately one third of these fats should be essential fatty acids in a 3:1 ratio [9, 10, 11, 12]. It is estimated that this dietary goal can be met with three tablespoons of hemp seed oil [9, 10, 11, 12, 13, 26-55].

Numerous other health benefits and potential therapies are reported for hemp seeds [9, 10, 11, 12]. Hemp seed delivers a desirable ratio of omega-6 to omega-3 PUFA, which can improve cardiovascular health, reduce osteoporosis symptoms, and diminish eczema conditions [9, 10, 11, 12]. CBD exerts pharmacological properties that make it a potential therapeutic agent for central nervous system diseases, such as epilepsy, neurodegenerative diseases, and multiple sclerosis. Hemp seeds and sprouts are rich in beneficial bioactive compounds with both in vitro and ex vivo antioxidant activities [9, 10, 11, 12, 13].

For grain production, cultivation is managed for a harvest around 70 to 90 DAP (days after planting), and subsequently processed according to its commercial purpose. Currently, the products with the most demand include the production of raw material by transforming the oilseed into oil through the processing process [9, 10, 11, 12, 13]. The hearts of the seed, called hemp hearts, which consist of the protein-rich interior of the seed, are also benefiting. Hemp grains are a valuable source of nutrients and offer various nutritional benefits. They contain high-quality proteins and omega-3 and omega-6 fatty acids, as well as essential vitamins and minerals. The protein in the seed also features a favorable amount of glutamic acid, a neurotransmitter that helps individuals cope with psychological stress. Hemp grains can be used in the production of healthy foods such as edible oils, dietary supplements, and baked goods. Additionally, they have a low gluten content [9, 10, 11, 12, 13].

Hemp seed oil contains tocopherol isomers, beta-tocopherol, gamma-tocopherol, alpha-tocopherol, and delta-tocopherol, with the gamma-tocopherol derivative present in the highest quantity [9, 10, 11, 12, 13, 26-55]. Tocopherols are natural antioxidants that can reduce the risk of disorders related to oxidative degeneration [9, 10, 11, 12]. Moreover, terpenes and polyphenols have been detected, which contribute to the odor/flavor and intrinsic antioxidant activity, respectively. Among phenolic compounds, flavonoids, such as flavanones, flavonols, flavanols, and isoflavones were the most abundant [9, 10, 11, 12, 13]. Furthermore, the human diet supplemented with 30 mL of hemp seed oil daily for four weeks detected positive changes in the serum lipid profile [9, 10, 11, 12]. Evidence suggests that phyto-, endo-, and synthetic cannabinoids contain properties that aid in the treatment of brain, prostate, breast, skin, pancreas, and colon cancer [9, 10, 11, 12]. Cannabinoids have also been found to prevent the differentiation and proliferation of glioma stem-like cells, which may help treat the difficult-to-eliminate nature of gliomas [9, 10, 11, 12, 13].

Hemp seeds present a viable feedstock option for biodiesel production [9, 10, 11, 12, 26-55]. This is demonstrated by the plants high yield, ability to grow on infertile soil, and resilience to disease and bugs. Hemp biodiesel performs well in biodiesel blends. Its yield was calculated at 207 gallons/hectare. This is higher than the yield of biodiesel from rapeseed and soybeans oil but lower than that of palm oil. Hemp biodiesel can meet ASTM D6751 and EN 14214 requirements; the U.S. quality standard for biodiesel is ASTM D6751, established by ASTM, while the European Union follows the EN 14214 standard by CEN. Both standards set specifications for biodiesel quality, covering physical, chemical, and performance characteristics. Compliance ensures safety and effectiveness in production, storage, and use, promoting international acceptance. The kinematic viscosity and oxidation stability of hemp biodiesel is poor, yet this can easily be improved with the use of additives [9, 10, 11, 12, 13]. Dilution/blending, micro-emulsification, pyrolysis, and trans-esterification are the four techniques applied to solve the problems encountered with the high fuel viscosity.

