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Review Article

Effects of Artificial Electromagnetic Fields on Bees: A Global Review

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Abstract

Background and Objective: Electromagnetic fields coming from electric and electronic devices, mobile telephony antennas, or electrical installations are continuously growing and are in direct relation with population growth. In that sense, the purpose of this investigation was to determine what are the effects of artificial electromagnetic fields on the behavior and viability of bees through a global perspective (1968-2022). **Materials and Methods:** The methodology used in this research consisted of the review of literature obtained from platforms such as Scopus, EBSCO, IEEE, Wiley, Google Scholar and Taylor & Francis. **Results:** It was possible to review 36 studies on the field and to state that investigations on this topic have increased in 2019, at a compounded annual growth rate (CAGR) of 6.86% (in a period of 54 years). Poland and USA are the leading countries in the number and importance of investigations on this topic. Keywords were grouped on the basis of the advancement of the research (honeybee, animals, *Apis mellifera* and apoideos). **Conclusion:** The study of the effects of electromagnetic fields on bees makes it possible to understand its impact on the metabolism and viability of bees.

Key words: Electromagnetic fields, impact, bees, *Apis mellifera*

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INTRODUCTION

Around the world, we can see the appearance of new technology in electronics and communication, as a result of times of change and development. It provokes higher consumption of energy¹. The exponential increase in the use of electronic devices during the last decades has created a bigger exposition to electromagnetic fields, according to their frequency^{2,3}. Electromagnetic fields are created by mobile telephony and Wi-Fi devices, which cause a negative impact⁴.

Several studies show that living beings are always in touch with electromagnetic fields of different frequency⁵, bees are not an exception⁶, this species can be found all over the world and are essential for economic activities, the production of honey and pollen are vital for the development of agriculture and human wellbeing^{7,8}. In addition, they are responsible for the pollination of 70% of all arable crops, which represent 35% of worldwide food production^{2,9,10}. For that reason, bees were considered one of the most important pollinators in the agriculture and apiculture fields^{11,12}. Bees bring pollen from stamens to pistils, which permits plants to sexually reproduce¹³. Approximately 75-95% of plant species rely on bees to sexually reproduce and increase crop production¹⁴.

However, in recent years, the bees population experienced a decrease, due to harmful and stressful factors such as plagues, monoculture, parasites, climate change and pollution (as it reduces bee colonies' health and also weakens bees' immune systems)^{15,16}, pesticides and artificial electromagnetic fields¹⁷⁻¹⁹, the latter, caused by electronic and electronic devices and electronic installations^{20,21}, will continuously grow due to the ongoing progress of technology and rising demand of electricity²². Therefore, according to some studies, these factors will affect the behavior of bees, the production of honey and the laying of eggs²³, facing this reality, bees have created both individual (humoral immunity, cellular immunity and anatomic barriers) and social defense mechanisms (behavioral immunity)²⁴.

To this date, there hasn't been set a maximum limit on the permissible amount of pollution animals can cope with. However, it is directly linked to public health^{25,26}. Every country has set its own standards for the maximum acceptance of electromagnetic fields both at home and in the environment²⁷. These standards are those established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and accepted by the World Health Organization (WHO)^{28,29}.

For that reason, the purpose of this research was to determine the effect of artificial electromagnetic fields on bees, on a global scale. To do so, four research questions have to be answered: RQ1: How much the interest in studying the

effects of artificial electromagnetic fields on bees has evolved? RQ2: What are the main countries leading the investigations on this topic? RQ3: What are the main trends found in the investigations about this topic? RQ4: What are the main effects of artificial electromagnetic fields on bees?

Search method: The literature consulted dates back from 1968, up to 2022. Boolean operators were applied, by using the following terms: "electromagnetic fields" "bees", "electromagnetic radiation" and "electromagnetic pollution". All research was made through Google Scholar, due to its capacity to compile open-access texts³⁰. Other platforms used were Ebsco, IEEE, Wiley, Taylor & Francis. Moreover, all indexed articles found in Scopus were taken into consideration, as a support of all discoveries on this topic, but only after a rigorous peer revision³¹. A total of 73 scientific articles were found, but only 36 of them were used as sources for this study.

