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Technological surveillance of medical Cannabis horticultural production

Vigilancia tecnológica de la producción hortícola de Cannabis medicinal

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Abstract

The medical Cannabis industry has experienced significant growth in recent years thanks to changes in the legislation of many countries. Latin America has been no stranger to these dynamics. Therefore, it is interesting to study the progress made in this industry, and investigation of the impact may have on the competitiveness in the production and processing of this plant. This article aims to identify and analyze the salient aspects of the use and development of technologies for the medical cannabis industry. There is a particular emphasis on the horticulture of the plant. To this end, the authors carried out a technological surveillance exercise. Technological surveillance is a systematic analysis of scientific and technical information to identify research and technological development trends. As a result, it was possible to focus on three areas: improving growing conditions, products related to cultivation, and improving genetics. These results contribute to describing the global technological panorama of medicinal Cannabis cultivation. Additionally, they are the basis for decision making in orienting the use of technologies of interest internationally and in considering the possibilities of diversification in this emerging industry in countries such as Colombia.

Keywords: *Cannabis sativa*; Technological development; Agronomy; Plant breeding; Horticulture; Patents.

Resumen

La industria del Cannabis medicinal ha tenido un gran crecimiento en los últimos años gracias al cambio en la legislación de muchos países, y Latinoamérica no ha sido ajena a estas dinámicas, por lo que resulta interesante estudiar el progreso en torno a esta industria como base para aportar a la competitividad de la producción y la

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transformación de esta planta en la región. El objetivo del presente artículo es identificar y analizar los aspectos destacados sobre el uso y desarrollo de tecnologías en la industria del Cannabis medicinal, con particular énfasis en la horticultura de la planta. Para ello, se realizó un ejercicio de vigilancia tecnológica, entendido como un análisis sistemático de información científica y técnica para identificar tendencias de investigación y desarrollo tecnológico, que permitió establecer que los avances se han dado en tres áreas: mejoramiento de las condiciones de cultivo, productos vinculados al cultivo y mejoramiento genético. Estos resultados aportan a la descripción del panorama tecnológico global del cultivo de Cannabis medicinal y son base para la toma de decisiones orientadas al empleo de tecnologías de interés en el ámbito internacional y a las posibilidades de diversificación en esta industria emergente en países como Colombia.

Palabras Clave: *Cannabis sativa*; Desarrollo tecnológico; Agronomía; Fitomejoramiento; Horticultura; Patentes.

1. Introduction

Researchers have been studying the Cannabis plant due to its potential in various fields, given the different phytochemicals and products it produces. More than 150 terpenes and 100 cannabinoids with great medicinal and industrial potential have been identified (Booth and Bohlmann, 2019). According to Baron, Lucas, Eades, and Hogue (2018), Cannabis has positive effects in more than 21 diseases with treatments based on medicinal Cannabis. Furthermore, they used different Cannabis species in these treatments. Their cannabinoid and terpene contents change from one to another, resulting in effects targeted to treating specific diseases.

However, Karche and Singh (2019) compiled other uses of Cannabis sativa ranging from the production of fiber with textile use or seeds with high nutritional values to construction, paper production, plastics, biofuels, and the automotive industry, among others. For Cherney and Small (2016), the industrial potential of Cannabis has shown the need to establish a new infrastructure for the industry as the demand for Cannabis-based products increases. These authors also state that the plant's capacity should not be exaggerated, although more research is needed. It is of great value to identify possible business opportunities in this sense. In particular, there are opportunities to exploit the competitive advantages that may strengthen the nascent industry based on the use of this plant.

Along with medical research, recent reforms in the legislation of many countries have boosted the industry of Cannabis. That is why technological management, i.e., decision-making regarding the proper administration of the technological factor to promote innovation and competitiveness in this business, is increasingly relevant for organizations and countries seeking to build this industry. According to Ortiz and Nagles (2013), technological management enables the identification of opportunities to achieve long-term sustainable and competitive businesses. These opportunities may evolve by developing or incorporating new technologies and their means of exploitation. Likewise, according to Jiménez, Castellanos, and Morales (2012), technology management faces the challenge of the continuous dynamization of knowledge. That is, the quality, timeliness, and reliability of the information handled are increasingly crucial in supporting decision-making.

