Article

Technological Advances to Reduce *Apis mellifera* Mortality: A Bibliometric Analysis

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Abstract: Bees play a fundamental role in the ecological balance of ecosystems, due to the pollination process they carry out on crops, including the production of honey. However, the mortality of bees is a significant concern; bee mortality can occur for several reasons, such as pesticides, mites, viruses, climate change, pathogens and a reduction in food resources and nests. The honey bee (*Apis mellifera*) is the most widely used bee for commercial pollination and honey production. Therefore, the main objective is to compare the development of patent families and article publications related to the reduction in *A. meliifera* mortality. Data on patent families were collected on the Orbit platform, while data on scientific articles were collected on the Scopus database, with a time interval of 1980–2019. Subsequently, the data were analyzed in order to show the main priority countries, main assignees, and main IPC (International Patent Classification) codes, an analysis of the technology life cycle and the correlation between the data of patent families and articles published. The technologies that help to decrease bee mortality showed a technological maturity rate of 27.15% for patent families data and 53.35% for data from articles published in journals. It was noticed that the principal interest regarding the reduction in *A. mellifera* mortality is focused on universities, mainly in the United States and China.

Keywords: *Apis mellifera*; bee mortality; bibliometric analysis; patent analysis; technology life cycle

1. Introduction

Bees play an essential role in the ecological balance of ecosystems, due to the pollination of different plants, as well as producing honey, propolis and wax, which all contribute to financial income generation [1–3]. The greater diversity and quantity of pollinators, such as bees, increases the productive yield of agricultural crops [4,5].

In terms of economic values, it is estimated that between $235 billion and $577 billion in annual global food production depends on direct contributions from pollinators such as bees [6]. In Europe alone, the annual contribution by bees is EUR 14.6 billion [7]. In Brazil, the contribution of pollinators corresponds to USD 12 billion per year [8].

Given the importance of bees, a concern about mortality is catching the attention of researchers around the world [9–11]. However, there is still no plausible explanation for these facts [12,13]. It is believed that the decline of bees may be related to exposure to several stressors, such as pesticides, mites, viruses, climate change, pathogens and a reduction in food resources and nests [14,15]. *Apis mellifera* is one of the species that suffers from this reduction in number of hives. At present, *A. mellifera* is one of the best known and most managed species in the world [16].

With all these problems that cause honey bee mortality, technologies are being developed to minimize damage. These technologies are deposited as a form of patents or even through the publication of scientific articles. Patents are documents with legal status to describe and claim technological inventions [17]. These documents provide a public

disclosure of an invention or improvement, which may be a piece of equipment, a process or a new type of material [18].

The development of patents represents how much technology is evolving, as they are important results of innovative activities [19]. Patent analyses assess the degree of technological development, identifying possible partners or competitors in the market, in addition to collaborating in decision-making on new research projects [20].

The literature still lacks an analysis of patents related to technologies that reduce stressors to honey bee colonies, and an analysis of articles published in journals. In this scenario, given the importance of this insect, with numerous losses of beehives around the world, the main question of this study is: How are technologies evolving, in terms of the preservation of the honey bees? How are patents evolving and research publications and manuscripts, in terms of honey bee preservation?

The objective of this research is to map patent families and publications of research that discuss the mortality of *A. mellifera*. A secondary objective is to compare the advancement of patent families with scientific publications focused on the subject of study. In this sense, the evolution of publications of patent families, distribution of publications by assignee, analysis of publication by priority country, identification of the technology domain, technology domain by assignee, main categories of patent families, and life cycle analysis are exposed technologies and a correlation between patent families and scientific articles.

Regarding the innovation of this research, similar studies were not found in the Scopus journal base, which referred to technological advances in patent families to reduce honey bee mortality, rendering this an innovative and original theme in scientific research.

