CHAPTER 5

Sustainability and Innovation in the Beekeeping Sector: A First Approach

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5.1 Introduction

Apiculture is a socially relevant activity, and its approach must be based on sustainability. The benefits derived from the consumption, commercialization, and use of its products (honey and wax, among others) have positive implications for climate change, food security, and poverty alleviation [1]. Under the principles of sustainable development, apiculture is defined as a group of activities aimed at breeding bees, producing derivatives that meet current consumption needs, and preserving resources for future

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use. However, further work is necessary to improve reference frameworks geared toward the operationalization, evaluation, and measurement of the role of sustainability in the field [2]. In this regard, the Triple Bottom Line (TBL) perspective is a combination of economic, environmental, and social dimensions, known colloquially as the 3P's: Planet, People, and Profits [3–5]. TBL's interactive elements pursue an integrating equilibrium to approach the problem from a broad perspective [6].

The study of sustainability has evolved. Its most significant advances relate to the 17 Sustainable Development Goals (SDG), which integrate social, environmental, and economic matters and constitute the most recurrent and straightforward way of communicating the sustainability concept and its complex underlying relationships [4]. Currently, there is no consensus for measuring each of the pillars (economic, environmental, and social) and the topics that comprise them [7]. Thus, it is important to note that the economic pillar consists of concepts related to money flows and the market, such as income, expenses, taxes, subsidies, job creation, positive and negative externalities, innovation processes, and commercial exchange activities.

The environmental dimension refers to the rational use of natural resources, biodiversity conservation, promotion of renewable energy sources, protection against risks, and environmental care. For its part, the social dimension is linked to education, community, solidarity, security, health, well-being, equality, quality of life, culture, values, and personal development. Thus, the purpose of the present study consisted in identifying the convergences and interdependencies derived from the challenges faced by apiculture to achieve sustainable development through the construction of economic, environmental, and social pillars. Our goal was to make an initial diagnosis to propose feasible and systemic alternatives contributing to the attention of this problem and promote the generation of innovative and comprehensive solutions. Therefore, the following sections present apiculture's theoretical framework in two parts, the first related to the environment, and the second to the analysis of the economic and social dimensions of the problem. In addition, a third section deals with innovation in the sector and the use of digital tools to study apiculture.

5.1.1 Apiculture and the Environment

Like other species such as butterflies, hummingbirds, flies, and bats, bees play a leading role in transferring pollen between flowers for their reproduction. According to data from the United Nations [8], this phenomenon occurs in approximately 90% of flowering plants, and its impact is fundamental in biodiversity conservation and ecosystem services at a global level. Recently, global ecosystem services have been threatened by the loss of colonies and the decrease in bee populations, especially since 2010. As a result, conservation programs and public policies have been created that favor beekeeping worldwide.

The causes attributed to this incident are systemic [9]; that is, they are not due to a specific or individual component, but to the sum of factors that cause the stress problems both in bees and in their hives. Stress can be attributed to both biotic and abiotic factors: habitat, climate, genetics, pesticide use in agriculture, bad management practices in apiculture, poor food availability, malnutrition, and parasites and diseases. Examples of parasites and diseases include Varroa destructor, Acarapis woodi, American foulbrood, European foulbrood, and microsporidia (Nosema apis) [9–12]. To date, more than twenty-four types of viruses that affect honeybees have been identified, which, together with other pests and diseases, represent one of the greatest threats to colony survival [10, 12] and ecosystem preservation.

Different actions are performed to combat these problems, such as the case of Varroa destructor (mites); the attempt to mitigate its population has been approached using insecticides containing pyrethroids. However, adverse effects have followed this treatment both in the resistance of the mites to be eradicated as well as on bee populations, their feeding system, and the contamination of derived products [12]. Other investigations have indicated the presence of trace chemical pollutants due to pesticide use in products such as bee bread, pollen granules, wax, and royal jelly, although there are still no conclusive studies on the effects on humans [13, 14]. Moreover, it has been observed that fungicide contamination increases the propensity of bees to become infected with parasites such as Nosema ceranae [11]. Thus, one of the main drawbacks to researching the effects that chemicals cause on bee populations is the difficulty of measuring and quantifying the specific incidence of these products since, as previously mentioned, the loss of colonies is systemically influenced by other factors [12].

The adverse effects in bees derived from the use of pesticides occur at three levels: (1) Individual: Characterized by changes in the bees' behavior, life expectancy, and olfactory capacity; (2) Colony-level: Changes in the distribution of activities according to the animals' age and how they care for their young, mate, and lay eggs; and (3) Community-level: Related to the spread of diseases and pests to other hives and the accumulation of residues in the derived products [10]. For example, in a three-year study on the impacts of insecticides on bees conducted in Italy, [10] it was found that more than 60% of the examined pollen samples contained at least one pesticide; in some cases, the levels exceeded the permissible exposure limits for humans. Among the most frequently detected pesticides were chlorpyrifos in 30% of cases. This effect has important implications for the revaluation of pollen as a "superfood," and it provides a parameter to determine the illegal and inappropriate use of pesticides that undoubtedly affect long-term soil contamination, thus affecting the quality of crops.