As one of the tools for technology management, technological surveillance can contribute to managing and employing the increasing information related to the Cannabis industry. Technological surveillance is an exercise of systematic search and monitoring external data on science and technology from various sources (scientific articles, patents, books, among others). Specifically, it deals with a sector or specialized area to identify trends in research and technological development using techniques such as scientometrics and bibliometrics (Castellanos, Fúquene, and Ramírez, 2011; Marulanda, Hernández, and López, 2016). Organizations and systems can prepare for and anticipate constant changes in the scientific and technological context (Palop and Vicente, 1999; Escorsa and Maspons, 2001). The possibility of finding and taking advantage of valuable and quality information within the enormous amount of data and information on a subject (every year, researchers produce more than three million articles and more than three million patents) is one of the main advantages offered by technological surveillance. Additionally, it provides identifying, among others, new developments, potential threats, or solutions to current technical problems (Patterson, 2021).

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Following this trend of thought, the purpose of this article is to identify and analyze the salient aspects of using and developing technologies in the medical cannabis industry. There is a particular emphasis on the horticultural production of the plant. For this purpose, information from different scientific and technical sources was used and processed. It followed the methodology of technological surveillance exercises, which allowed for identifying relevant research and technological development topics in the cultivation of Cannabis. This research can turn into the basis for decision-making in aspects related to the use of technologies of international interest in cultivating this plant and assessing the possibilities of diversification of the Cannabis industry beyond its medicinal use.

2. Methodology

For the technological surveillance exercise on the horticultural production of medicinal Cannabis, the methodology described by Castellanos *et al.* (2011) was used and developed in 3 stages: 1) determining information sources; 2) searching and debugging information; and 3) organizing and analyzing the information.

In the first stage, when determining the sources of information, the SCOPUS database was selected for its broad coverage of topics and given its availability through the National University of Colombia library. This enabled us to obtain information about scientific articles on Cannabis cultivation. Additionally, the LENS platform was employed, which can be accessed free of charge through the Internet, to obtain patent documents related to technological developments in growing and producing medicinal Cannabis.

In applying the first stage of technological surveillance methodology, the observation window is between April 2011 and April 2020. In defining the search equation used within each selected database, we picked keywords representing the subject of interest, i.e., Cannabis horticulture and production. The keywords used in the search were chosen to reinforce the emphasis on production and horticulture. Furthermore, the search was limited to areas related to agriculture and environmental sciences. There is no emphasis on Cannabis oil extraction or technologies used in the transformation process. Additionally, we only use the term Cannabis because, although there are other names for the plant, this is considered the most general term (hemp is mainly used for fiber, seed, or biofuel production, while marijuana has connotations of flower consumption, oil, or even trafficking).

In the second stage of applying the technological surveillance methodology used in this study, *information was searched and filtered*. The equation used in the search as of May 20th, 2020, in the SCOPUS database is as follows:

TITLE-ABS-KEY (Cannabis AND production OR horticulture OR industry) AND PUBYEAR > 2010 AND PUBYEAR < 2021 AND (LIMIT-TO (SUBJAREA, “AGRI”) OR LIMIT-TO (SUBJAREA, “ENVI”))

With this equation, we found 420 articles. Then, we verify the information contained in the abstract to ensure alignment with the proposed subject matter. This refining reduced the number of records to 231.

For the patent search, which we performed on the same date, we used the keyword Cannabis in the LENS database. This approach reduced the results to the last ten years and granted patents. Thus, we found 1395 Cannabis-related granted patents.