2. Materials and Methods

2.1. Data Collection and Processing

To illustrate the steps for data collection and processing, Figure 1 was elaborated. Data were collected from patent families and scientific articles.
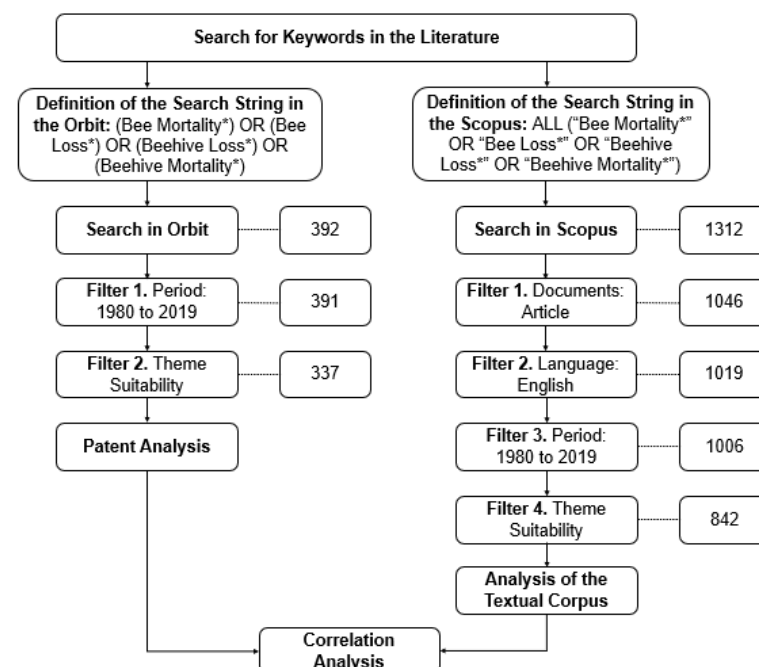

Figure 1. Research protocol.

For the research strategy, the following keywords were searched on the subject under study: ((bee mortality*) or (bee loss*) or (beehive loss*) or (beehive mortality*)). The search for patent families was performed in the title, abstract and claims. This keyword search gave rise to the String, as show in Figure 1, used to search for patent families in Orbit and

scientific articles in the Scopus database. After performing the search in the Orbit and Scopus database, filters were applied in order to minimize selection bias.

The initial search on Orbit found 392 patent families. The first filter to be applied was from the period from 1980 to 2019, resulting in 391 patent families. The second filter was of adequacy to the objective under study, keeping only patent families that present technologies for reducing mortality and impacts on bees, more specifically of the impacts on the *A. mellifera* genus; this step resulted in 337 patent families.

Using the 337 families of patents, several analyses were carried out. The first one presented the evolution of publications during the period under study. The next step was to analyze the number of patent families produced by the 10 main research institutions/companies in the context. Next, the priority order numbers for each country were exposed. After that, the categories were presented by technology domain, in addition to listing them with the main institutes/companies holding the patent families. The next step was to verify the distribution of the main IPC (International Patent Classification) codes for the patent families under research.

The initial search in Scopus resulted in 1312 documents, including articles published in indexed journals, conference articles, abstracts and books. The first filter used in these data was to keep only peer-reviewed journals, resulting in 1046 articles. The next filter applied was to consider exclusively articles written in the English language, resulting in 1019 articles. The time restriction used was the same as for the patent families, from 1980 to 2019, covering 1006 documents. The fourth filter was to adapt to the objective of the study, keeping only articles related to *A. mellifera* mortality, covering 842 documents. This filter was performed by inserting the term "*Apis mellifera**" in the search field on the Scopus database.

Considering all of the 842 documents, the main countries that carry out studies, the main authors, the institutions involved in the research and the funders are discussed.

2.2. Technology Life Cycle Analysis

The next stage of the study was to analyze the life cycle of technologies associated with the decrease in mortality of *A. mellifera*. Technologies or products go through different phases within the life cycle that range from introduction, growth, maturity and saturation [21,22]. Technology life cycles can be modeled using data from patents, scientific articles or even product sales [23].

With the cumulative number of patent families and the cumulative number of scientific articles in the analyzed period, through the logistic model, it is possible to evaluate the life cycle of the technologies. Loglet Lab 4 software was used to analyze the data.

The logistic model was described as Equation (1), according to Yoon et al. [24]:

$$Y(t) = \frac{L}{1 + e^{-k(t-to)}} \tag{1}$$

where "*to*" and "*k*" determine the location and shape of the curve and "*L*" is its maximum asymptotic value. These coefficients are estimated by the appliance of the ordinary least squares regression method to the log linearized function. The technological maturity rate (*TMR*), potential for patents to appear (*PPA*) and estimated lifetime (*ERL*) are calculated with Equations (2)–(4), respectively, according to Yoon et al. [25]; Yoon et al. [24]:

$$TMR(t) = \frac{L_{now}}{L} \tag{2}$$

$$PPA(t) = L - L_{now} \tag{3}$$

$$ERL(t) = T\rho - t \tag{4}$$

where "L_{now}" is the cumulative number of patents in the present tense and *t* is the current year. A technology's *ERL* only is possible to be calculated if a "ρ" threshold value for

technological advancement is provided, as the number of cumulative patent registrations at time *t* never reaches the saturation level *L*.