Inclusion criteria: Publications from 1968 to October, 2022 in all languages were considered. Titles, abstracts and main results were examined to select articles of interest. The geographical scope was worldwide in order to identify all papers related to the field of study³².

Terms of exclusion: Scientific articles, books, book chapters, conferences and reviews that didn't fit the subject of study were excluded. Additionally, non-concluding studies and duplicates were not considered during the research at the database (Ebsco, IEEE, Wiley, Taylor & Francis)³³.

Compound annual growth rate (CAGR): The CAGR was a key factor in measuring economic growth³⁴. In order to describe the evolution of scientific studies, the previous 54 years were studied. Calculations were made by using a CAGR calculator³⁵. An open calculator was applied because it was easier and faster to use³³.

Data analysis: Data analysis was performed through graphs in Minitab 19.1 (Minitab, 2019), for the mapping networks (keywords, countries and co-citation) the "full count" method was used in VOS viewer v.1.6.17 software³⁶.

RESULTS

Evolution of scientific production: Taking into account the methodology applied, we can affirm that there has been a gradual growth in scientific publishing since 1968, to this date. Thus, it was stated that most scientific publications occurred in 2019, 2020 and 2021 (Fig. 1a) with 6, 5 and 7 publications

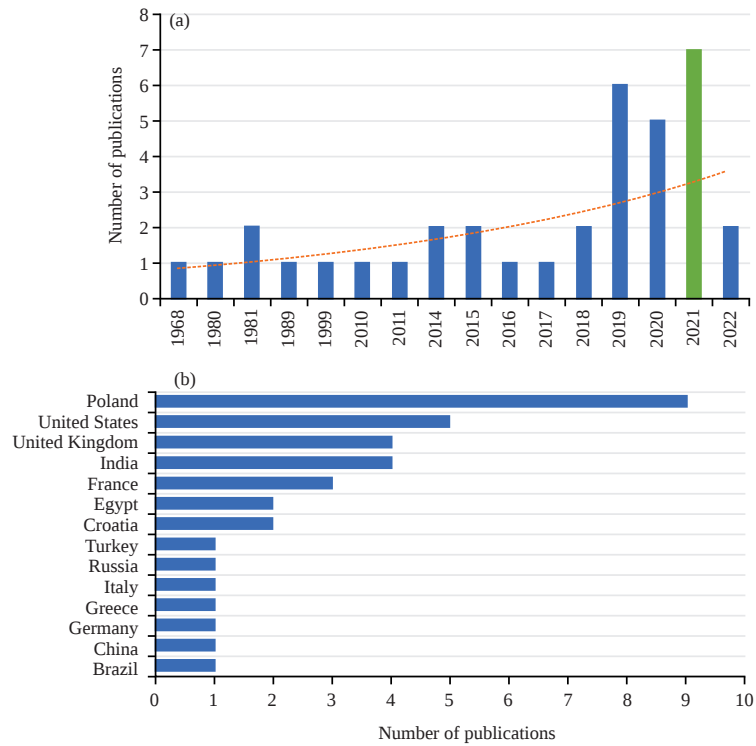


Fig. 1(a-b): Evolution of scientific production (a) Per year and (b) Per country

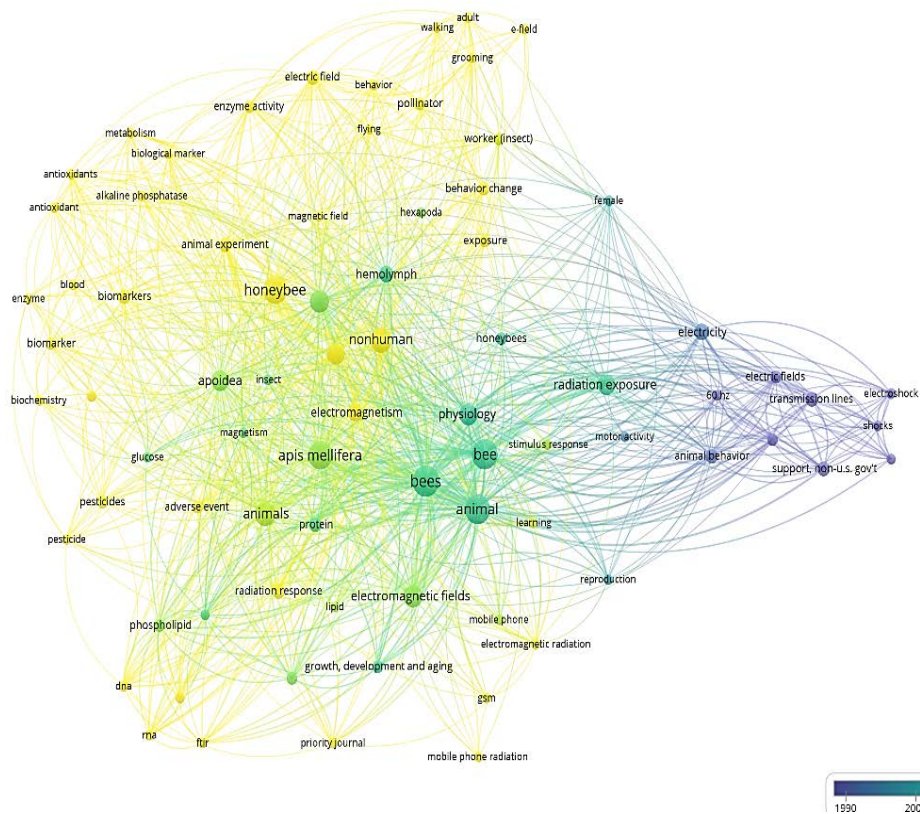


Fig. 2. Map of keywords' co-occurrence network

