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ARI VE ARICILIK TEKNOLOJİLERİ DERGİSİ

Amaç ve Kapsam

Aims and Scope

Arı ve Arıcılık Teknolojileri Dergisinin amacı, arı, arıcılık ve arıcılık teknolojileri üzerine etik kurallara uygun olarak hazırlanan bilimsel çalışmaların aktarılması, böylelikle arı ve arıcılık teknolojileri arasında yeni fikirlerin oluşumunun sağlanmasıdır. Bu kapsamda dergi ifade edilen alanda araştırma makalelerinin, derleme çalışmalarının, olgu sunumlarının ve editöryel mektupların yayınlanması amacını gütmekle birlikte bu alanda literatüre katkı sağlayarak konu üzerine bilimsel tartışmaların gerçekleştirilmesine hizmet etmeyi hedeflemektedir. Bu amaçlar doğrultusunda rahatlıkla ulaşılacağının tahmin edildiği diğer bir amaç ise arı ve arıcılık teknolojileri alanındaki araştırma ve geliştirme faaliyetlerinin ve bu konudaki bilgi paylaşımlarının artacağıdır. Bu kapsamda dergi arı ve arıcılık teknolojilerine dair tüm disiplinleri kapsamakla birlikte bu disiplinlerde çalışan uzman ve araştırmacıları temel hedef kitlesi olarak belirlemektedir.

Arı ve Arıcılık Teknolojileri Dergisi, Bayburt Üniversitesi Arıcılık Araştırma Geliştirme Uygulama ve Araştırma Merkezi tarafından oluşturulmuş olan ulusal, bilimsel, tarafsız, açık erişimli ve akademik resmi bir dergidir. Derginin kapsamı arı ve arıcılık teknolojilerine yönelik tüm disiplinlerden oluşmakla birlikte bu disiplinler çatısı altında oluşturulmuş etik kurallara uygun araştırma makaleleri, derleme makaleler, editör mektupları ve editöryel yazılardan oluşmaktadır. Arı ve Arıcılık Teknolojileri Dergisinde değerlendirilecek ve yayınlanacak makaleler Dergipark ve https://ojs.bayburt.edu.tr/index.php/aricilik internet sitesi üzerinden PDF formatında yayınlanacaktır. Dergi elektronik ortamda ve yılda iki kez yayımlanmaktadır. Dergi Türkçe ve İngilizce dilinde yayımlanmaktadır. Yayımlanan bilimsel çalışmaların dil, bilim, yasal ve etik sorumluluğu yazarlara aittir.

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DERLEME
REVİEW

FROM FLOWER TO FOOD: HONEY BEES AND THEIR ROLE IN CROP PRODUCTION

Muhammad Yasir NAEEM[1], Zeliha SELAMOGLU[2,3*]

ABSTRACT

Honey bees (*Apis mellifera*) are fundamental to the functioning of global agricultural systems, providing essential pollination services that significantly enhance crop yields, quality, and economic value. As key pollinators, honey bees facilitate the reproduction of many flowering plants and crops, making their role crucial for both biodiversity and agriculture. This review examines the multifaceted contributions of honey bees to agriculture, highlighting their critical role in the pollination of key crops including fruits, vegetables, nuts, and oilseeds. Empirical studies reveal that honey bee pollination can lead to substantial increases in agricultural productivity: up to 20% for apples, 80% for blueberries, and 33% for cucumbers. Additionally, honey bee activity is vital for high-value crops such as almonds and canola, with reported yield increases of 40% and 25% in nut set and oil content, respectively. Despite their importance, honey bee populations are under severe threat from a range of challenges including pesticide exposure, habitat loss, diseases, parasites, and climate change. These stressors compromise bee health and pollination efficiency, with potential negative repercussions for agricultural productivity and food security. Addressing these challenges requires a multifaceted approach encompassing improved agricultural practices, habitat restoration, and integrated pest management. This review underscores the urgent need for concerted efforts to support and sustain honey bee populations to ensure the continued provision of their vital pollination services, which are crucial for the stability and productivity of global agricultural systems.

Keywords: Honey Bees, Pollination Services, Agricultural Productivity, Crop Yields, Bee Health

ÇİÇEKTEN GIDAYA: BAL ARILARI VE ÜRÜN ÜRETİMİNDEKİ ROLÜ

ÖZET

Bal arıları (*Apis mellifera*), mahsul verimini, kalitesini ve ekonomik değeri önemli ölçüde artıran temel tozlaşma hizmetlerini sağlayarak küresel tarım sistemlerinin işleyişi için temel öneme sahiptir. Temel tozlaştırıcılar olarak bal arıları, birçok çiçekli bitki ve mahsulün üremesini kolaylaştırır ve rollerini hem biyolojik çeşitlilik hem de tarım açısından hayati hale getirir. Bu inceleme, bal arılarının tarıma çok yönlü katkılarını inceleyerek meyveler, sebzeler, kabuklu yemişler ve yağlı tohumlar gibi önemli mahsullerin tozlaşmasındaki kritik rollerini vurguluyor. Ampirik çalışmalar, bal arısı tozlaşmasının tarımsal üretkenlikte önemli artışlara yol açabileceğini ortaya koyuyor: elma için %20'ye, yaban mersini için %80'e ve salatalık için %33'e kadar. Ek olarak, badem ve kanola gibi yüksek değerli mahsuller için bal arısı faaliyeti hayati önem taşıyor; fındık tutumunda ve yağ içeriğinde sırasıyla %40 ve %25 oranında verim artışı rapor ediliyor. Önemlerine rağmen, bal arısı popülasyonları pestisit maruziyeti, habitat kaybı, hastalıklar, parazitler ve iklim değişikliği gibi çeşitli zorluklar nedeniyle ciddi tehdit altındadır. Bu stres etkenleri, arı sağlığını ve tozlaşma verimliliğini tehlikeye atıyor ve tarımsal üretkenlik ve gıda güvenliği açısından potansiyel olumsuz sonuçlar doğuruyor. Bu zorlukların üstesinden gelmek, gelişmiş tarım uygulamalarını, habitat restorasyonunu ve entegre zararlı yönetimini kapsayan çok yönlü bir yaklaşımı gerektirir. Bu inceleme, küresel tarım sistemlerinin istikrarı ve üretkenliği için hayati öneme sahip olan hayati tozlaşma hizmetlerinin sürekli olarak sağlanmasını sağlamak amacıyla bal arısı popülasyonlarını desteklemek ve sürdürmek için ortak çabalara duyulan acil ihtiyacın altını çiziyor.