2.3. Data Correlation Analysis

The last stage of the research comprises analyzing the relationship between publications of patent families and scientific articles in the period under study. The technique used to assess this relationship was correlation analysis, more precisely Pearson's linear correlation coefficient. This coefficient is defined by Equation (5) [26].

$$r_{xy} = \frac{Cov(x, y)}{\hat{\sigma}_x \hat{\sigma}_y} = \frac{S_{xy}}{\sqrt{S_{xx}.S_{yy}}} \tag{5}$$

where "*n*" represents number of observations.

The sums of squares are given by Equations (6)–(8).

$$S_{xy} = \sum x.y - \frac{\sum x . \sum y}{n} \tag{6}$$

$$S_{xx} = \sum x^2 - \frac{(\sum x)^2}{n} \tag{7}$$

$$S_{yy} = \sum y^2 - \frac{(\sum y)^2}{n} \tag{8}$$

The result of the Pearson coefficient corresponds to a range of intensity variation between −1 and 1. The perfect correlation, *r* = 1 or *r* = −1, occurs when one variable establishes a precise relationship over the other; however, when *r* = 0, there is no linear correlation between the variables [27].

The interpretation of the degree of correlation is calculated as follows [28]:

$0.00 < |r| < 0.30$: weak linear correlation;
$0.30 \leq |r| < 0.60$: moderate linear correlation;
$0.60 \leq |r| < 0.90$: strong linear correlation;
$0.90 \leq |r| < 1.00$: very strong linear correlation.

3. Results and Discussions

3.1. Patent Families Reviews

Figure 2 illustrates the evolution of publications by patent families related to the increased mortality of *A. mellifera* colonies in the period between 1980 and 2019.
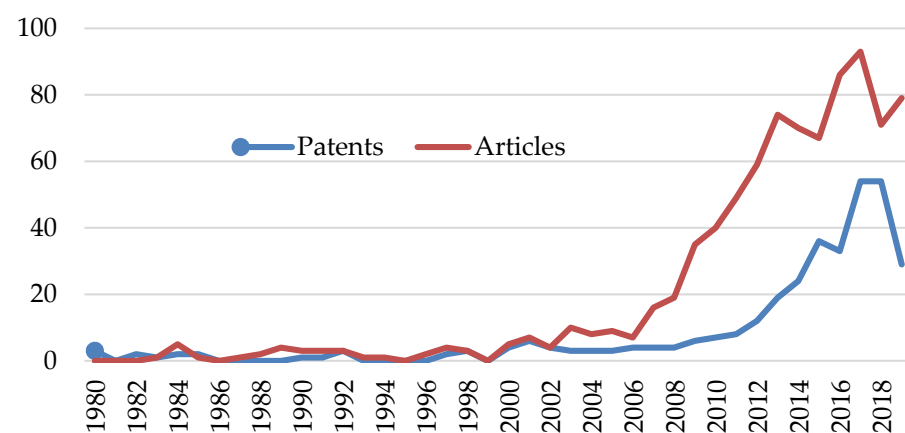

Figure 2. Number of patent family and published articles of *A. mellifera* mortality.

An increase in the number of patent families after 2000 is perceived, but mainly after 2008, as shown in Figure 2. One of the causes for this increase could be colony collapse disorder reported in 2006 in the United States [27]. Since 2008, China has also devoted

considerable investments to bee research [28]. The decline in the number of patents in 2019 is explained by the fact that, after the filing of patent families, there is a time of about two years until patents become public. Therefore, the 2018 and 2019 data may still be incomplete. This could affect the accuracy of the predictions made with the logistic growth curve in Figure 3. After the year 2012, the number of patents grew considerably.
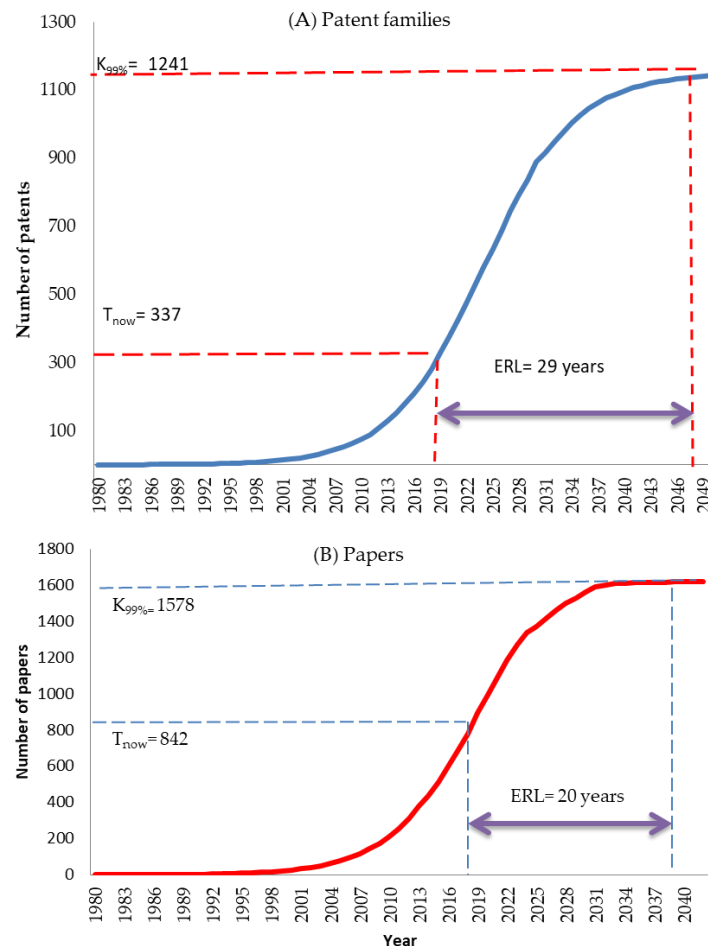