The information was organized and analyzed in the final stage of the technological surveillance exercise. We processed 231 records from the SCOPUS database with the free tool VOSviewer. It allows the representation of data in maps, which facilitates the analysis of a large amount of information (Van Eck and Waltman, 2010). Thus, we generated the map in Figure 1, delimiting in VOSviewer the number of co-occurrences (joint occurrences of two terms in a text) to 15. Then, a thesaurus was created to eliminate synonyms in the results. Furthermore, we eliminated words that were not descriptive and may have generated distortion in the map. At the end of this manual process, we identified 44 keywords and used them to establish relevant technological developments among the patent records.

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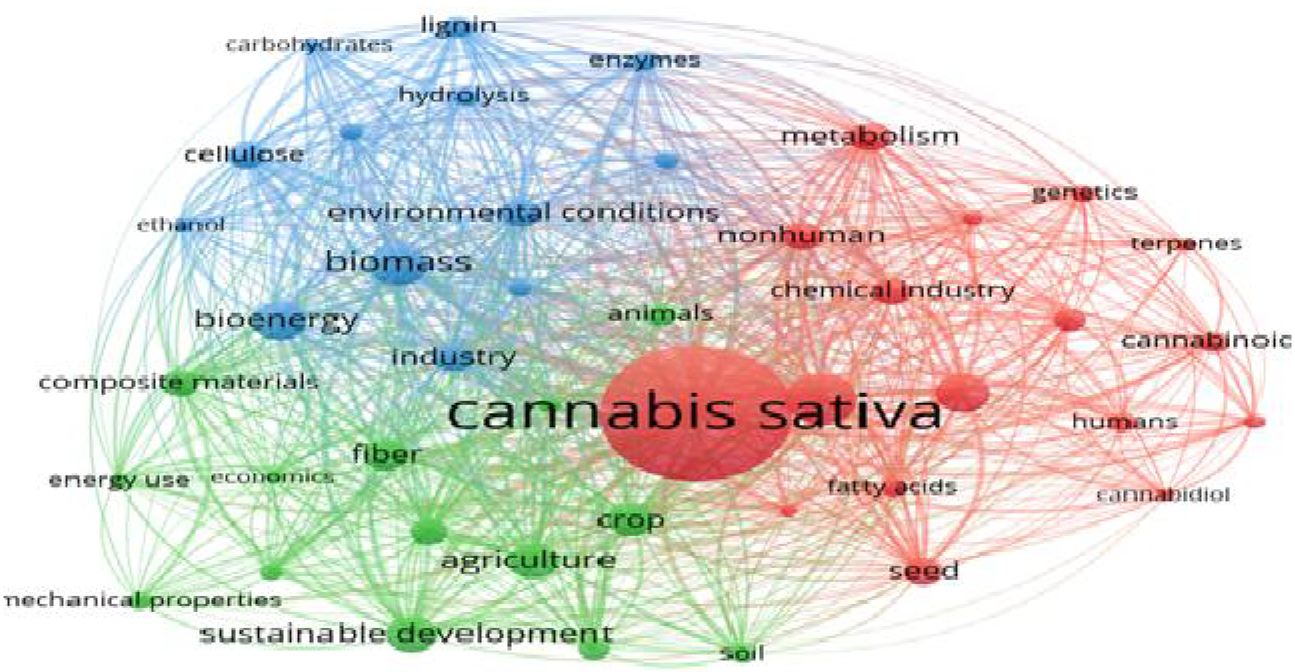
Through the patent search in the LENS database, we found 1395 Cannabis-related granted patents. Some were selected to illustrate the inventions linked to the topics covered by the map's clusters of Figure 1. Therefore, we generated Table 1.

Figure 1. Map of co-occurrence of keywords in articles



Source: Authors' own elaboration.

