# EXPERIMENTAL APPLICATIONS OF NATURAL AND TECHNOLOGICAL DRUGS WITH HONEY BEES: STATUS, OPPORTUNITIES AND CHALLENGES

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## ABSTRACT

Beekeeping is a field of study that requires considerable attention due to both workload and easy effects from environmental factors. The intensive coexistence in culture and the preference of yield-based breeds increase the frequency of various bee diseases. These diseases and their control can be quite difficult with the effects of climate change. Existing bee diseases can be caused by more than one microorganism group such as parasites, fungi, bacteria and viruses. Although there are various chemicals for the control of microbial diseases, these chemicals can cause problems such as environmental damage or residues in bee products, and even there are completely banned chemicals (OTC etc.). An alternative method of control is the deployment of natural or technological (micro or nano technological) products that are completely harmless or do not leave residues. The application of these products should be done directly in the field and with bee colonies rather than in laboratory conditions. In this case, it is quite easy to apply to honey bees in colonies in hives and it can be practical to get the results. However, environmental conditions (wind, rain, amount of flowers and nectar, etc.) and uncontrolled parameters can produce results far from standard work.

**Keywords:** honey bee, beekeeping, bee diseases, technological drugs.

# DOĞAL VE TEKNOLOJİK İLAÇLARIN BAL ARILARI İLE DENEYSEL UYGULAMALARI: DURUM, FIRSATLAR VE ZORLUKLAR

## ÖZET

Arıcılık, hem iş yükü hem de çevresel etkenlerden kolay etkilenmesi nedeniyle oldukça dikkat gerektiren bir çalışma alanıdır. Kültürde yoğun bir arada bulunma ve verime dayalı ırkların tercih edilmesi çeşitli arı hastalıklarının sıklığını artırmaktadır. Bu hastalıklar ve bunların kontrolü iklim değişikliğinin etkileriyle oldukça zorlaşabilmektedir. Mevcut arı hastalıkları parazitler, mantarlar, bakteriler ve virüsler gibi birden fazla mikroorganizma grubundan kaynaklanabilmektedir. Mikrobiyal hastalıkların kontrolü için çeşitli kimyasallar bulunmasına rağmen bu kimyasallar çevresel hasar veya arı ürünlerinde kalıntı gibi sorunlara yol açabilmekte, hatta tamamen yasaklanmış kimyasallar (OTC vb.) dahi bulunmaktadır. Alternatif bir kontrol yöntemi ise tamamen zararsız veya kalıntı bırakmayan doğal veya teknolojik (mikro veya nano teknolojik) ürünlerin kullanılmasıdır. Bu ürünlerin uygulanması laboratuvar koşullarından ziyade doğrudan sahada ve arı kolonileriyle yapılmalıdır. Bu durumda kovanlardaki kolonilerde bal arılarına uygulanması oldukça kolay olup sonuç almak pratik olabilir. Ancak çevresel koşullar (rüzgâr, yağmur, çiçek ve nektar miktarı vb.) ve kontrolsüz parametreler standart çalışmalardan uzak sonuçlar ortaya çıkarabilmektedir.

**Anahtar Kelimeler:** bal arısı, arıcılık, arı hastalıkları, teknolojik ilaçlar

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## 1. INTRODUCTION

Honey bees (*Apis mellifera*) play a pivotal role in both ecological stability and economic prosperity. Ecologically, they are indispensable pollinators, supporting the reproduction of countless flowering plants and maintaining biodiversity across ecosystems (Ahmed, 2023). Their pollination activities not only ensure the survival of wild plant species but also maintain habitats for numerous other organisms, making them critical contributors to ecological balance (Potts et al., 2016). Furthermore, *A. mellifera* serve as bioindicators, reflecting the health of their environments and highlighting issues such as pollution and habitat degradation (Quigley et al., 2019). Economically, *A. mellifera* significantly enhance agricultural productivity by pollinating crops essential for global food security (Malav et al., 2022). Their contributions extend beyond the farm, fueling industries reliant on high-quality fruits, vegetables and oilseeds while also underpinning the beekeeping sector, which produces valuable commodities such as honey, beeswax and royal jelly (Genç & Dodoloğlu, 2017).