Figure 3. Logistic growth curves of *A. mellifera* technology of bee mortality reduction.

Figure 3 shows the logistic growth curves, Equation (1), for the data on patent families (A) and for the data on published articles (B), drawn from the Loglet Lab 4 software. The rate of technological maturity (*TMR*) for 2019 was 27.15%, calculated with Equation (2) for patent families data. The *PPA* for the patent families is 904 documents (Equation (3)). It can be noted that the estimated time remaining (*ERL*) (Equation (4)) for the saturation in the number of patent families is 29 years, with 1241 patent families. The r^2 (coefficient of determination) for the analysis with data from patent families was 0.947, while the ρ value was 2.97×10^{-12}. In a cumulative analysis of articles published in journals, it can be inferred that the *ERL* for saturation in the number of articles is 20 years, with 1578 documents. The *TMR* in 2019 was 53.35%. The PPA for data from articles published in journals indicates 736 documents. The r^2 (coefficient of determination) for the analysis with data from scientific articles was 0.985, while the ρ value was 8.39×10^{-19}. This study presents a statistic that follows a logistic distribution with n − 2 degrees of freedom (df). Therefore, it is clear that these are technologies that are in the growth phase, needing more research and development to reach technological maturity.

The graph in Figure 4 shows the number of patent families in the sector's research institutions/companies. This representation is a good indicator of the propensity of these institutions/companies to collaborate with the development of the subject.
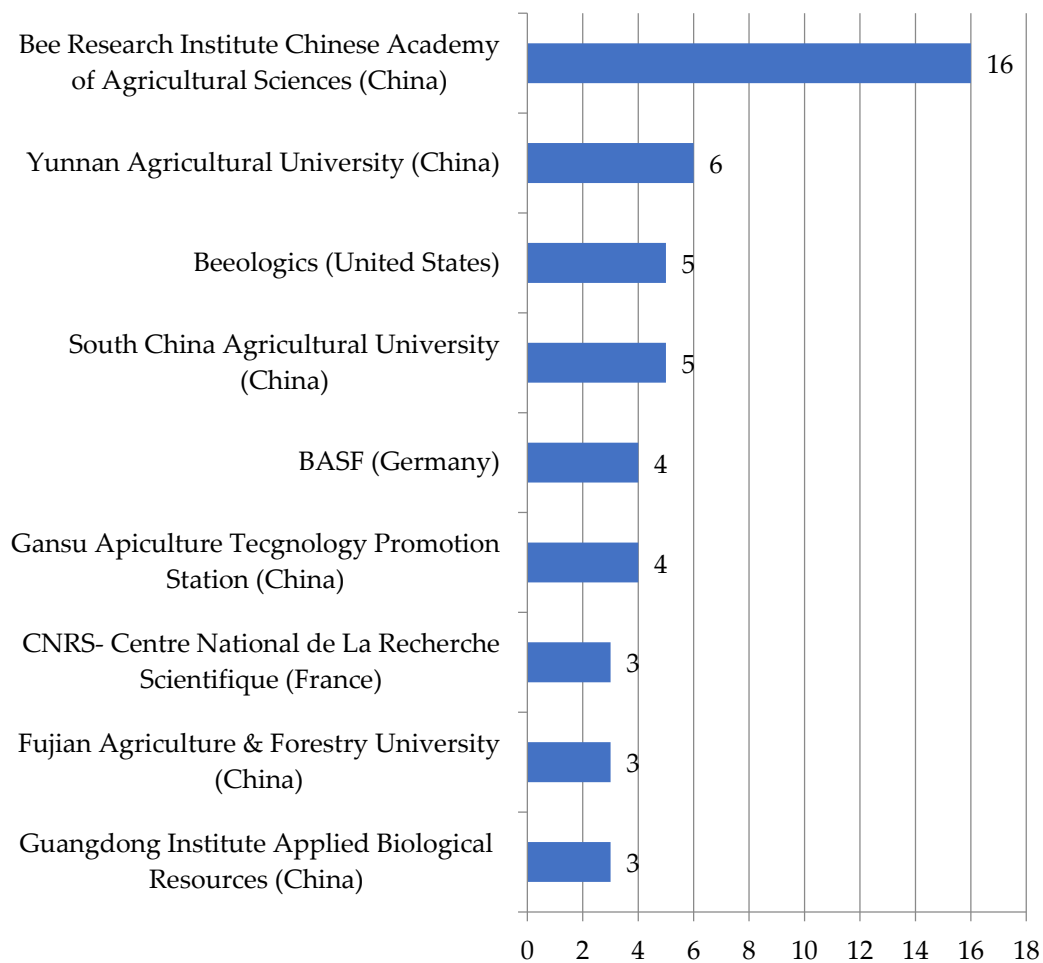
Figure 4. Family of patents by institutions/companies for technologies to reduce bee mortality.