The literature reports on sustainable actions to mitigate pests, such as using organic components. These are made up of acids and essential oils generated in the bee colonies themselves, whose properties reduce the risks of contaminating derived products and help the bees to resist pests. Despite this, viral infections from contact with mites remain [12], so it is imperative to know the ecological interactions between bees, parasites, and associated viruses [15].

There are sustainable mitigation solutions using probiotics to reduce the pathogen load of the Paenibacillus larvae [16]. This type of practice could be affordable and easy to implement for beekeepers, making it a compelling alternative against this disease and meeting the needs of beekeepers in developing countries. Likewise, another threat to the sustainable development of apiculture is malnutrition and the lack of food availability for bees, given periods of flowering shortage, during which bees feed on weeds [17]. Particular care should be taken in the introduction of managed bees such as honeybees that can affect wild pollinator species (food competition and disease transmission) and affect the reproduction of wild plants [18] and is a determinant for the maintenance of bee colonies.

An existing practice to counteract this phenomenon is the mobilization of hives. However, this is not practiced by traditional beekeepers.

A solution frequently used is to provide the bees with a sugar-based diet; unfortunately, it lacks the proteins and other necessary elements that pollen provides to guarantee a balanced diet. Other proposals to address malnutrition problems are related to the diversity of floral resources and crops. Examples include the cultivation of Fabaceae and the increase and conservation of the vegetation cover of semi-natural habitats [17]. In addition, constant monitoring provides information on the loss of honey-producing bee (melliferous) colonies, the type of bee most used globally, allowing for the implementation of necessary actions. However, not all countries show a commitment to implementing this measure. Such as in Latin America, a region where this indicator is not regularly monitored despite its high rate of lost colonies; in the region, this level could be above the global average, but there is a lack of information to confirm this [19].

It is important to note that the environmental implications of apiculture are ambivalent. Although they represent a means of conserving a tree and plant pollinating species, they also lead to the artificial and intensive introduction of bee species in wild and semi-agricultural environments, representing a potential risk for local wild species [20]. Concurrently, activities such as foraging competition affect the bees' collection of nectar and pollen [20]. In addition, diseases present in introduced bees are transmitted to wild bees and other wild pollinators through interconnection networks that allow the proliferation of viruses [9] and the loss of endemic species due to the hybridization of the species [21].

A case study by Valido et al. [22] found that high-density apiculture affects the communication channels that create networks to stimulate pollination, which has repercussions on the hierarchical structures of wild pollinators and a consequent reduction in nectar availability [18]. In this regard, Requier et al. [21] propose a comprehensive conservation system that includes both species of Apis mellifera based on the assumption that both wild and managed bees are endangered due to the loss of their habitat at a global level. Therefore, it is necessary to conduct genetic identification studies to delimit protection zones and differentiate them from agroforestry regions and natural zones where conservation hives (local subspecies) can be used under traditional production schemes to help solve this problem.

5.1.2 Economy, Society, and Apiculture

The concept of social innovation is still consolidating and in constant evolution, the collaborative approach can help to increase its scope in terms of sustainable development and social justice because it promotes the exchange of ideas and includes social stakeholders [23]. Crises and the pursuit of solutions to meet basic needs are two fundamental factors to develop social innovation in a context where governance converges with cooperation among social actors and economic players to deliver the desired social and democratic changes, where the local and social exchange is prioritized and effectively reduces social impact [24]. For such a purpose, non-governmental organizations are an ad hoc vehicle to address social needs via mechanisms that promote innovation and contribute to solving poverty and social impact problems [25].

Social innovation may be seen as a multidimensional concept that materializes different processes with the purpose to achieve an actual impact on society. Initially, social innovation focused mostly on organizational issues and was mainly centered on efficiency. This predominantly economic approach led to the observation that technological innovation can coexist with social innovation to promote economic development, and its relevance in the societal and political spheres has been pointed out, including, of course, its cultural elements [26]. Thus, although corporatist interests are the dominant force in the economy, all social actors must be considered since the impact of business actions affects them, which is also why social entrepreneurship becomes an alternative to materialize these interests [27].

Thus, apiculture can help promote social innovation, especially in developing countries, through social enterprises and cooperatives conducting technology management as well as social and economic practices. In this regard, it has been pointed out that scientific production is limited in apiculture's social and economic spheres, but its contributions from these perspectives are diverse and relevant. For instance, 75% of crops require pollination by insects such as bees [8]. This percentage exhibits the importance of this activity as a critical factor for food security. Likewise, it improves the well-being of the sector's workers, increases the participation of women in paid activities and empowers them, and provides them with greater equality in family decision-making. Additionally, it contributes to access to healthcare and generates positive changes in family and community relations since it promotes the formation of exchange networks between local and external actors [28–30].