The history of combating bee diseases and pest control is closely intertwined with the evolution of beekeeping practices and scientific advancements. In the early days of apiculture, beekeepers relied on simple, natural methods to maintain colony health. Smoking, for example, was used not only to calm bees during hive inspections but also as a rudimentary measure to ward off pests (Langstroth, 2004). Other traditional remedies, such as the use of herbs and plant extracts, were employed based on empirical knowledge passed down through generations.

As beekeeping became more systematic in the late 19th and early 20th centuries, the identification of specific diseases and pests such as American foulbrood (*Paenibacillus larvae*) and tracheal mites (*Acarapis woodi*) spurred efforts to develop targeted treatments (Genç & Dodoloğlu, 2017). Early interventions often involved mechanical approaches, like destroying infected hives, to prevent the spread of pathogens (Rossi et al., 2018). However, these methods were labor-intensive and economically unsustainable for large-scale operations.

The mid-20th century marked a turning point with the introduction of synthetic chemicals for pest control. Coumaphos, fluvalinate, flumethrin, formamidine and amitraz became widely used to combat Varroa destructor mites and other threats (Mitton et al., 2022). These chemicals were effective in the short term but came with significant drawbacks, including the development of resistance in pests, the potential toxicity to bees and the contamination of hive products such as honey and wax (Lodesani & Costa, 2005). Increasing awareness of these issues in the late 20th century led to a shift in focus towards safer and more sustainable solutions.

The concept of Integrated Pest Management (IPM) emerged as a cornerstone of modern beekeeping. IPM combines chemical treatments with cultural practices, biological controls and mechanical interventions to reduce dependence on harmful pesticides. Natural substances such as oxalic acid, formic acid and essential oils gained popularity because of their lower environmental impact and reduced risk to bee health (Bava et al., 2023).

Today, research focuses on developing innovative solutions, including biotechnological and nanotechnological interventions, to address the growing challenges posed by bee diseases and pests. This evolution reflects the on going quest for sustainable and effective methods to protect *A. mellifera* health.

## 2. Natural And Organic Drugs In Beekeeping

Natural and organic compounds are increasingly being used in beekeeping as sustainable and environmentally friendly alternatives to synthetic treatments (Cengiz, 2012). These remedies are derived from natural sources such as plants, minerals and organic acids. The remedies are valued for their lower toxicity, minimal environmental impact and reduced likelihood of contaminating hive products like honey and wax.

Nowadays, as organic feeding becomes increasingly important, synthetic acaricides used in Varroa control are being replaced by organic acids, which are natural components of honey (Wehling et al., 2003). In the control of Varroa mites, the use of organic compounds that have no toxic effects on humans and bees can be an effective solution to this serious problem. Organic acids such as oxalic acid, formic acid and lactic acid are the most commonly used organic compounds against the Varroa parasite today. When applied at the appropriate time and dose, these organic acids do not cause queen losses in colonies or have negative effects on adult bees and brood populations (Milani, 1999; Goodwin et al., 2002).

Oxalic acid, which is naturally found in many plants, only kills Varroa on adult bees (Qadir et al., 2021) and is not effective on closed brood cells. For this reason, its use in early spring and late autumn, when closed brood cells are the least, gives successful results. It is reported that this use provides 90-95% success (Nanetti, 1999; Paradin et al., 2000). In case of high doses and multiple repetitions of oxalic acid, it can cause loss of queen and adult bees in the colony (Gerogorc and Planic, 2001). Formic acid has been used in Varroa control in other European countries, especially in Germany, since 1980. It is stated that the effectiveness of the acid varies between 60-92% depending on the application method (Imdorf et al., 1997). In order to see the desired effect in Varroa control with formic acid, the application temperature is important and the high or low environmental temperature is effective in success. In order to achieve the desired success, the air temperature should be between 10-25 ºC (Akyol & Özkök, 2005). Since lactic acid does not affect the closed brood cells, it gives successful results in Varroa control in the early spring and late autumn periods when the brood population in the colony is at its lowest (Imdorf & Kilchenmann, 1990).