Figure 4 shows the Bee Research Institute Chinese Academy of Agricultural Sciences with the largest number of published patent families, demonstrating its importance in research in this area. Bee Research Institute is part of the Chinese Academy of Agricultural Sciences, a national research institute, founded in 1958, located in the western suburb of Beijing, China. The Bee Research Institute develops research on beekeeping, queen breeding, honey production and royal jelly production; in addition, it also works with the creation of technologies aimed at bee diseases [29]. It is noticed that there is greater interest from universities and research centers.

There is a predominance of Chinese institutions in the families of patents by assignee. Of the 10 institutions shown in Figure 4, six are from China. The reason that China has the main research institutions aimed at developing technology for bee preservation is the fact that this country is the most significant country in bee pollination services in the world. Having a huge diversity of species, and more than eight million colonies of managed bees, contributes to making this country the largest honey producer in the world [30].

Publication by priority country represents the number of priority orders placed at country offices in each country, used to identify where research teams are located. Most patent applications are carried out with local priority, and therefore represent the main R&D locations in the sector under study. China is the country with the highest number of patent families, with 177, corroborating the results found for patents by assignee. The second country with the second highest number of patent families is South Korea, with 57, followed by the United States of America with 50. Although other bee species, such as *A. cerana*, are more common to Chinese researchers, some of the technologies analyzed in this research are commonly used in *A. mellifera*. *A. mellifera* and *Apis cerana* are impacted by

common stressors, such as: *Varroa* mite [31], virus [32] and the *Nosema* fungus [33]. For this reason, the patents were kept for this analysis.

The divisions of technology categories are divided in the patent families, called technology domains. Technology domain categorizations are based on IPC (International Patent Classification) code groupings, making it possible to find patents in several different categories. Figure 5 helps to identify the diversity of areas present and shows which is the main group that the theme is inserted in.
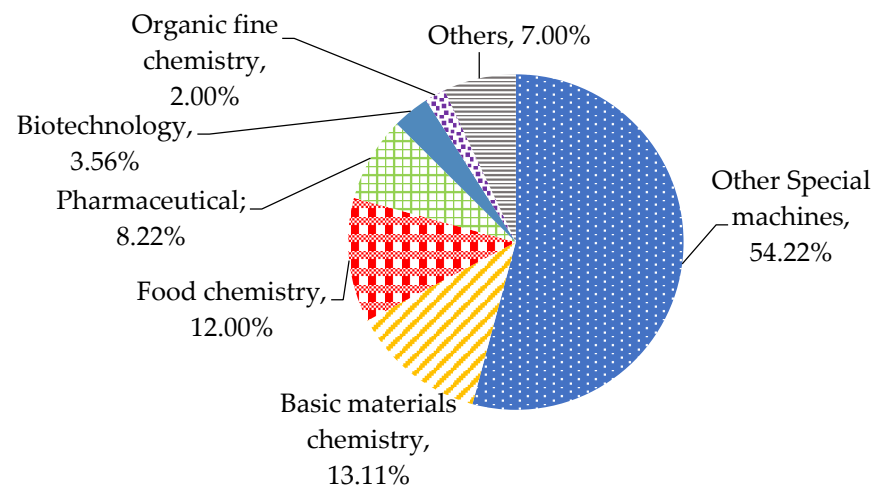

Figure 5. Technology domain of patents to decrease mortality of *A. mellifera*.