Hemp biodiesel provides substantial environmental benefits [9, 10, 11, 12, 13, 26-55]. The amount of emission reduction corresponds roughly to the biodiesel blend rating of the fuel [9, 10, 11, 12]. Hemp biodiesel may be used an alternative to the highly controversial biodiesel produced from palm oil.

Hemp faces many perception and legal challenges that prevent wide-scale production of hemp seed oil. Hemp remains a niche crop in the food supply chains, rendering it prohibitively expensive as a feedstock in biodiesel production.

Legalization and increased production of hemp oil may improve the cost of producing hemp oil and subsequently hemp biodiesel [9, 10, 11, 12, 13].

9. Phytocannabinoids

Phytocannabinoids are cannabinoids that occur naturally in the Cannabis plant [9, 10, 11, 12, 13]. The classical cannabinoids are formed through decarboxylation of their respective 2-carboxylic acids (2-COOH), a process that is catalyzed by heat, light or alkaline conditions [9, 10, 11, 12, 21, 22]. These cannabinoids are abundant in the viscous resin that is produced by glandular structures in the Cannabis plant called trichomes [9, 10, 11, 12, 21]. This resin is also rich in terpenes, which are responsible for the characteristic smell of Cannabis [9, 10, 11, 12, 21]. The phytocannabinoids are mostly insoluble in water but are soluble in alcohol, fat and other non-polar organic solvents. In alkaline conditions, they can form water-soluble phenolate salts, being essentially phenols [9, 10, 11, 12, 21, 22, 26-55]. Furthermore, only around 100 out of over 500 different compounds present in Cannabis have been identified as cannabinoids.

The cannabinoids are separated into subclasses that include: cannabigerols (CBG), cannabichromenes (CBC), cannabidiols (CBD), tetrahydrocannabinols (THC), cannabinol (CBN), cannabinodiol (CBDL), cannabicyclol (CBL), cannabielsoin (CBE), cannabitriol (CBT), cannabivarin (CBV), tetrahydrocannabivarin (THCV), cannabidivarin (CBDV), cannabichromevarin (CBCV), cannabigerovarin (CBGV), and cannabigerol monoethyl ether (CBGM) [9, 10, 11, 12, 21]. The most well-known compound is the Δ9-tetrahydrocannabinol (Δ9-THC), the main psychoactive ingredient in the plant [22, 23]. Other common cannabinoids include cannabidiol (CBD) and cannabinol (CBN) [9, 10, 11, 12, 21]. THC reduces pain perception in the brain and is also neuroprotective [22, 23]. It has a similar affinity for the CB1 and CB2 receptors. Cannabidiol (CBD), conversely, is not psychoactive and has been found to act as a CB1 receptor antagonist [9, 10, 11, 12, 21]. CBN is effective at relieving convulsions or seizures, anxiety, nausea, and inflammatory changes [9, 10, 11, 12, 21]. Cannabigerol is also not psychoactive and acts as a CB1 receptor antagonist [9, 10, 11, 12, 21, 22, 23, 26-55].

Industrial hemp contains phytocannabinoids – cannabidiol (CBD) is one of the most well known [9, 22, 23, 24]. These substances have sparked significant interest in the pharmaceutical and medicinal industry due to their potential therapeutic properties [9, 10, 11, 12, 13]. As a result, hemp has been cultivated as a medicinal plant, and investigations into the uses of hemp as a therapeutic and medicinal plant continue [9, 10, 11, 12, 22, 23]. CBD, for example, has been studied for its anti-inflammatory, analgesic, and anxiolytic effects. Although more research is needed, phytocannabinoids present in hemp and Cannabis sativa sp. show promise in treating conditions such as epilepsy, anxiety, and chronic pain [9, 10, 11, 12, 13, 22, 23].

The discovery of cannabidiol (CBD) in 1963 and Δ9-tetrahydrocannabinol (THC) in 1964 isolated from Cannabis sativa is attributed to Dr. Raphael Mechoulam, affectionately referred to as the godfather of cannabis science, and his team at Israel's Weizmann Institute of Science [9, 10, 11, 12, 21, 22, 23]. THC and CBD are the neutral homologs of tetrahydrocannabinolic acid (THCA) and cannabidiol acid (CBDA), respectively [9, 10, 11, 12, 21, 22, 23, 26-55].