The most evident social contribution of apiculture is the well-being of beekeepers. Consequently, small producers have been the most affected by the loss of colonies, which could be due to their not integrating hive migration practices into their work [31]. In developing countries such as Mexico, Tanzania, Ethiopia, and Iran, small producer apiculture is dominated by vastly experienced men over 30 years of age, whose knowledge is usually acquired through informal and traditional methods [32, 33]. For beekeepers, the educational level has been mostly irrelevant; however, education could undoubtedly result in a factor that, like technology, would add to optimized work [34] and added-value products derived from the inputs of apiculture.

Among the problems affecting the sector's activity and sustainable development are low productivity, scarce use of derived products at the national level, and limited exports [35]. Other barriers faced by beekeepers in developing countries are: (a) Lack of management skills; (b) Absence of quality standardization processes; (c) Low technification; (d) In-service training needs; (e) Pest and disease control; (f) Forest fires; (g) Bee migration, the difficulty of mobilizing hives, and climate change; (h) Pesticides and use of harmful chemicals; (i) Inefficient and poorly organized markets; (j) Low capital and limited subsidies [32, 34, 36]. In terms of social development, the main focus is on studying improvements, the implications of economic and social development programs for beneficiary families, and the analysis of beekeeping practices [37].

Apiculture has two main economic benefits. The first regards agriculture, since pollination contributes to the reproduction of 75% of crops, including approximately 87 types of food crops [8, 38]. The second regards the substantive activities of apiculture: bee raising and caretaking and the use of derived products such as pollen, honey, royal jelly, and wax, among others. Economically, the main threats are: (a) Undervaluation of beekeeping activities and little attention to the value chain; (b) Low perception of value by customers; (c) Uncompetitive consumer prices; (d) Limitations on income generation, and (e) Apiculture classified as a secondary activity despite its high potential [39].

In developing countries, many beekeeper families obtain a meager income, most likely due to the lack of training, protective equipment, and hive management. Apiculture cannot directly alleviate poverty; additional elements are necessary, such as an education that allows beekeepers to recognize, manage, and market the product to achieve tangible economic benefits [40]. It is essential to highlight that the traditional, inherited stance toward production and commercialization must evolve and become an entrepreneurial approach under a well-defined business model [41]. This novel approach would greatly help beekeepers to identify opportunities, maximize production, streamline processes, and increase their interest in bee conservation and business profitability [42, 43].

As previously mentioned, another threat to the sector is the use of pesticides, which significantly impact the apicultural and natural agricultural potential since they harm the distinct species of bees and other pollinators. The close relationship between apiculture and agriculture is an essential factor in the integration of activities for the development of organic apiculture due to the specific conditions required in the surrounding areas, which can represent severe limitations for beekeepers if not met [32]. Commercially, honey is the most important apicultural product in the world. In industry, it is used as a sweetener, a medicine, and for its antioxidant properties.

According to information from 2019, producer prices can vary from $1270.70 to $26,534.00 US dollars per ton, depending on the region. Although the median is $3728.40 US dollars per ton, the annual value [44]. Thus, the price differences are enormous and linked to technological use, honey production-quality processes, determination of floral origin, and the scarce use of economies of scale by small-scale beekeepers [39].

In 2019, the main honey producers worldwide were China, with an estimated production of 447,007 tons, followed by Turkey (109,330 tons), Canada (80,345 tons), Argentina (78,927 tons), Iran (75,463 tons), United States (71,1791 tons), Ukraine (69,937 tons), India (67,141 tons), Russia (63,526 tons), and Mexico (61,986 tons). However, the countries with the best yield (hg) are Ukraine (268,885 hg), Latvia (208,932 hg), Fiji (205,385 hg), Belarus (126,493 hg), Rwanda (11,845 hg), and Canada (1126 hg) [44]. In certain cases, low yields can be attributed to the low availability and quality of food due to intensive agriculture involving GMOs, agrochemicals, monocultures, and low temperatures [45–47]. In addition to honey, another apiculture derivative is propolis, a high-value product due to its antimicrobial and antioxidant properties with potential applications to preserve foods such as meat and fish and other uses in the cosmetics and health industries [48]. In conclusion, apicultural products other than honey should also be considered since they are additional sources of income. However, this requires parallel efforts to design and construct value chains to reach target markets.

5.1.3 Apiculture, Innovation, and Digital Tools

The concept of innovation has evolved toward a more comprehensive perspective, one in which novelty lies not only in processes, products, organizations, or marketing. Innovation can be observed in cultural, environmental, and social areas, where the aim is not always the market but its use per se [49]; it represents a reasonable means to adapt to the significant changes observed in the beekeeping sector. Furthermore, the depletion of natural resources derived from economic activity has given rise to proposals for sustainable development goals including both the beekeeping and the agricultural sector due to their close connection. Hence, sustainability actions undertaken for agricultural development represent a social well-being vehicle [50–54] and, in turn, a contribution to agricultural development.