Essential oils have gained popularity as natural alternatives the control of Varroa destructor mites in A. mellifera colonies due to their effectiveness, safety and minimal environmental impact (Bava et al., 2023). Among these, thymol, derived from thyme plants, is the most widely used. Thymol disrupts mite activity and reproduction, often incorporated into commercial formulations like Apiguard. Its vapor action works well at warmer temperatures, making it effective during active beekeeping seasons (Giacomelli et al., 2016).

Other essential oils, such as menthol, eucalyptus and camphor, also show potential against Varroa mites. Menthol is particularly effective against tracheal mites, while eucalyptus and camphor oils act as repellents or fumigants to reduce mite loads (Singh, 2014). Essential oils are commonly used in treated pads, strips or sugar syrups to enhance their dispersion within the hive. Essential oils like thymol, lemongrass and eucalyptus have antifungal properties that help control *Nosema apis* and *N. ceranae* infections (Topal et al., 2020).

## 3. Technological Drugs And Approaches In Beekeeping

Recent advances in science and technology have revolutionized the development of drugs and strategies to protect A. mellifera from pests, diseases and environmental challenges. These technological approaches aim to provide more precise, effective and sustainable solutions, reducing the reliance on traditional chemical treatments and addressing the growing threats to bee health.

Biotechnology has introduced novel methods for managing A. mellifera health, such as RNA interference (RNAi). RNAi works by silencing specific genes in pests like Varroa destructor, disrupting their biological functions and ultimately leading to their death (McGruddy et al., 2024). This approach is highly specific, targeting only the pest while leaving

A. mellifera and other beneficial organisms unharmed. Additionally, research into genetically engineered bees with enhanced resistance to diseases and environmental stressors is gaining momentum, offering a potential long-term solution to colony losses (Guichard et al., 2023).

Nanotechnology offers innovative tools for drug delivery and pest control. Nanoparticles are used to encapsulate and deliver active ingredients such as acaricides or antimicrobial agents directly to target areas within the hive (Gamal Eldin et al., 2024). These systems allow for controlled release, minimizing dosage and reducing side effects on bees and the environment. Nanotechnology is also being used to combat diseases such as Nosema, American and European foulbrood (Santos et al., 2014; Özüiçli et al., 2023).

Technological advancements have led to the development of smart hives equipped with sensors to monitor environmental conditions, colony health, and hive activity in real-time. These systems collect data on temperature, humidity, brood development and foraging behavior, providing beekeepers with actionable insights. Early detection of anomalies, such as pest infestations or diseases, allows for timely and targeted treatments, reducing colony losses and improving management efficiency (Zheng et al., 2024).

Modern drug formulations are being designed to enhance specificity and efficacy while reducing side effects. For instance, slow-release strips impregnated with acaricides or essential oils ensure sustained mite control with minimal exposure to bees. Similarly, probiotics tailored for A. mellifera are being developed to improve gut health and enhance immunity, particularly after exposure to antibiotics or pesticides.

## 4. Opportunities In Beekeeping Research Today

Beekeeping research is flourishing as the global awareness of the critical role bees play in ecosystems and agriculture continues to grow. One of the most promising areas is the development of sustainable pest management solutions.

Another significant opportunity lies in the study of A. mellifera genetics and breeding programmes. Advances in genomics and molecular biology allow researchers to identify and propagate traits that enhance disease resistance, productivity and adaptability to climate change. Breeding efforts now focus not only on increasing honey yields but also on creating bees that are resilient in diverse environments and sustainable for local ecosystems.

The impacts of climate change on A. mellifera populations present another urgent research frontier. Scientists are investigating how shifting temperatures, altered blooming periods, and extreme weather events affect bee behavior, physiology and colony health. By understanding these impacts, researchers can develop mitigation strategies, such as adaptive foraging models and climate-resilient beekeeping practices.