Figure 5 allows us to identify into which domain of technology the subject under study is inserted, especially in other special machines (54%). In this sense, it can be said that most of the patent families aiming to reduce honey bee mortality are linked to technologies, equipment or improvement of hives, mainly for management. These families of patents are strongly related to devices to prevent attacks from mites and other pests that affect the development of the hive. The following patents are some examples of technologies or methods for controlling pests, especially the *Varroa* mite: WO 2017214272 [31]; WO2015143536 [32]; WO2012170420 [33]; CN106719106 [34]; US6620025 [35]; CA2295898 [36]; CN206462194 [37]; CN204426328 [38]; WO2014107664; WO2015032753.

The technology domain is also verified according to the main developers, called technology domain by assignee. Figure 6 shows the main technology areas related to the main institutes/companies holding the patent families. This makes it possible to research the positioning of the institutes/companies and identify potential partners.

In Figure 6, it is possible to identify that most Chinese institutes are focused on the development of technologies in the other special machines category, while companies such as BASF (Badische Anilin and Soda Fabrik, Ludwigshafen, Germany) and Beeologics rely on developing technologies aimed at biotechnology, pharmaceutical and chemical materials.

The IPC clusters determine the distribution of the principal categories of patent families. The analysis of IPC clusters shows the distribution of the main IPC codes contained in the portfolio of patents under study, making it possible to identify the areas in which the applicant seeks protection. Some patent families are registered with more than one IPC, to receive protection in more areas.

Table 1 presents the 10 main categories of IPC where the patent families in the study are under protection. Most of the patent families in the study focus at the technological improvement of hives and coupled devices, with 106 deposits in this area. Technology exclusively focused on hives has the second highest number of deposits, 60 in total. This result corroborates the results discussed above in the technology domain.
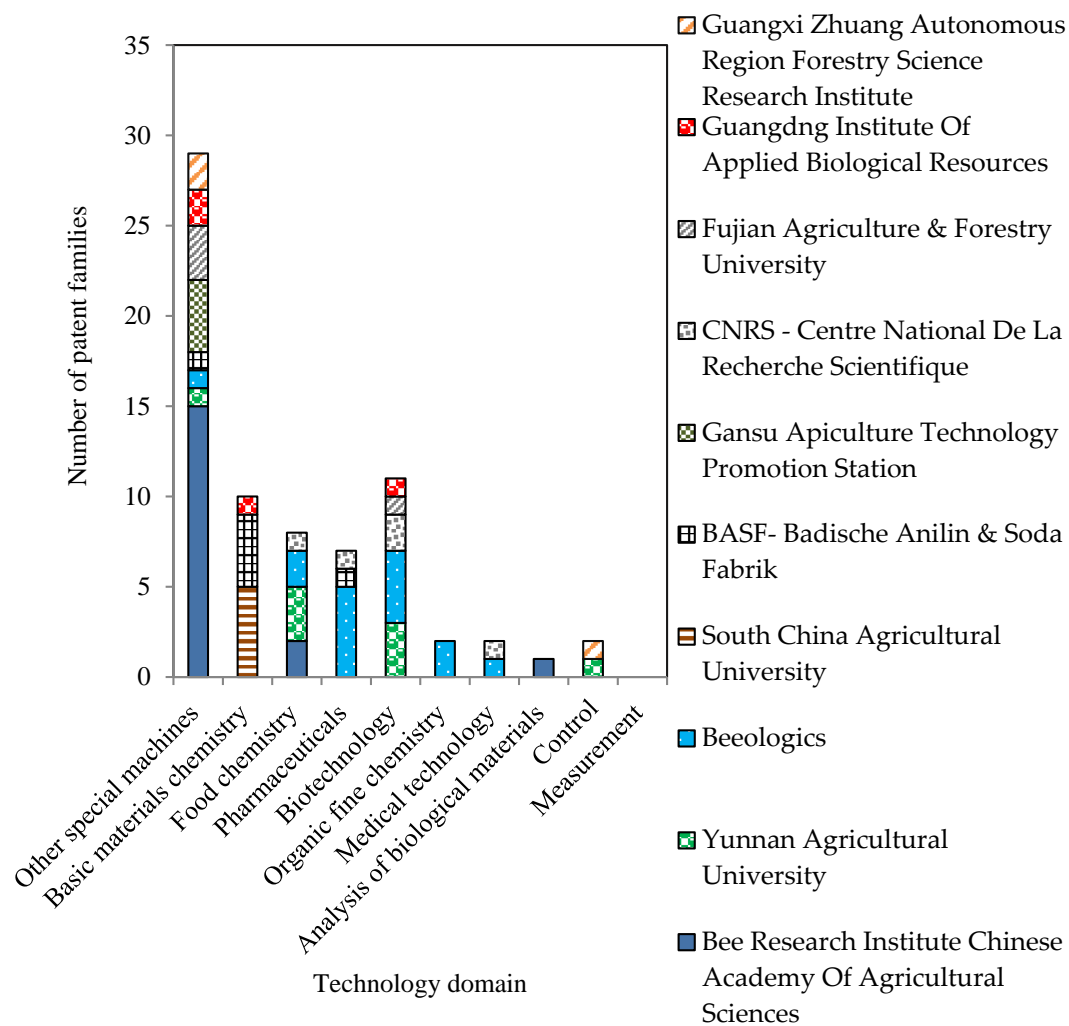
Figure 6. Technology domain by assignee of technologies to decrease the mortality of *A. mellifera*.