Scientific advances related to hemp have allowed the identification of cannabinoids, which are the most active compounds found primarily in the glandular trichomes present in the female inflorescences [9, 10, 11, 12]. Among the cannabinoids present in the plant, Δ9-THC (Tetrahydrocannabinol) is the most potent in terms of psychoactive effects, although it is found in lower proportions in the leaves of the Cannabis plant. It is important to mention that the male hemp plant produces lower quantities of cannabinoids, terpenes, and flavonoids compared to the female plant [9, 10, 11, 12, 13, 26-55].

The bodies of humans and other mammals have an endocannabinoid system (ECS), which plays a significant role in maintaining processes as diverse as appetite, sleep, mood, stress, energy levels, and reproduction [9, 10, 11, 12, 21, 22, 23]. It is an ancient, evolutionary stable homeostasis system that consists of three components – ligands, including 2-arachidonoylglycerol (2-AG) and arachidonoyl ethanolamide (AEA or anandamide), receptors, such as cannabinoid receptor 1 (CB1) and cannabinoid receptor 2 (CB2), and the metabolizing enzymes – fatty acid amide hydrolase and monoacylglycerol lipase [9, 10, 11, 12, 21, 22, 23, 26-55]. The ECS is a complex cell-signaling system that helps to regulate our body functions, including sleep, mood, digestion, memory, reproduction, fertility, appetite and digestion, metabolism, chronic pain, inflammation and other immune system responses, motor control, cardiovascular system function, muscle formation, bone remodeling and growth, liver function, the reproductive system, stress, skin and nerve function [9, 10, 11, 12, 21, 22, 23]. These functions all contribute to homeostasis, which refers to the stability of our internal environment – for example, if an outside force, such as pain from an injury or a fever, affects homeostasis, the ECS is activated to help the body return to its ideal operation.

The discovery of Δ9-THC opened the gate for many of the subsequent developments in the field of endocannabinoid system research [9, 10, 11, 12, 21, 22, 23, 26-55]. The entry of the ECS into modern research as a potential target of pharmacotherapeutic intervention began with the discovery and cloning of specific Gi/o protein-coupled cannabinoid receptors (CB1 and CB2 receptors). While CB1 receptors are primarily located in the central nervous system, CB2 receptors are mostly expressed on cells of the immune system. Around the turn of the millennium, the non-selective cation channel transient receptor potential vanilloid 1 (TRPV1) was described as an additional receptor target for several cannabinoids such as AEA and the non-psychoactive phytocannabinoid CBD [9, 10, 11, 12, 21, 22, 23].

As a regulator of homeostasis, the ECS regulates the activity of the brain, endocrine, and immune systems [9, 10, 11, 12, 21, 22, 23]. One such regulatory mechanism is the regulation of energy metabolism. The ECS increases the energy intake, facilitates its storage, and decreases expenditure. It represents a critical part of understanding THC and its potent effects on the human body [9, 10, 11, 12, 21, 22, 23]. The ECS produces endogenous cannabinoids (produced internally) and responds to exogenous cannabinoids (produced externally), like the ones found in Cannabis, which are called phytocannabinoids. Endogenous cannabinoids are now generally referred to as "endocannabinoids" and, together with cannabinoid receptors, constitute the ECS [9, 10, 11, 12, 21, 22, 23].

10. Carbon Offset

Biochar is defined as the burning of the organic material at high temperatures under limited oxygen supply to produce a carbon-rich material formed under pyrolysis of different organic materials [9, 10, 11, 12, 13, 26-55].

Biochars were generally characterized by having a porous nature and large surface area. They can directly provide nutrients to the soil because they contain nitrogen, phosphorous, potassium, magnesium, and calcium [9, 10, 11, 12, 13]. Progressive mineralization of biochar in soil releases inherent nutrients into the soil. Hemp biochar carbonized at 800–1000°C displayed interesting electrical conductivity, opening opportunities for its use in electrical purposes [9, 10, 11, 12]. Biochar is an important material for environmental management to mitigate greenhouse gas emissions, such as sequestration of CO2 and CH4, and ozone-depleting N2O emissions. Biochar can be utilized as a soil conditioner and a container substrate amendment in agriculture and horticulture [9, 10, 11, 12, 13]. Biochar also has the potential to improve a variety of physical, chemical, and biological qualities of the soil and substrate.