per year, respectively. On the contrary, the lower number of scientific publications occurred in 1968, 1980, 1989, 1999, 2010, 2011, 2016 and 2017, with only one article per year. Among the countries that conducted more research were Poland and the USA, with a total of 9 and 5 publications, respectively (Fig. 1b). In respect of CAGR-generated growth, it was possible to determine a 6.86% scientific production increase worldwide.

On the other hand, the main trends in research held through a co-occurrence network of keywords and their different types of connection, can be seen in Fig. 2. Most used words are bees, animal, *Apis mellifera* and electromagnetism. These words have a direct connection with the great number of studies about electromagnetic contaminants. Yellow nodes reflect emerging studies, in which the term honeybee stands out. While, purple nodes reflect more ancient studies.

Effects of artificial electromagnetic fields on honeybees:

There is ample evidence of the main effects electromagnetic fields cause on bees. Among them are mobile telephony antennas, mobile telephony, electric towers, electric fences and capacitor plates (Table 1). All publications made up to date let us infer that mobile telephony and capacitor plates are responsible for the most harmful effects on bees' viability. The former impacts negatively on bees' metabolism and locomotion, which consequently cause adult bees' death and even impairment in the development of larvae and pupae. The latter affects mostly cells enzymatic activity, metabolism and locomotion of adult bees. Other effects caused by electromagnetic fields are a lower capacity of learning, dynamic and flight alterations, shorter efforts to find food, DNA damage, an increase in aggressive behavior and a reduction of the production rate of larvae and eggs.

Table 1: Sources of electromagnetic field emission and the effects caused on bees