Table 1. Main IPC Code.

IPC Code	Description	Quantity
A01K-047/06	Other details of beehives, e.g., ventilating devices, entrances to hives, guards, partitions or bee escapes	106
A01K-047/00	Beehives	60
A01K-067/033	Rearing or breeding invertebrates; New breeds of invertebrates	52
A01K-051/00	Appliances for treating beehives or parts thereof, e.g., for cleaning or disinfecting	34
A23K-050/90	For insects, e.g., bees or silkworms	34
A01K-047/02	Construction or arrangement of frames for honeycombs	33
A01K-053/00	Feeding or drinking appliances for bees	24
A23K-020/163	Sugars; Polysaccharides	24
A01K-049/00	Rearing-boxes; Queen transporting or introducing cages	21
A23K-010/30	From material of plant origin, e.g., roots, seeds or hay; from material of fungal origin, e.g., mushrooms	20

3.2. Analysis of the Textual Corpus

Figure 7 shows countries with the highest number of peer-reviewed publications that examine the mortality of *A. mellifera*.
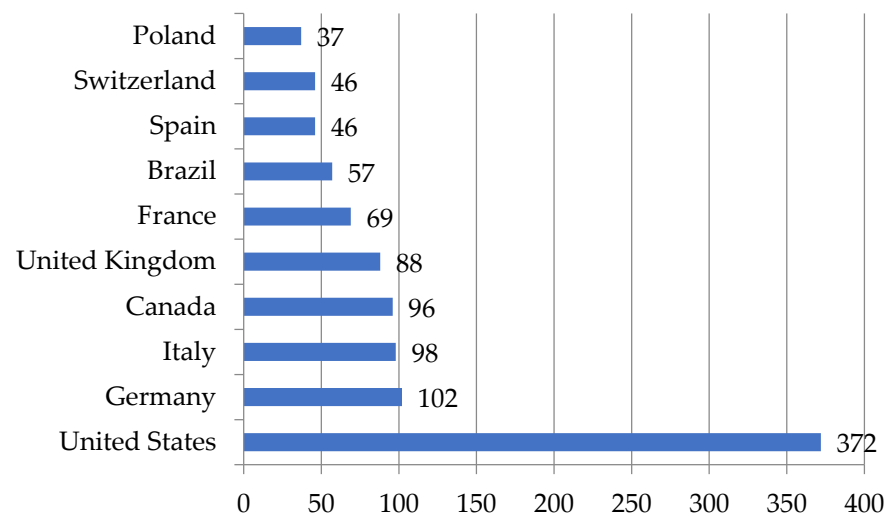
Figure 7. Documents by country, in terms of *A. mellifera* mortality.

Figure 7 demonstrates that the United States is the main producer of scientific articles on this particular subject, followed by Germany and Italy. In terms of number of patents, United States ranks third, while China leads the ranking among the number of patents, but does not perform well in article publications. This is likely to be partly because only English literature is considered in the present research.

Scientific articles published in journals that showed greater dissemination of knowledge and technologies were analyzed through citations. Among the articles analyzed, those with the highest number of citations in Scopus are:

- "Economic valuation of the vulnerability of world agriculture confronted with pollinator decline" [39] with 1216 citations. The authors assessed the contribution of insect pollination to the economic value of world agricultural production, and the vulnerability of agriculture in the face of pollinator decline. The authors concluded that between crop categories there was a positive correlation between the rate of vulnerability to pollinator decline in a crop category and its value per unit of production.

- "Wild pollinators enhance fruit set of crops regardless of honey bee abundance" [40] with 1060 citations: the authors showed that visitation by wild insects and honey bees promoted independent fruiting, so that pollination by managed bees supplemented, rather than replaced, pollination by wild insects.