However, biochar has some disadvantages, including the fact that the addition of biochar resulted in such a high pH that plant growth was severely reduced, which might have obscured any potentially beneficial effect of using biochar [9, 10, 11, 12]. This highlighted the challenge in using biochar in organic growing media due to the difficulty in maintaining the pH at an adequate level for plant growth [9, 10, 11, 12, 13, 26-55].

The decarbonization of the atmosphere is an urgent challenge in the fight against climate change. In this context, industrial hemp has garnered interest as a crop capable of contributing to the reduction of carbon emissions [9, 10, 11, 12]. The rate of photosynthesis of the plant is high, absorbing significant amounts of CO2 from the atmosphere during its growth and sequestering it in the soil. Additionally, the cultivation of industrial hemp can contribute to a decrease in the use of materials and products with a higher carbon footprint, such as conventional plastic and cotton [9, 10, 11, 12, 13].

Industrial hemp has also been studied for integration into agroforestry and agroecological systems, providing additional benefits for atmospheric decarbonization. Combining hemp with leguminous plants, for instance, can enhance nitrogen fixation in the soil, reducing the need for synthetic fertilizers and consequently emissions associated to it [9, 10, 11, 12, 13]. Furthermore, the presence of hemp in agroforestry systems or as a secondary crop in timber production can improve nutrient circulation, enhance soil resilience, and increase natural soil fertility, contributing to the reduction of environmental stress and the improvement of soil quality [9, 10, 11, 12, 13, 26-55].

It has been proven that hemp is an excellent carbon trap, absorbing more CO2 per hectare than most agricultural crops and some forest systems [9, 10, 11, 12]. Each hectare of hemp has the capacity to absorb 22 to 40 tons of CO_2 per hectare, potentially increasing with proper management. High-biomass crops like hemp can sequester more carbon through photosynthesis and subsequently deposit it in the body and roots of the plant through biosequestration [9, 10, 11, 12, 13].

In addition to conventional hemp cultivation, there are alternative and sustainable practices that can enhance the contribution of this crop to atmospheric decarbonization [9, 10, 11, 12, 13]. An example is the no-till farming technique, where the soil is not plowed or disturbed, promoting organic matter conservation and reducing carbon release into the atmosphere [9, 10, 11, 12]. Moreover, the use of organic fertilizers and crop rotation can increase nutrient use efficiency and reduce greenhouse gas emissions associated with industrial hemp cultivation [9, 10, 11, 12, 13]. Another strategy is the comprehensive utilization of hemp, exploiting not only fibers and seeds but also plant residues for the production of biofuels and sustainable construction materials [9, 10, 11, 12]. This approach can help reduce dependence on fossil energy sources and materials with a high carbon content, contributing to the mitigation of climate change [9, 10, 11, 12, 13].

11. Tropical Regenerative Agriculture

Regenerative agriculture is an agricultural paradigm that aims to restore and enhance agricultural ecosystems, promoting soil health, biodiversity, climate resilience, and food quality. This approach goes beyond sustainability, focusing on the regeneration and recovery of productive systems [9, 10, 11, 12, 13]. Regenerative agriculture is based on a set of principles, such as the use of soil management practices that promote soil health and structure, crop diversification, animal integration, and the reduction of external inputs [9, 10, 11, 12]. This set of practices has garnered increasing interest among researchers, farmers, and consumers concerned about the sustainability of the agri-food system. This approach offers promising prospects for addressing global challenges such as soil degradation, loss of biodiversity, and climate change [9, 10, 11, 12, 13]. Through the adoption of regenerative practices, such as agroforestry, conservation agriculture, and regenerative livestock management, agricultural systems can become more resilient, reducing dependence on external inputs and promoting farmers' self-sufficiency. Additionally, regenerative agriculture aims to create production systems that can adapt to local conditions and promote food and nutritional security in rural communities [9, 10, 11, 12, 13].