In apiculture, the focus of innovation ranges from increasing hive productivity, minimizing sting risks, and honeycomb management, bee feeding, and beekeepers' well-being and quality of life. In other cases, various aspects of health, social structures, and the family environment are considered [55, 56]. Ultimately, there are potential development areas in the economy of apiculture that can be facilitated by digital components, and their repercussions should also be observed in the social sphere [57]. Although innovation in apiculture is increasingly being analyzed from different perspectives, technological innovation remains the predominant approach in the sector.

For example, its interrelation with science has facilitated the use of information and communication technologies (ICT) in this area and, therefore, technological innovation. It is focused on the measurement of factors such as colony loss (Colony Collapse Disorder), monitoring and follow-up, temperature, weight, and hive vibration conditions using technologies such as Low Power Wide Area (LPWAN), 3GPP protocols, Internet of things, and machine learning [58, 59]. In particular, colony monitoring seeking better yields and production efficiency is known as precision beekeeping [60].

From an economic perspective, ICTs provide solutions for connecting disassociated actors; an example of this is digital intermediaries, which constitute a replacement for local intermediaries and prepare for the emergence of new trade networks among different entities [61], which would improve consumer prices of apicultural derivatives and their diversity, enhance buying and selling conditions, and open new internationalization opportunities.

Regardless of the technological supply, traditional practices are often chosen over modern and formal practices in developing countries. This is attributed to distinct reasons, such as the low academic level of beekeepers, the value they give to tacit and traditional knowledge passed from generation to generation [62], the lack of dissemination and training on the use of technologies [63], and the weak relationship between local needs and conditions and cutting-edge technological solutions [34]. Thus, one of the significant innovation challenges of the sector is the strengthening of technological capacities and the development and integration of technologies that can converge with traditional practices [64]. Other pending problems are related to feasible technology transfer prices for small producers and the generation of philanthropic and governmental agendas [33, 34], whose vision predominates over an alternative path of innovation traditionally offered to external actors belonging to research institutes, academia, and the government [50].

An innovative approach involves technological processes, technology adoption [33], organizational change, business models [30, 36], sustainable development, social structures, and livelihoods [55]. Difficulties derived from the COVID-19 pandemic, climate change, and poverty are additional issues. Hence the emerging necessity to stimulate and promote diverse types of innovation. A possible path leads to open innovation as a substitute for the linear idea of R&D so that external and internal networks can coexist to promote the creation of value, favoring the growth of local competitive systems that can take advantage of the strengths of converging resources and capacities [65, 66]. Examples of open innovation in apiculture are observed in the socialization of local modifications to honeycombs. These actions are given feedback by different community members and lead to integrated government and philanthropic institution networks that allow the communication and flow of resources to address specific problems. Many others could be derived from cross-border collaboration through ICTs and social networks generated between urban and rural communities [57].

Another option is social innovation, whose objective is to resolve and positively impact social problems in a novel way through community participation. For example, Yap et al. [55] show how the problem of technology adoption can be addressed through participatory mechanisms, which include democratic processes and social restructurings such as the formation of groups and cooperatives that favor the exchange of knowledge and resources. Also, in certain regions, frugal innovation—which seeks to provide solutions through functional products at the lowest possible cost—constitutes yet another opportunity [33, 67]. In countries such as Ethiopia, new techniques and modifications made by beekeepers satisfy the minimum conditions for preserving a healthy habitat for bees, although they do not aim at maximizing yield. It is interesting that, through their observation skills, intuition, local materials, and tacit knowledge, these beekeepers have obtained favorable results in honeycomb construction using materials such as mud and manure [33].

5.2 Methods

Network analysis has proven useful to understand the dynamics of different areas of knowledge. It can be used to highlight the main related themes and other elements of interest (authors, countries, etc.) through search in databases such as Scopus and Web of Science (WoS) and the use of software tools such as VOSviewer, among others. Several researchers have used this approach to study honey, its pesticide contents, and the antioxidant properties of derived products [68–70]. Similarly, research based on patent documents is a valuable tool to understand the different technology sectors and disciplinary fields focusing on apiculture, as demonstrated by studies focused on nanotechnology, agricultural biotechnological, food-related, textile, and general and organic agricultural applications [71–74]. Given its economic importance and usefulness to generate technological forecasts, these tools anticipate market dynamics [75–77], and combined studies use both scientific production and patent documents to explain relevant factors to mitigate the mortality of species as important as *Apis mellifera* [78].

Thus, network analysis was conducted in addition to patent analysis to identify the most recent study topics associated with apiculture and the forefront of technological development in this sector. Firstly, a search was done in the Scopus database (accessed on August 17, 2021) [68] using the terms "beekeeping" and "apiculture" in the fields: Title, Abstract, and Keywords. From this search, 3688 documents were found (spanning 1909 to 2022). The bibliographic data was obtained to perform a network analysis with VOSviewer (version 1.6.17); this was conducted by downloading the first 2000 documents sorted by date. A co-occurrence analysis (author's keywords) was then performed for the interval from 2014 to 2022, using the full counting method and a minimum parameter of five occurrences per word. Additionally, it was normalized using the LinLog/modularity method, although the procedure can dispense with normalization or use other normalization methods such as association strength or fractionalization [79].