Author	Country of study	Species	Electromagnetic field emitting source	Electromagnetic field range	Phase	Effects caused
Caldwell and Russo ³⁷	United States	<i>Apis mellifera</i>	Nodes of 3001 gauss alternating current electromagnet	0.5 and 22-330 Gauss	Adulthood	Attraction is caused by the electromagnetic field
Hepworth <i>et al.</i> ³⁸	United Kingdom	<i>Apis mellifera</i>	Infrared equipment	3.75 ± 0.15 Oe (Oersted)	Adulthood	Slight changes in the ambulatory activity
Greenberg <i>et al.</i> ³⁹	United States	<i>Apis mellifera</i>	Transmission line	7 kV m ⁻¹	Adulthood	Increase of motor activity, abnormal propolis production, weight alteration Loss of queens and abnormal production of queen individual cells, decrease in the number of offspring and low rate of survival during the winter season
Greenberg <i>et al.</i> ⁴⁰	United States	<i>Apis mellifera</i>	Transmission line	7 kV m ⁻¹	Adulthood	Loss of queens and individual queen cells, weight gaining
Bindokas <i>et al.</i> ²⁰	United States	<i>Apis mellifera</i>	Isolation transformer and shifter	Greater than 400 kV m ⁻¹	Adulthood	Induced vibrations on wings, bee antennas and body hair
Kefuss <i>et al.</i> ⁴¹	France	<i>Apis mellifera</i>	Superconducting magnet, Thor Cryogenics	160, 90 and 30 µT	Adulthood	Reduction of trehalase enzymatic activity and bigger concentrations of phospholipidsam
Sharma and Kumar ⁴²	India	<i>Apis mellifera</i>	Mobile phones	8 V m ⁻¹	Adulthood	High mortality rate, less honey production
Ratan <i>et al.</i> ⁴³	India	<i>Apis mellifera</i>	Mobile phones	No mention	Adulthood	Reduction of motor activity, migration of bees, increasing concentration of biomolecules (total carbohydrate, glycogen, total lipids, cholesterol and proteins)
Mall and Kumar ⁴⁴	India	<i>Apis mellifera</i>	Electric tower and Mobile phones	345.60 mV/m y 57.70 mV m ⁻¹	Adulthood	No effects
Ferrari ⁴⁵	United States	<i>Apis mellifera</i>	Magnets	≤0.2 × 10 ⁻⁶ T y ≥2.0 × 10 ⁻⁶ T	Adulthood	Decreasing rate of return of bees to beehives
Shweta and Pramod ⁴⁶	India	<i>Apis mellifera</i>	Mobile telephony tower	541.22 µA m ⁻¹	Adulthood	No effects
Darney <i>et al.</i> ⁴⁷	France	<i>Apis mellifera</i>	Two radio wave generators, whether high frequency and ultra-high frequency	13.56 MHz y 868 MHz	Adulthood	Increase of mortality rate
Lázaro <i>et al.</i> ⁴⁸	Greece	<i>Apis mellifera</i>	Telecommunication antenna	0.010-0.556 V m ⁻¹	Adulthood	More abundance
Vilić <i>et al.</i> ⁴⁹	Croatia	<i>Apis mellifera</i>	Mobile phones	10, 23, 41 and 120 V m ⁻¹	Larvae	Decrease on catalase activity and peroxide level, DNA damages
Migda <i>et al.</i> ⁵⁰	United Kingdom	<i>Apis mellifera carnica</i>	Amateur antennas	7 V m ⁻¹	Adulthood	No effects