It is evident that regenerative agriculture is intrinsically linked to sustainable rural development, as it shares the same principles and objectives [9, 10, 11, 12, 13]. Both approaches seek to promote environmental sustainability, social equity, and economic viability in rural communities [25]. Regenerative agriculture is also aligned with the Sustainable Development Goals, addressing issues such as eradicating hunger, protecting the environment, promoting gender equality, and combating climate change [9, 10, 11, 12, 14], highlighting its potential to contribute to a more sustainable and resilient future [9, 10, 11, 12, 13].

12. SDG 2 – Zero Hunger and Sustainable Agriculture

The relationship between Cannabis and sustainable development has been studied and analyzed due to the widespread cultivation and use of the Cannabis sativa plant and its implications for the Sustainable Development Goals (SDGs) of the 2030 Agenda [9, 10, 11, 12, 13]. This plant and the policies surrounding its regulation and legalization are directly related to a series of objectives and operational recommendations, as observed in the final document of UNGASS 2016 , the 30th Special Session of the UN General Assembly on drug policies.

A sustainable approach to Cannabis can have both positive and negative impacts on the SDGs. On the positive side, the non-psychotropic use of industrial hemp has historically been explored to provide food from its seeds, as well as for the production of sustainable building materials. Additionally, the plant has shown the ability to clean the soil and contribute to the production of energy and recyclable plant-based plastic [9, 10, 11, 12, 13].

The adoption of policies promoting the non-psychotropic use of Cannabis can contribute to the reduction of poverty, eradication of hunger, promotion of sustainable agriculture, and advancement of clean energy, among other SDGs. However, policies related to Cannabis use in general need reform to achieve goals such as health and well-being, reduction of inequalities, peace, justice, effective institutions, and global partnerships for the sustainable development of countries [9, 10, 11, 12, 14].

This fact directly implies the hindrance of cultivation, research, and development of alternatives for the use of industrial hemp due to the misinterpretation of drug laws where, even though it does not produce THC, it faces repression under the legislation for belonging to the Cannabis sp. family. The revision of current repressive, prohibitive, and marginalized policies and the dissemination of scientific information about hemp are essential to address this issue [9, 10, 11, 12, 14].

In the context of sustainable agriculture, hemp can play a crucial role. Its seeds have high nutritional value and can be used to combat malnutrition in impoverished areas [9, 10, 11, 12, 13]. Moreover, Cannabis cultivation can be done sustainably by applying practices aimed at reducing the carbon footprint and promoting agricultural diversification, resulting in increased biodiversity and positive contributions to climate change mitigation [9, 10, 11, 12, 13].

By adopting hemp cultivation, traditional communities can not only promote more sustainable agricultural practices in their territories but also inspire other farmers to embrace a regenerative approach, thus fostering a broad and beneficial transformation in the agricultural landscape [9, 10, 11, 12, 13]. The production of Cannabis plants for the extraction of cannabinoids, such as CBD and CBG, among others, has been growing and gaining space in several markets, especially in the preference of doctors and patients seeking to treat pathologies through natural and herbal medicines instead of invasive treatments with synthetic substances [9, 10, 11, 12, 14, 26-55].

This context creates possibilities and drives a market that is still in its infancy. This high demand favors small-scale producers who, with a future vision, may find an excellent tool to promote improvements in sustainable development indicators in Cannabis production. The choice of management and production can directly impact goals such as sustainable agriculture, where soil management techniques are used, aiming for a lower environmental impact, energy efficiency, and quality of life for those using the produced medication. It is also extremely important to remember that grain production, which has high nutritional and protein value, directly influences SDG number 2, which aims to reduce hunger and include sustainable agriculture techniques in the production process [9, 10, 11, 12, 14].