For the patent applications analysis (1953–2021), a search was performed on September 12, 2021, in the Lens database [80]. It was structured by the keywords "beekeeping" and "apiculture," but with the following fields: Title, Abstract, or Claim. For this purpose, the following filters were used: Document type: Patent application; Classifications: IPCR classification code; Query tools: Stemmed; Query language: English. The rest of the parameters were left as default (see Table 5.1 for the results and search criteria). The Lens database was selected due to its robustness and because it has remained in service over time, providing free document searches [81].

5.3 Results Analysis

A total of 4410 keywords (author) were detected, of which 203 met the minimum frequency threshold criterion and were used in the keyword map. Thus, twelve clusters were formed (for more details, see the tables obtained from the co-occurrence analysis in Annex 1). The three keywords with the most occurrences are listed by cluster below using the following nomenclature: (a) N—Node; (b) O—Number of occurrences; (c) L—Number of links; and (d) TSL—Total link strength. Thus, the

Table 5.1 Queries for data search

No.	*Database*	*Query*	*Results*
1	Scopus	(TITLE-ABS-KEY (beekeeping) OR TITLE-ABS-KEY (apiculture))	3688
2	Lens	(title:(beekeeping) OR abstract:(beekeeping) OR claim:(beekeeping)) OR (title:(apiculture) OR abstract:(apiculture) OR claim:(apiculture))	727

Source Prepared by the authors based on Scopus [82] and Lens [80]

results for clusters one through four were: **Cluster 1** (red)—N: apiculture, O: 119, L: 88 TSL: 185; N: honey, O: 118, L: 82, TSL: 193; N: beeswax, O: 23, L: 23, TSL: 39. **Cluster 2** (green)—N: monitoring, O: 21, L: 35, TSL: 65; N: colony losses, O: 16, L: 23, TSL: 49; N: beekeepers, O: 15, L: 17, TSL: 20. **Cluster 3** (blue)—N: apis mellifera, O: 257, L: 144 TSL: 512; N: honeybee, O: 59, L: 58, TSL: 97; N: nosema ceranae, O: 29, L: 34, TSL: 69. **Cluster 4** (yellow)—N: biodiversity, O: 24, L: 33, TSL: 52; N: honey production, O: 21, L: 23, TSL: 30; N: conservation, O: 16, L: 26, TSL: 35.

From 5 to 12, results were: **Cluster 5** (lilac)—N: honey bee, O: 124, L: 101, TSL: 254; N: honey bees, O: 33, L: 42, TSL: 63; N: varroa, O: 15, L: 19, TSL: 33. **Cluster 6** (light blue)—N: pollen, O: 30, L: 31, TSL: 56; N: nectar, O: 16, L: 13, TSL: 25; N: mite, O: 12, L: 19, TSL: 28. **Cluster 7** (orange)—N: precision beekeeping, O: 31, L: 17, TSL: 60; N: agriculture., O:26, L: 27, TSL: 52; N: precision apiculture, O: 17, L: 10, TSL: 32. **Cluster 8** (brown)—N: varroa destructor, O: 81, L: 52, TSL: 153; N: environment, O: 12, L: 15, TSL: 25 y N: honeybee health, O: 12; L: 18, TSL: 23. **Cluster 9** (pink)—N: beekeeping, O: 293, L: 150, TSL: 465; N: honeybees, O: 54, L: 54, TSL: 93; N: pollination, O: 44, L: 43, TSL: 103. **Cluster 10** (light pink)—N: paenibacillus larvae, O: 18, L: 16, TSL: 36; N: bee, O: 17, L: 20, TSL: 29 y N: American foulbrood, O: 15, L: 15, TSL: 32. **Cluster 11** (light green)—N: meliponiculture, O: 22, L: 18, TS: 38; N: apis cerana, O: 21, L: 26, TSL: 45 y N: stingless bees, O: 19, L: 18, TSL: 29. **Cluster 12** (sky blue)—N: beekeeper, O: 9, L: 7, TSL: 11; N: classification, O: 5, L: 4, TSL: 7, and N: data mining, O: 5, L: 5, TSL: 9.