Table 1: Continue

Author	Country of study	Species	Electromagnetic field emitting source	Electromagnetic field range	Phase	Effects caused
Shepherd <i>et al.</i> ²¹	United Kingdom	<i>Apis mellifera</i>	Transmission line	20-100 μ T and 1000-7000 μ T	Adulthood	Lower capacity of learning, alteration off light dynamics, reduction of flying success rate on the search of food
Erdoğan ⁵¹	Turkey	<i>Apis mellifera</i>	Electric fence	251.7 mV m ⁻¹	Adulthood	Decrease of flight activity, weight gaining and increase of aggressive behavior
Favre and Johansson ⁵²	Poland	<i>Apis mellifera carnica</i>	Coil	0.1 - 8 mT	Adulthood	Low survival capacity and locomotive activity
Lopatina <i>et al.</i> ⁵³	Russia	<i>Apis mellifera</i>	LinkSys E1200-EE/RU Router Wi-Fi	2.4 GHz	Adulthood	Reduction of pollinator activity
Odemer and Odemer ⁵⁴	Germany	<i>Apis mellifera</i>	Mobile phones (AEG M1220)	0.95 - 3.79 V m ⁻¹	Larvae and pupae	Reduction of the hatching rate of larvae and alteration of pupae formation
Shepherd <i>et al.</i> ⁵⁵	United Kingdom	<i>Apis mellifera</i>	Helmholtz coil	100 and 1000 μ T	Adulthood	Reduction of aversive learning, increase of aggressive behaviour
Gagnaire <i>et al.</i> ⁵⁶	France	<i>Apis mellifera</i>	137Cs liquid source contained in a polystyrene tube (20 MBq in HCl 0.1 M) and a 137Cs line solid source (1.85 GBq)	4.38 $\times 10^{-3}$ a 588 mGy/d	Adulthood	Decrease of immune (phenol oxidase -PO, carboxylesterase metabolism -CaEs, alkaline phosphatase -ALP) and antioxidant (acetylcholinesterase -AChE, antioxidant catalase-CAT, superoxide dismutase-SOD, glutathione peroxidase-GPx, glutathione-S-transferase-GST) systems biomarkers
Migdał <i>et al.</i> ⁵⁷	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	5.0, 11.5, 23 and 34.5 kV m ⁻¹	Adulthood	Increase on dismutase superoxide (SOD) activity and proteolytic systems Decrease of antioxidant power capable of reduce ferric ions (FRAP)
Migdał <i>et al.</i> ⁵⁸	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	5.0, 11.5, 23 and 34.5 kV m ⁻¹	Adulthood	Increase on dismutase superoxide (SOD) system, catalase (CAT) and antioxidant power capable of reduce ferric ions
Koziorowska <i>et al.</i> ⁵⁹	Poland	<i>Apis mellifera</i>	Magneris electricity generator	1.6 mT	Adulthood	Change on chemical compounds (DNA, RNA, phospholipides and protein vibrations)
Lupi <i>et al.</i> ⁶⁰	Italy	<i>Apis mellifera</i>	Electricity line	132 kV	Adulthood	Enzymatic overactivation: acetylcholinesterase (AChE), catalase (CAT), glutathione S-transferase (GST) and Alkaline Phosphatase (ALP)
Vale and Acosta-Avalos ⁶¹	Brazil	<i>Tetragonisca angustula</i>	Magnets	80 μ T	Adulthood	Flight direction
Migdał <i>et al.</i> ⁶²	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	5.0, 11.5, 23.0 and 34.5 kV m ⁻¹	Adulthood	Difficulty to walk, fly, groom and keep contact with peers. Bigger protease activity
Mahmoud and Gabarty ⁶³	Egypt	<i>Apis mellifera</i>	Mobile phones (Samsung F400)	No mention	Adulthood	Damage to stomach cells and increase of Mg, Ca, Zn and Fe levels
Migdał <i>et al.</i> ⁶⁴	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	5.0, 11.5, 23.0 and 34.5 kV m ⁻¹	Adulthood	Decrease of the movement of wings, difficulty to walk and groom
Migdał <i>et al.</i> ⁶⁵	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	<1, 5.0, 11.5, 23.0 and 34.5 kV m ⁻¹	Adulthood	Decrease of aspartate aminotransferase (AST) activity, Alanine Aminotransferase (ALT) and alkaline phosphatase (ALP) levels on hemolymph. Alteration of creatinine and albumin concentrations
Migdał <i>et al.</i> ⁶⁶	Poland	<i>Apis mellifera carnica</i>	Plate capacitor	5.0, 11.5, 23.0 and 34.5 kV m ⁻¹	Adulthood	Higher concentration of proteins, lower concentration of glucose and triglycerides
Vilic <i>et al.</i> ⁶⁷	Croatia	<i>Apis mellifera</i>	Microwave oven	23 V m ⁻¹	Adulthood	Decrease of S-transferase glutathione activity and increase of catalase activity
Sawires <i>et al.</i> ⁶⁸	Egypt	<i>Apis mellifera carnica</i>	Cesium source Cs137	20, 50, 100, 150 and 200 rad	Adulthood	Increase of fatty acids (linoleic, oleic and palm) and food-searching activity
Migdał <i>et al.</i> ⁶⁹	Poland	<i>Apis mellifera carnica</i>	Solenoid	1 and 1.7 mT	Adulthood	Alteration of behavioral patterns
Li <i>et al.</i> ⁷⁰	China	<i>Apis cerana</i>	Generador (Litian Magnetoelctrican Science & Technology, Co., Ltd.)	3 mT	Larvae	Decrease of survival rate and body weight. Prolongation of the period of growth Decrease on the metabolic process of nutrients and energy