Table 1. List of relevant research areas with patents granted on the subject of Cannabis

Area		# Patent and holder	Name	Summary
Improvement of growing conditions	Lighting	US 9844518 B2 Mjar Holdings	Method of growing cannabaceae plants using artificial lighting	The patent covers a system for growing Cannabis sativa using artificial lighting of different wattages for different stages of the plant. The vegetative stage provides between 125 and 500 micromoles per m^2/second. The flowering stage offers between 400 and 975 micromoles per m^2/second. (Lowe *et al.*, 2017)
		US 10238043 B1 Hurst William E, Morrow Kenneth.	System of photomorphogenically enhancing plants	The patent protects a lighting system that claims to boost natural plant processes by irradiating the plant with ultraviolet and other light bands (Rami, 2019)
	Fertilization	US 10542759 B2 Ralco Nutrition Inc	Agricultural composition and applications utilizing essential oils	The patent consists of a product for use in agriculture based on essential oils from 16 different plants (one of which is Cannabis) that claim it can improve the growth, health, and harvest of various crops (Dale & David, 2020)

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		US 9981886 B2 Acupac Packing Inc.	Fertilizer	The patent covers a line of fertilizers containing varying amounts of one or more of the phytochemical compounds in Cannabis oil and elements such as phosphorus, potassium, and nitrogen, among others (Babak & J, B. M, 2018)
	Culture environment	WO 2019/028542 A1 CO2gro Inc.	Plant growth acceleration system and methods	Patent claims that it can promote plant growth by applying CO_2-infused water and specific methods (Archibald *et al.* 2019)
		US 10231469 B2 Multiple Energy Technologies Llc.	Myceliated products and methods for making myceliated products from cacao and other agricultural substrates	The patent protects a cocoa-based fertilizer product and its method of production. The product may contain different strains of fungi beneficial to plants (Kelly Brooks, Langan, 2019)
Products of Cannabis sativa cultivation	Oil (from the flower)	US 9192598 B2 Univ. Of North Texas, Schetz John, Hoger, Sally. Texas A&M Univ.	Prevention of bacterial growth biofilm formation by ligands that act on cannabinoidergic systems	The patent claims that inhibiting bacterial growth is achieved using cannabinoid compounds with antibacterial effects (Schetz, 2015)
		US 9078838 B2 Lvmh Recherche	Cosmetic or dermatological compositions comprising of a mixture of essential oils, and their uses thereof, particularly for the care of sensitive skin	The product is a cream for sensitive skin composed of essential oil of the everlasting bush plant, a topical medium, and Cannabis oil without cannabinoids (only with terpenes) (Andre *et al.,* 2015).
	Fiber	US 10415155 B2 Avex Group Holdings Inc	A production method of hemp fiber for spinning and hemp fiber for spinning	The patent includes a method for producing hemp fiber for spinning consisting of several steps, such as performing a liquid treatment to the plant material (Shinichirou & Keisuke, 2019)
		KR 20170099584 A Park Tong Ryung	The method of manufacture for hemp paper fiber	The patent consists of making paper based on Cannabis sativa fiber (among other possible fibers) (Ryung, 2017).
	Seed	CN 109123686 A Angel Co Ltd.	A novel juice having improved anti-hypertensive activity	This product consists of a preparation of pear juice with hemp seeds. It claims to enhance hypertensive activity. (Chunjing *et al.,* 2019)
		KR 101886421 B1 Heilongjiang Heike Tech Co Ltd	Method for manufacturing bean-curd using hemp seed	The invention consists of a tofu preparation using liquids extracted from Cannabis seed as a coagulant for soy milk, preventing using a chemical coagulant (Kim Min-seok & Changjin Yang, 2018)
	Biomass	US 8778418 B2 Bisterfeld Von Meer Galathea U. Claremont Collection Handelsgmbh	Method of obtaining hemp plant juice and using it in producing beverages	The process consists of squeezing hemp (Cannabis sativa L.) using a pressing method in different steps to get a juice (extract) for other drinks (Bisterfeld, 2014)
		US 9913874 B2 Fabre Pierre Dermo Cosmetique, Pf Medicament	Obtaining a juice from fresh plants by thermomechanical treatment and cosmetic and therapeutic use of such.	The patent consists of obtaining a juice from the Cannabis plant using a thermomechanical process. Such a juice can produce biogas, food, or beverages (Mandeau & Talon, 2018)

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Genetics	Plant Breeding	CN103416206 B Economic Crops res Inst of Shanxi Academy of agricultural sciences	Improved variety breeding technology for industrial Cannabis sativa L.	The patent protects a breeding method for *Cannabis sativa* varieties (Hongmei *et al.,* 2013).
		US 2017/0339907 A1 New West Genetics	Industrial hemp Cannabis cultivars and seed with stable cannabinoid profiles	The patent contains a Cannabis seed, or variety, with a stable phytochemical profile and the seed crossing method used to obtain the distinct phytochemical profile (Fletcher *et al.,* 2017)

Source: Authors' own elaboration.