- "Biology and control of *Varroa destructor*" [41] with 768 citations: the authors carried out a review of knowledge in the main areas of research in *Varroa*, such as mite biology, host damage, host tolerance, reproduction with tolerance and treatment of *Varroa*. The authors concluded that knowledge about *Varroa* honey bee interactions shows that we are far from a solution to *Varroa* infestation, and more research is needed on mite biology, tolerant reproduction and treatment with *Varroa*.

- "High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health" [42] with 758 citations: the authors analyzed the presence of pesticide residues in samples from migratory beekeepers and other beekeepers in 23 states, a Canadian province and various cropping systems during the 2007 and 2008 seasons. There were 98 pesticides and metabolites in mixtures of up to 214 ppm in bee pollen representing a remarkably high level of toxics in the brood and adult food of this primary pollinator. During exposure to many of these neurotoxins there have been acute and sub lethal reductions in bee wellness, the effects of these materials in combinations and their direct association with colony collapse disorder and honey bee health decline remains to be determined.

- "Colony collapse disorder: a descriptive study" [43] with 753 citations: the authors performed a descriptive epizootiological study in order to characterize colony collapse disorder and compare exposure to risk factors between affected and non-affected

populations. The authors suggest that honey bee populations affected by colony collapse disorder involve an interaction between pathogens and other stressors.

3.3. Correlation between Patent Families and Articles

Applying Equation (5), the results of Table 2 are obtained. The coefficient (*r*) indicates that the variables have a significant, positive, and strong correlation; the value is close to one.

Table 2. Result of the correlation between patents and articles.

Coefficient	Value
r	0.8869
r^2	0.7865
ρ value (approx.)	0.0001

Academic articles and patents are considered documents that represent the technological advancement of humanity [44,45]. Visualizing progress in both aspects of science allows for a more comprehensive understanding of the innovation process [46]. Through the analysis of correlation between articles and patents in this research, it is possible to state that according to research on bee mortality, *A. mellifera* has a very similar technological advance in research in both sources.

The increase in publications and patents after 2006 coincides with the increase in research on the topic of colony collapse disorder (CCD) [47]. The same authors point out that from that period onwards there was a greater awareness of the importance of bees as pollinators in modern agriculture. This fact contributed to the growth of research on the impacts of bees on the ecosystem and the consequences of their decline. All five articles with the highest number of citations in the Scopus database, discussed in Section 3.2, were published after 2006, that is, after the report of the large number of colony collapse disorder cases that occurred in 2006.

4. Conclusions

Honey bees play a fundamental role in the ecological balance of ecosystems, including agricultural production. This study aimed to develop a technological mapping of patents and articles aimed at reducing the mortality of *A. mellifera*. The main conclusions related to this study are:

- Technologies aimed at decreasing bee mortality are in the growth phase in the technology's life cycle. They present a technological maturity rate of 27.15% for patent family data and 53.35% for data from articles published in journals. The estimated time remaining to saturation is 20–29 years for published article and patent families data, respectively.
- Evidence shows that the main interest in the production of technologies and knowledge about reducing bee mortality is concentrated in universities and research centers.
- As for the publication of patent families, China is the leader, while for data on scientific articles, the USA is the main producer of knowledge.
- Of the patent families, 55.22% are linked to other special machines. It consists about technologies for equipment or improvement of hives, mainly focused on management. These families of patents are strongly related to devices to prevent attacks from mites and other pests that affect the development of the hive.
- It is also essential to develop more knowledge and technologies, focusing on reducing honey bee mortality. It is perceived that this subject of research has not attracted much attention in the industry so far.

The pollination carried out by honey bees is essential to maintaining the sustainability of agriculture, especially the cultivation of fruits and vegetables. In addition to agriculture, bees are essential for the pollination of native forests and production of honey.

Therefore, research and development of technologies or practices to reduce bee mortality represent an important mechanism for maintaining harmony between economic and environmental development.

This article develops three important contributions on the subject: First, (i) it presents the possibility of studying technological advances on the subject, both for the production of patents, including scientific articles. Second, (ii) it proves, through statistic correlation, the relation between patent production and scientific articles. Third, (iii) presents a characterization of the most relevant authors, institutions and countries, referring to the technological evolution of the subject. This research provides a discussion with the purpose of impacting the scientific community and other people in the sector, given the relevance and magnitude of the topic.

It must be noted that despite the contributions made by this research, there are some important limitations and restrictions. Not all inventions related to the prevention of honey bee mortality are patented, whether for reasons of secrecy or because it is a handcrafted/handmade technology. Knowledge can also be present in other knowledge sources, such as technical reports. The patent data considered in this research takes into account only the total number of published patent families, not taking into consideration the quality of these patents, developed with the number of citations as a measure.

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