The inclusion of family farmers, small-scale farmers, and traditional communities is essential to prioritize sustainable production models and strengthen market viability, rural economic development, and environmental health. Policies should also ensure fair and equitable access to Cannabis genetic resources, including non-monetary benefits, in line with global biodiversity frameworks [9, 10, 11, 12, 14].

The cultivation of industrial hemp can be integrated into crop diversification strategies in rural communities [9, 10, 11, 12, 14]. By diversifying crops, farmers not only reduce the risks associated with pests and diseases specific to a single crop but also increase local food security. Additionally, diversification can allow farmers to have multiple sources of income throughout the year, contributing to the economic stability of rural communities [9, 10, 11, 12, 13, 26-55]. When addressing crop diversification, it is possible to discuss how industrial hemp can be grown in rotation with other compatible crops, such as grains, vegetables, or legumes. This not only benefits the soil but also expands economic opportunities for local farmers, promoting a more holistic approach to sustainable rural development [9, 10, 11, 12, 14]. In summary, hemp cultivation has an intrinsic relationship with sustainable development, with potential benefits for the sustainable rural development process. The adoption of policies that promote the non-psychotropic uses of the plant, encourage sustainable agriculture, seek clean energy, health, and quality of life, and align with the SDGs may contribute to achieving a more sustainable, just, and inclusive rural development [9, 10, 11, 12, 14, 26-55].

13. Conclusion

Throughout human history, the cultivation and refinement of plants have played a fundamental role in the development of societies, representing a central part of the connection between humans and nature. However, the advent of the capitalist societal system, which began in the 16th century with the process of primitive accumulation, profoundly transformed this relationship. Nature came to be subjugated by the dynamics of surplus value extraction and capital accumulation, leading to dehumanization and reification of the human-nature relationship.

Beyond the mercantile exploitation of nature, Western capitalist development has also shaped a view of nature from the perspective of human morality. Plants like Cannabis were stigmatized and endowed with human characteristics, justifying repression around the consumption of their psychoactive varieties and obscuring the contributions of industrial hemp to social and environmental development.

In this context, it is imperative to highlight successful international experiences, such as that of the Netherlands, where controlled cultivation of non-psychoactive Cannabis boosted the rural economy and created jobs, demonstrating the potential to overturn deeply ingrained prejudices.

Industrial hemp, as a commodity, holds considerable potential to promote sustainable rural development, especially in territories prone to socio-economic marginalization and areas inhabited by traditional populations. In the case of Brazil, these potential cultivation territories are located in some of the most underdeveloped regions. Therefore, its strategic exploration aligns with the pursuit of inclusive and participatory development, in line with the Sustainable Development Goals (SDGs).

For this to become a reality, it is essential to establish flexible and sensible legislation, as well as effective partnerships between the government, research institutions, and the communities themselves, following the example of European countries such as France and Italy and Paraguay, among others.

Furthermore, in the context of regenerative agriculture, industrial hemp plays a promising role. Its low-impact cultivation characteristics, such as the ability to improve soil quality and natural resistance to pests, are in perfect harmony with the principles of this agricultural approach. The reintegration of hemp into agricultural practices can drive the restoration of rural ecosystems, contributing to soil health and local biodiversity.

By examining SDG2, which focuses on combating hunger and implementing sustainable agriculture practices, it becomes evident how the adoption and regulation of industrial hemp and Cannabis can contribute to these objectives. Crop diversification through hemp cultivation provides an additional source of food and raw materials, reducing dependence on monocultures and increasing the resilience of the food system. Additionally, sustainable hemp cultivation contributes to the implementation of agricultural practices that preserve soil quality, increase productivity, and alleviate pressure on natural resources.

Conscious adoption and promotion of socially responsible policies, in line with global experiences, can usher in a new era of harmonious coexistence between Cannabis cultivation, sustainability principles, regenerative agriculture, and the achievement of Sustainable Development Goals. By undoing historical misconceptions, the strategic integration of industrial hemp and Cannabis into the agricultural landscape can provide tangible advances in eradicating hunger, improving quality of life, promoting sustainable agriculture, and building more resilient and equitable production systems.

Compliance with ethical standards

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No conflict of interest to be disclosed.

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