3. Results

We generated a map from the searched records in the SCOPUS database, that is, Figure 1. It shows the co-occurrence of words in the articles identified. It is possible to identify three clusters of different colors, where there are 44 words distributed and whose central axis is the term Cannabis sativa, interconnected with all the other keywords. The clusters are:

The red cluster is the central cluster in different areas in the Cannabis sativa industry. Examples of those areas are plant extracts, the chemical industry, and research around the plant. Additionally, another area is its growth characteristics and phytochemicals that have not yet been identified or studied (represented through the use of words such as *"drug industry"*, *"unclassified drug"*, cannabinoids). Relevance is given to seed genetics for oil production, given its high content of fatty acids and its possible food uses in animals and humans.

The green cluster has the same size as the other secondary cluster, i.e., blue. There are words in this cluster oriented to different uses of Cannabis, such as fiber composite materials or energy production. Relevant topics such as sustainable development, economy, agriculture, possible benefits of Cannabis-related to animal feed, and the carbon footprint generated by this crop. In this cluster, there is an emphasis on development possibilities for the industry, but problems are highlighted, such as high electricity consumption in Cannabis production.

– *Blue cluster:* this secondary cluster has particularly relevant topics linked to bioenergy production and other industries such as construction. In addition, there are words related to fiber production methods such as sugars, lignin, and carbohydrates—finally, the environmental conditions required for cultivating different *Cannabis sativa*.

By relating the keywords in Figure 1 to the articles identified in the SCOPUS search, we can highlight specific areas of research that are relevant to this study in Cannabis horticulture:

– *Improvements in growing conditions* with work in biotechnology, growing conditions, and fertilization. Red cluster (for research around the plant and its genetics) and blue cluster (for research on environmental growing conditions).

– *Products linked to Cannabis cultivation*, represented in biofuels from biomass, construction materials based on fiber, food products based on seed, medicinal products from oil, for example, red cluster (for the production of seed with different uses), blue cluster (for other industrial uses of Cannabis, highlighting bioenergy) and green cluster (for topics such as composite materials, fiber, mechanical properties).

– *Genetics* with studies on genetic improvement of Cannabis to achieve different objectives such as higher biomass or oil production, for example, red cluster (for words such as genetics or seeds) and green cluster (for terms such as "crop yield", linked to the genetics of the plant and its productive purpose).

Based on the results obtained from the search of patents in the LENS database, some were selected, as shown in Table 1. These data present relevant characteristics compared to a cluster in Figure 1; they show a diversity of products obtained from Cannabis or related to its cultivation, which turns into business opportunities.

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In the first column of Table 1 are the three identified areas in Figure 1. They are associated with aspects delimited to organize the patents in different topics related to horticulture and Cannabis production. These aspects are lighting, fertilization, growing environment, oil, fiber, seed, biomass, and plant breeding. Each was related to some patent documents selected according to the criteria previously indicated.

4. Discussion

From the technological surveillance exercise conducted and, in particular, from the results shown in Table 1, it is possible to identify opportunities and threats in the medical cannabis industry. Such threat and opportunity analysis could guide decision-making in terms of the possibility of establishing links with other sectors and of achieving product diversification.

The information identified and grouped by clusters allows one to understand the determining elements (i.e., investment or development opportunities, problems and organization) for horticulture and the medical Cannabis industry. For example, it allows one to understand the importance of photoperiod and lighting. In this sense, authors such as Chandra, Lata, Khan, and ElSohly (2017) state that Cannabis cultivation, both "indoor" and outdoor or in a greenhouse, requires 18 hours for its vegetative growth stage, 12 hours to enter its flowering stage and that the decrease in hours reflects production losses.