Research into bee products and their applications offers expanding opportunities in both human and animal health. Studies on the bioactive compounds in honey, propolis, royal jelly and bee venom. These items are uncovering their potential uses in medicine, nutrition and even industrial applications. Similarly, there is increasing interest in how bee-derived products can contribute to sustainable agriculture and livestock management, such as their potential role as natural antibiotics or growth enhancers.

Finally, the integration of technology into beekeeping is revolutionizing the field. Smart hives equipped with sensors and artificial intelligence enable real-time monitoring of hive health, temperature, humidity and bee activity. These tools not only improve management practices but also provide rich datasets for researchers to analyze trends and predict colony outcomes. This intersection of traditional beekeeping and modern technology ensures a more efficient and sustainable future for apiculture.

Beekeeping research today is a vibrant, interdisciplinary field with numerous opportunities to address global challenges. By harnessing scientific advancements and fostering collaboration across sectors, the potential to enhance the health and sustainability of bee populations and their ecosystems is immense.

## 5. Challenges In Beekeeping Research

While natural, organic, and technological approaches in beekeeping offer promising solutions for managing pests, diseases and environmental stressors, they also present a number of challenges. These difficulties must be addressed to fully realize the potential of these innovations and ensure their successful implementation in apiculture.

One of the primary challenges is the variability in effectiveness of natural and organic treatments. Factors such as environmental conditions, colony size and the specific pest or disease being targeted can significantly influence the efficacy of these methods. For example, essential oils and organic acids require precise dosing and application to achieve desired results without harming bees or leaving residues in hive products. In addition, these natural remedies may not provide immediate or complete control, requiring repeated applications or integration with other methods.

The adoption of technological approaches also faces hurdles, particularly for small-scale and traditional beekeepers. Advanced technologies like smart hives, RNA interference, and nanotechnology-based treatments often involve high initial costs, complex maintenance, and the need for specialized knowledge. These factors can limit accessibility and scalability, especially in developing regions where resources and technical expertise may be scarce.

Another significant issue is the potential for unintended side effects. Even natural and organic compounds can disrupt hive dynamics if misused. For instance, excessive use of essential oils might alter bees' behavior or interfere with queen pheromones, while improper application of organic acids can harm brood or adult bees. Similarly, technological solutions like nanoparticle-based drugs must be carefully tested to ensure they do not pose long-term risks to bees, other pollinators or the environment.

Regulatory and market challenges also present obstacles. The approval process for new natural and technological treatments can be lengthy and costly, delaying their availability to beekeepers. Furthermore, some beekeepers may hesitate to adopt these methods due to a lack of clear evidence or education about their benefits and limitations. Misinformation or skepticism about emerging technologies can further slow adoption rates.

Another difficulty is the need for extensive research and development. Many natural and technological approaches are still in experimental stages, requiring extensive studies to optimize their application and assess their long-term impacts. Limited funding and resources for apicultural research can hinder progress, especially in addressing region-specific challenges such as local pests, diseases and environmental conditions.

Finally, climatic and ecological variations can complicate the implementation of these approaches. The effectiveness of treatments like organic acids and essential oils may fluctuate with temperature, humidity, and other climatic factors. Additionally, changes in agricultural practices, pesticide use and habitat availability can influence the success of natural and technological solutions.

## 6. CONCLUSION

Natural, organic and technological approaches represent a transformative shift in beekeeping, offering innovative solutions to address the pressing challenges facing by *A. mellifera* populations. These methods have significant potential to improve colony health, increase productivity and reduce the environmental and health risks associated with conventional chemical treatments.

Despite the difficulties, the opportunities presented by these approaches far outweigh the challenges. They offer not only immediate solutions to pest and disease management, but also long-term strategies to enhance the resilience of *A. mellifera* colonies in the face of climate change and environmental pressures. By embracing these advancements, the beekeeping industry can safeguard *A. mellifera* populations, support biodiversity and ensure the continuation of vital pollination services critical to global ecosystems and agriculture. Natural, organic and technological approaches will play a key role in shaping the future of sustainable beekeeping.

## Additional Information

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