The size of the larger nodes reveals the importance of the topic within the beekeeping sector. However, regardless of size, emerging topics appear that will undoubtedly play a fundamental role in this production area. An example is the precision beekeeping node, linked to terms such as bee colony monitoring, wireless sensor networks, Internet of things, swarming, deep learning, machine learning, and data mining, clearly reflecting an interest in modernizing and digitizing beekeeping monitoring tools, especially in developed economies, as discussed in the theoretical and conceptual framework. Additionally, a second node highlights the importance of economic, social, and environmental development: sustainability. Sustainability shows a low number of occurrences, but it has links to fundamental elements such as bee products, beekeepers, and bees, as well as elements present in Cluster 2: acaricide, apiary management, beekeepers, behavior, brood, citizen science, colony, colony losses, colony strength, disease, diversity, feeding, landscape, monitoring, morphology, mortality, nutrition, organic beekeeping, pest, survey, treatment, varroa

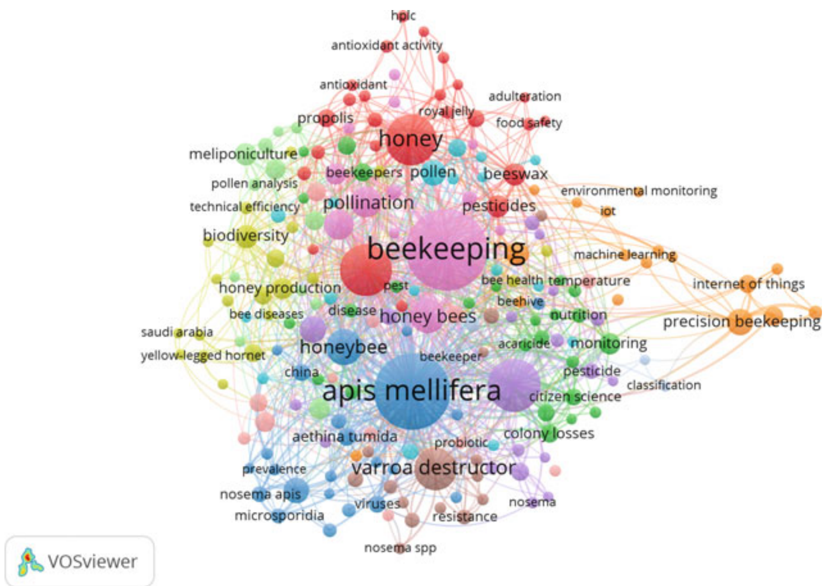

Fig. 5.1 Network Visualization (*Source* Prepared by the authors based on Scopus [2021] and VOSviewer [2021])

Table 5.2 Top ten jurisdictions and applicants

No.	*Jurisdiction*	*Documents*	#	*Top applicants*	*Patent document*	*Country of residence*
1	China	254	1	Breat SL	26	Spain
2	Republic of Korea	116	2	Bee Res Inst Caas	9	China
3	WIPO	89	3	Anderson Cedar	8	Australia
4	Japan	41	4	Anderson Stuart	7	Australia
5	United States	37	5	Jeong Hyuk	7	Republic of Korea
6	Spain	30	6	Healthy Bees LLC	5	United States
7	European Patents	25	7	Henan Inst Science & Tech	5	China
8	Russia	24	8	Batista Gonçalves Carla Maria	4	Portugal
9	France	16	9	Bazhong Yerui Miyuan Beekeeping Ind Co LTD	4	China
10	Mexico	14	10	Beewise Tech LTD	4	Israel

Source Prepared by the authors based on the results of Lens (2021)

control, and varroa mite. This scenario shows that sustainability is heavily oriented toward environmental problems; therefore, it is necessary to generate studies considering economic and social perspectives (Fig. 5.1).

A total of 727 patent applications were found to meet the previously described search filters. A Top Ten analysis of the most relevant results by indicator was performed based on this information. China tops the list of applications for the top ten jurisdictions, followed by South Korea, World Intellectual Property Organization (WIPO) PCT (Patent Cooperation Treaty) applications, Japan, and the United States. Not surprisingly, the most sizable number of applications is in China due to its position as the world's leading honey producer and its vigorous technological growth in multiple areas of knowledge. Asia is the region where 41.2% of honey is produced globally, followed by America (23%), where Mexico appears as a relevant producer in Latin America; in this ranking, Mexico occupies

Table 5.3 Patent applications by IPC classification

No.	*IPCR classification code*	*Document count*	*Description*
1	A01K47/06	181	"Other details of beehives, e.g., ventilating devices, entrances to hives, guards, partitions, or bee escapes…"
2	A01K47/00	152	"Beehives…"
3	A01K47/02	104	"Construction or arrangement of frames for honeycombs"
4	A01K47/04	93	"Artificial honeycombs"
5	A01K59/00	70	"Honey collection…"
6	A01K67/033	61	"Rearing or breeding invertebrates New breeds of invertebrates"
7	A01K51/00	53	"Appliances for treating beehives or parts thereof, e.g., for cleaning or disinfecting…"
8	A01K53/00	29	"Feeding or drinking appliances for bees…"
9	A01K49/00	28	"Rearing-boxes Queen transporting or introducing cages…"
10	A23K50/90	26	"Feeding stuffs specially adapted for particular animals, e.g., bees or silkworms"

Source Prepared by the authors based on LENS (2021)

the last position, this is an initial indicator of the interest of the country in developing and commercializing of these technologies. The most important applicants are companies, research institutes, and individuals. The presence of Australian and Israeli applicants in this list is worth noting, showing the interest of other actors from countries where honey production to generate inventions associated with apiculture is modest (see Table 5.2).