Therefore, the field of illumination becomes relevant. Bilodeau, Wu, Sen, Rufyikiri, MacPherson, and Lefsrud (2019) point out that although we have not identified a superior lighting value for Cannabis cultivation, some studies have given good results with values between 1500 and 2000 µmoles/m^2/s. One of these studies is Chandra *et al.* (2008), where temperature, CO_2 concentration, humidity, and light intensity are related to producing a Mexican Cannabis variety of high productivity. Its conclusions indicate that Cannabis grows better in a PPFD (photon flux per second) of 1500 µmoles at a temperature of 25 to 30 degrees Celsius and with increases in CO_2 levels in the cultivation area.

On the other hand, Namdar, Charuvi, Ajjampura, Mazuz, Ion, Kamara, and Koltai (2019) state that different types of lighting, such as LEDs, can affect plant metabolites, modifying their biological functions. This information is decisive for developing the industry in countries such as Colombia. Furthermore, the information allows establishing primary and optimized growing conditions for each given region. Depending on how many hours and intensity of light are applied, the plant reacts to artificial lighting, maintaining a vegetative stage.

Patents in lighting, such as US 9844518 B2 (Lowe, Franz, and Curran, 2017) and US 10238043 B1 (Rami, 2019), show that research influences the products developed. These products reflect investigations such as Parma and Baxant (2018), who state that plants absorb different light spectra to different extents, and each spectrum influences natural plant processes. Therefore, there can be an optimal lighting system for each process. In this sense, the industry can address investment elements based on each development's benefits in optimizing a crop. For example, the light component of patent US 9844518 B2 offers up to 975 µmoles/m2/s. Additionally, a system can vary the light spectrum and intensity according to the stage of the plant.

This information can also represent threats or potential undesirable effects identified in the green cluster. That is, the high use of electricity in artificial lighting means a significant negative impact on the environment. The same is true in achieving controlled environments. The carbon footprint and sustainable development can be related. That is, Mills (2012) estimates that producing 1 kg of Cannabis indoors results in approximately 4,600 kilograms of carbon dioxide. This production is due to the need to use artificial lighting, irrigation systems, and environmental controls, among other energy-consuming activities.

Regarding pollution, fertilization and soil use are essential. Some studies promote the use of microorganisms to reduce the impact of fertilization. Research such as Vujanovic, Korber, Vujanovic, Vujanovic, and Jabaji (2020) or Pagnani *et al.* (2018) focuses on these

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synergistic effects of microorganisms and plants. Similarly, some of the phytochemicals produced by the plant have properties that can be beneficial. That becomes relevant in patent US 10542759 B2 (Dale and David, 2020), concerning a fertilizer that claims to contain essential oils from 16 plants, one of the Cannabis, that can improve plant health and growth. In addition, Punja and Rodriguez (2018) found a high incidence of pathogens such as Pythium or Fusarium in hydroponic cultivation modalities, making disease and pest management in cultivation relevant.

We also identify opportunities in the form of developing new products or markets. For example, there is the use of seeds for animal feed. On the other hand, in the Cannabis seed market, there are patents linked to human foods, such as patent CN 109123686 A, on Cannabis seed powder juice (Chunjing *et al.,* 2019). Additionally, there is KR 101886421 B1 regarding tofu based on Cannabis seeds and soybean (Kim Min-seok & Changjin Yang, 2018). They show diversification options in the food market from seeds, which can be a byproduct of obtaining medicinal oil.

In the same food area, the patent US 8778418 B2 (Bisterfeld, 2014) describes a process for obtaining Cannabis juice from its biomass (flowers). This juice is a different method to administer medicine to a patient or a food product presentation. However, it also illustrates a risk related to legislation in some countries because some of the components of medicinal Cannabis are considered psychoactive, particularly tetrahydrocannabinol (THC). The Colombian market is an example, where Decree 613 dated 2017 (Ministry of Health and Social Protection, 2017) stipulates that if a variety has 1% or more THC, it is considered psychoactive. Because of this, products must develop, considering legal limitations, with prevention protocols. On the other hand, patent US 9913874 B2 (Mandeau and Talon, 2018) proposes a method for processing Cannabis-based juice used for biogas (or feed) production, also linked to biofuel production.