DISCUSSION

Most of the 36 articles that focus on the effects electromagnetic fields can cause on bees date back to 2019, 2020 and 2021. These articles were indexed on high impact magazines (Scopus), being Poland and USA the leading countries. On the other hand, the lower number of scientific publications occurred in 1968, 1980, 1989, 1999, 2010, 2011, 2016 and 2017. Interest on conducting a research about electromagnetic fields and bees is directly linked to the increase of scientific evolution in recent years. This may be because of the interest on supervising and managing the effects electromagnetic fields cause on society and the environment⁷¹ and because of an increase on the number of radiant devices and data transmission rates over radio frequency channels⁷².

Studies show that the bigger sources of electromagnetic field are transmission lines and mobile telephony, due to worldwide demand, urban expansion and the appearance of new technology^{73,74}, this represents a latent risk to pollinators and pollination⁷⁵. Experimental studies conducted on laboratories have stated that insects can track electromagnetic fields and go through them, which affect their behavior, cell development and physiological function⁷⁶⁻⁷⁸ moreover, a few numbers of studies indicated that it can also affect bees' reproduction and development^{79,80}.

Poland has conducted most of the studies about this topic, due to the importance their population give to bees and because they have a great amount of bee colonies, in 2020 there was a total of 1,766,000 bee colonies in Poland, which positioned the country among the top five countries that have bee colonies⁸¹. The United States is the second leading country in the number of scientific researches about this topic, which could be linked to the great interest researchers have on finding new solutions that help fight the extinction of American bees (*Bombus pensylvanicus*)^{82,83}.

Keywords clusters "honeybee", "animals", "*Apis mellifera*", "apoideos" are mostly related to the number of studies that were published in the past 12 years (2010-2022), because there is special interest on preserving bees and because of major efforts to understand the cause of bees' behavior⁸⁴.

Apis mellifera or European bee is the most preferred type of bee for honey production and pollination of crops⁸⁵, additionally, because of having the bigger number of populations, this bee species is the most studied⁸⁶. According to the Center for the Biological Diversity, Fish and Wildlife Service, one of the major threats and causes of the extinction of bees is radiofrequency radiation⁸⁷. It has been proved that bees' navigation and dispersion patterns are

affected by electromagnetic fields²¹. For that reason, it is important to create awareness of the need of preserving bees. Failure to do so could cause a catastrophic population breakdown⁸⁸.

Finally, it was affirmed that there is bigger interest on studying the effects of electromagnetic fields on bees and that, according to reviewed literature, electromagnetic fields have a big impact on the behavior of viability of bees, which could result on their extinction.

CONCLUSION

Since 2019, there has been more interest on developing studies about bees, especially in Poland, which leads investigations about the effects of electromagnetic fields in bees. Studies have shown transmission lines and mobile telephony are the main sources of such effects on bees. Additionally, studies conclude that bees' growth and behaviour can also be affected. Therefore, it is necessary to broaden the frequency of monitoring, in order to create scientific knowledge as a supporting tool of apiculture. That way human society can also be benefitted.

SIGNIFICANCE STATEMENT

The objective of the work was to determine the effects of artificial electromagnetic fields on bees through a global review, the main results found indicated that the leading countries in research are Poland and the United States. The bees are affected in their behavior, cellular development, physiological function and reproduction, on the other hand, these results are important to ensure the correct surveillance of honey bee populations.

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