Based on the International Patent Classification (IPC), the ten main technology areas focus on modifications and improvement of the physical conditions of honeycombs, cleaning, and disinfection means to collect honey, bee feeding applications, elements for breeding or reproduction of invertebrates, and the transport or introduction of queen bees, among others (see Table 5.3). This highlights the interest of technology developers to address nutrition problems, pest and disease mitigation, colony loss, and honey production. The technological sectors associated with apiculture present a moderate number of patent applications, and in many cases, these are associated with basic production activities. However, beyond the ten main technological classes, other patents are associated with genetic engineering, which should be studied in greater detail to analyze its impact on the environment and society. Similarly, it will be necessary to monitor the development of other technologies related to the digitization of the sector and higher added-value products that use inputs such as honey. Regardless of the categories, some patent applications include food formulations with anti-mite activity; food and feeding methods for improving honey production and bee rearing; honeycomb automation, including the use of technology to monitor bee conditions (feed, pesticides, and climate control), and data analysis and management, including its delivery to the user.

5.4 Conclusions

The results of this study highlighted the challenges faced by apiculture in the three dimensions of sustainability. The literature review identified the main problems in the sector: hive loss, bee mortality, diseases, and pests, lack of management capacities, and low productivity. As shown by the patent analysis, some of these problems are being addressed using technological developments, for example, monitoring, cleaning and sanitation, habitat improvement, and honey production methods. However, the social and economic aspects cannot be addressed solely from this perspective. Therefore, it is essential to find comprehensive solutions to overcome the obstacles to technology transfer and adoption that arise when these are delivered to beekeepers and integrated into the apiculture value chains.

The strong dominance of developed countries was noteworthy, and many of them invest in developing technological solutions for the field. However, it is most unfortunate that developing countries, where 84.39% of the world's honey was produced in 2019, depend entirely on these economies to gain access to cutting-edge technological innovations to improve productivity. Consequently, the development of endogenous technologies to improve the beekeeping sector in developing countries and the generation of proposals to address local problems is a paramount necessity. Although the literature review shows that the technological capabilities of beekeepers in developing countries are still based on traditional techniques and given that education has failed to be a significant factor, it is necessary to close the technological and skills gaps and allow the sector's workers a chance to implement the techniques and technology that best suit their needs and context. The challenge is to find a combination that takes advantage of traditional knowledge and makes technology available to producers.

As shown by the network map, very few terms were associated with social and economic aspects; this research void needs to be addressed in greater depth. These results show the need to develop environment-friendly scientific and technological solutions while approaching this phenomenon under a socio-economic development angle that includes the study and the generation of proposals to promote social innovation and the well-being of beekeepers and their families. The challenges faced by this sector due to climate change and agricultural intensification require policies and programs to promote sustainability, under a comprehensive approach, to generate the skills that producers need to meet the demands of their local consumers and the global market.

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Annex I

Cluster 1				*Cluster 2*				*Cluster 3*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Adulteration	5	6	5	Acaricide	18	23	8	Acarapis woodi	10	11	5
Analysis	10	13	6	Apiary manage-ment	11	13	5	Aethina tumida	15	32	16
Antibiotics	9	11	6	Beekeepers	17	20	15	Apis mellifera	144	512	257
Antioxidant	5	7	7	Behavior	9	9	6	Argentina	10	13	5
Antioxidant activity	4	5	8	Brood	9	11	5	Bioinformatics	9	12	6
Apiculture	88	185	119	Citizen science	17	43	13	China	21	27	13
Apis mellifera l	15	17	9	Colony	7	7	5	Colony collapse disorder	12	18	8
Apitherapy	6	7	8	Colony losses	23	49	16	Control	13	15	6
Bee pollen	13	18	13	Colony strength	19	23	9	Diagnosis	10	12	5
Bee products	21	26	11	Disease	17	27	9	Honey bee viruses	6	9	5
Beeswax	23	39	23	Diversity	9	9	5	Honeybee	58	97	59
Botanical origin	7	9	6	Feeding	10	11	6	Microsporidia	14	29	11
Contamination	12	16	5	Landscape	11	13	8	Nosema apis	19	38	12

(continued)

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Cluster 1				*Cluster 2*				*Cluster 3*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Food safety	10	12	8	Monitoring	35	65	21	Nosema ceranae	34	69	29
Fumagillin	5	7	5	Morphology	10	15	6	Nosemosis	10	16	9
Health	7	9	6	Mortality	17	37	13	Parasite	14	18	6
Honey	82	193	118	Nutrition	15	24	10	Phylogeny	14	17	7
HPLC	4	5	6	Organic beekeeping	10	11	5	Prevalence	14	17	6
Organic honey	5	7	5	Overwinterin	12	14	5	Probiotics	8	8	5
Pesticides	34	56	23	Pest	11	14	8	Real-time PCR	11	13	6
Physicochemical properties	6	10	5	Survey	13	29	8	RT-PCR	13	15	9
Propolis	18	27	16	Sustainability	9	15	15	Small hive beetle	12	25	11
Quality	5	12	7	Treatment	14	19	6	Viruses	25	35	13
Royal jelly	13	16	8	Varroa control	11	13	6				