Cannabis genetic research and development are relevant in contrast with opportunities in other areas, as they impact all products related to the Cannabis plant. For example, Konca, Yalcin, Karabacak, Kaliber, and Durmuscelebi (2014) studied the effect of feeding hens Cannabis seeds and found that the eggs of these birds increased their weight and fatty acid content. In this sense, developing seeds of greater size or quantity of fatty acids turn out to be a market option for animal feed. In the same way, a variety with better oil, fiber, biomass, or phytochemical yields will directly influence the aspect on which breeding develops.

The green cluster in Figure 1 also includes research such as Karche and Singh (2019). They push Cannabis cultivation as an alternative for different industries, from automotive and textile to medicinal and construction. On the other hand, Ivanovs, Rucins, Valainis, Belakova, Kirilovs, and Vidzickis (2015) promote research on hemp agglomerates in producing different materials. Finally, it is worth highlighting the research of Tang, Struik, Yin, Thouminot, Bjelková, Stramkale, and Amaducci (2016) oriented to dual-purpose Cannabis production. They evaluated the fiber and seed productivity of commercial cultivars to make the best use of the plant.

5. Conclusions

Technological surveillance studies, such as the one presented in this article, offer evidence of many research and technological development works around a particular area of study. Likewise, they allow filtering and refinement in facilitating access to the most relevant, timely, and pertinent information on an analyzed topic. For this exercise, specifically regarding the production and horticulture of Cannabis sativa, many studies and innovations have been found in the last decade. In addition, changes in legislation in many countries have facilitated the investigation and exploitation of this plant. Plant breeding has a relevant role, as it influences all aspects of Cannabis production, from oil to fiber.

Information on the patents identified and selected in this work shows possibilities for products and technological developments that can be the basis for the improvement of Cannabis cultivation in places and environments such as Colombia. The objective is to generate competitive

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advantages, either in increased production through innovations for the differentiation or diversification of products. Innovations may materialize through genetic improvements in the plant to achieve characteristics that provide conditions for greater productivity (high yield of fiber or cannabinoids, seeds with a higher fatty acid content). Likewise, patent information allows the identification of holders, which allows the establishment of links with organizations that develop technologies for the Cannabis industry. In this way, local producers in countries such as Colombia can negotiate technology and knowledge transfer agreements.

For plant production, different technologies and innovations are used, such as artificial lighting and specific fertilization oriented toward enhancing the biological processes of the plant, supported by microorganisms and elements to control the environmental impact and the increase in CO_2. In addition, the products resulting from Cannabis, such as fiber, seed, oil, and biomass, have many uses. Their uses can be boosted in plant production for purposes other than medicinal uses, whether for animal feed, the textile industry, or construction materials. The optimization and increase of these crops can have a considerable environmental impact, depending on the technologies used, representing challenges in terms of energy and the environment for producers. Hence, it is vital to study this impact.

Identifying critical research and technological development areas in Cannabis production can contribute to the consolidation of the industry in countries that have passed legislation, so Cannabis sativa is allowed in medicine and industry. In addition, these key areas make it easier to guide decisions toward issues such as lighting or genetic improvement that contribute to greater productivity. Those are decisions on benefits, but they may also guide decisions regarding mitigating risks and impacts such as adverse effects on the environment during production.

Not only does the medical Cannabis industry benefit from studies such as the one presented in this document, but advances in research and invention show products and uses of the plant and its derivatives beyond the medical field. This information enables diversification of the industry to be viable in nations with broader legislation. In countries with production potential, such as Colombia, there should be a discussion to promote greater flexibility in the laws based on scientific and technical evidence.

6. Conflict of interest

The authors declare no conflict of interest.

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