(continued)

Cluster 1				*Cluster 2*				*Cluster 3*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Turkey	14	20	9	Varroa mite	19	22	11				
Cluster 4				*Cluster 5*				*Cluster 6*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Adoption	5	8	5	Acaricides	11	12	5	Apiaries	14	15	6
Apis mellifera jemenitica	7	8	5	Biomarkers	7	8	5	Apiary	13	14	5
Bee diseases	10	11	5	Colony collapse	13	15	7	Climate	12	14	5
Bee health	17	22	8	Colony loss	11	13	5	Distribution	15	17	5
Biodiversity	33	52	24	Gene expression	15	18	8	Efficiency	8	12	5
Conservation	26	35	16	Honey bee	101	254	124	Foraging	9	10	6
Development	12	13	6	Honeybees	42	63	33	GIS	7	10	6
Food security	7	7	5	Imidacloprid	12	15	5	Melliferous flora	8	8	5
Honey production	23	30	21	Immunity	14	20	8	Mite	19	28	12
Impact	7	8	6	Insecticide	8	11	6	Nectar	13	25	16

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Cluster 4				*Cluster 5*				*Cluster 6*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Invasive alien species	7	10	5	Neonicotinoid	11	19	9	Pests	14	22	8
Invasive species	20	29	16	Neonicotinoids	15	17	13	Pollen	31	56	30
Land use	14	20	7	Nosema	11	17	6	Production	8	11	5
Mexico	7	8	6	Parasites	16	21	6	Productivity	5	7	5
Morphometry	10	13	5	Pesticide	18	32	12	Queen bee	9	12	5
Pollinators	18	28	15	Pollinator	6	13	9	Reproduction	13	16	7
Rural development	11	18	7	Urban beekeeping	9	12	10	Stingless bee	12	15	10
Saudi Arabia	8	9	5	Varroa	19	33	15				
Technical efficiency	6	10	8	Virus	10	14	5				
Vespidae	5	8	5								
Yellow-legged hornet	10	15	7								

Cluster 7				*Cluster 8*				*Cluster 9*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Agriculture	27	52	26	Australia	5	8	6	Beekeeping	150	465	293
Apis mellifera l	12	12	6	Breeding	7	9	7	Bees	32	63	40
Bee colony monitoring	4	18	9	Deformed wing virus	15	22	11	Climate change	14	19	11
Beehive	8	10	6	Environment	15	25	12	Economics	10	14	10
Beehives	6	6	5	Genetic Diversity	9	11	9	Ecosystem services	19	34	21
Deep learning	6	6	6	Honey bee health	18	23	12	Ethiopia	4	6	6
Environmental monitoring	6	7	5	Hygienic behavior	10	11	6	Geographical information systems	2	5	5
Internet of things	12	26	15	Management practices	9	13	6	Honey bees	54	93	54
Internet of things (IoT)	10	12	6	Mites	7	8	5	Land-use change	8	11	6
IoT	7	9	6	Mitochondrial dna	8	10	6	Livelihoods	4	6	7
Machine learning	11	14	7	Natural selection	12	17	6	Pollination	43	103	44
Pesticide residues	8	9	5	Nosema spp	12	17	6	Pollination services	5	7	5
Precision agriculture	10	12	5	Resistance	17	23	10	Remote sensing	6	6	5

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Cluster 7				*Cluster 8*				*Cluster 9*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Precision apiculture	10	32	17	Varroa destructor	52	153	81				
Precision beekeeping	17	60	31	Varroosis	14	18	7				
Swarming	10	13	6								
Wireless sensor networks	6	10	6								
Cluster 10				*Cluster 11*				*Cluster 12*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
American foulbrood	15	32	15	Apidae	11	18	7	Beekeeper	7	11	8
Bee	20	29	17	Apis cerana	26	45	21	Classification	4	7	5
Galleria mellonella	2	2	6	Apis dorsata	5	6	5	Data mining	5	9	5
Larvae	7	7	5	Brazil	9	11	5	Honey yield	10	18	11
Melissococcus plutonius	11	15	8	Hymenoptera	6	7	5				

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Cluster 10				*Cluster 11*				*Cluster 12*			
Items	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*	*Items*	*Links*	*Total link strength*	*Occurrences*
Migratory beekeeping	9	12	13	Meliponiculture	18	38	22				
Paenibacillus larvae	16	36	18	Meliponini	11	19	10				
Pathogen	14	19	8	Melissopalynology	14	29	17				
Pathogens	13	16	8	MtDNA	7	7	7				
Probiotic	12	14	7	Pollen analysis	11	13	8				
Temperature	15	19	10	Stingless bees	18	29	19				
Transcriptome	8	8	7	Subspecies	11	12	5				

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