Anahtar Kelimeler: Bal Arıları, Tozlaşma Hizmetleri, Tarımsal Verimlilik, Ürün Verimi, Arı Sağlığı

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1. INTRODUCTION

Honey bees (*Apis mellifera*) play an essential role in modern agriculture, providing crucial pollination services that underpin the productivity and diversity of many crops (Divekar et al., 2023). Their contribution extends beyond the production of honey, positioning them as vital agents in the pollination of a vast array of agricultural plants. Pollination, the transfer of pollen from the male anther to the female stigma of flowers, is a fundamental ecological process that enhances the reproductive success of flowering plants, thereby directly impacting fruit, vegetable, and nut yields (Osman and Shebl, 2020).

Approximately 75% of the world's leading crops benefit from animal pollination, with honey bees being the primary pollinators (Khalifa et al., 2021). The economic value of their pollination services is substantial, with estimates placing it in the range of hundreds of billions of dollars annually. For instance, crops such as apples, almonds, blueberries, and cucumbers rely heavily on honey bee pollination to achieve optimal yields and quality (Mashilingi et al., 2022). The dependency of these crops on honey bees highlights the bees' integral role in both agriculture and food security (Osman and Shebl, 2020; Requier et al., 2023).

However, honey bees are facing unprecedented challenges that threaten their populations and, consequently, agricultural productivity. Pesticide exposure, particularly from neonicotinoids, has been shown to impair bee health and foraging behaviour (Leska et al., 2021). Habitat loss due to urbanization, intensive farming practices, and climate change further exacerbates the decline in bee populations by reducing the availability of forage and nesting sites. Additionally, diseases and parasites such as *Varroa destructor* mites, *Nosema spp*., and the phenomenon known as Colony Collapse Disorder (CCD) pose significant threats to bee colonies, leading to high mortality rates and reduced pollination efficiency (Kline and Joshi, 2020; Leska et al., 2021).

This review aims to provide a comprehensive overview of the role of honey bees in crop production. It will examine the mechanisms of pollination, quantify the economic impact of pollination services, and explore the various challenges honey bees face. Additionally, it will highlight current and emerging strategies to support bee populations and ensure the sustainability of their pollination services. By synthesizing the latest scientific research, this review underscores the critical importance of protecting honey bee populations to maintain agricultural productivity and food security.

1.1.Mechanisms of Pollination by Honey Bees

Honey bees are highly effective pollinators due to their unique biological and behavioral characteristics. Their role in pollination begins with foraging behavior, where worker bees collect nectar and pollen from flowers to bring back to their hive (Khalifa et al., 2021). During this process, bees inadvertently transfer pollen from the anthers (male reproductive parts) of one flower to the stigma (female reproductive part) of another, facilitating cross-pollination, which is critical for genetic diversity and fruit set in many plants (Zariman et al., 2022).

1.2.Key Crops Dependent on Honey Bee Pollination

Honey bees are crucial to the successful cultivation of various crops, significantly impacting yield, quality, and economic value. Their role in pollination is essential across numerous agricultural sectors, with scientific studies highlighting their importance (Mashilingi et al., 2022).

1.2.1. **Fruits**

Honey bee pollination is vital for many fruit crops. For example, apple (*Malus domestica)* orchards show a marked increase in fruit set and quality with honey bee activity (Pardo and Borges, 2020). According to Weekers et al. (2022), apple yields can increase by up to 20% with the presence of honey bees. Stone fruits such as cherries (*Prunus avium*) and peaches (*Prunus persica*) also benefit significantly. Research by Joshi et al. (2021) showed that honey bees are responsible for up to 90% of the cross-pollination needed for these fruits. In blueberries (*Vaccinium spp.)*, honey bees can boost yields by up to 80% (Dufour et al., 2020). This is due to their efficient pollen transfer between flowers, enhancing fruit size and set.

1.2.2**. Vegetables**

Honey bees play a crucial role in the pollination of vegetables. Cucumbers (*Cucumis sativus),* for instance, produce better-shaped fruits with fewer deformities when pollinated by honey bees (Kumar et al., 2024). Ramello et al. (2024) reported that honey bee-pollinated cucumbers showed a 33% increase in yield compared to non-bee-pollinated crops. Pumpkins (*Cucurbita pepo*) and melons (*Cucumis melo*) also benefit from bee pollination, with research by Kiatoko et al. (2022) revealing a 25% increase in melon fruit weight and a 30% increase in sweetness.

1.2.3**. Nuts**

The almond industry (Prunus dulcis) heavily depends on honey bees. In California, over 2 million honey bee colonies are brought in annually to pollinate almond orchards, which produce about 80% of the world's almonds (Durant and Ponisio, 2021). Bommarco et al. (2012) found that honey bee pollination results in a 40% increase in almond nut set and a 30% increase in yield. Similarly, honey bee pollination enhances the production and quality of macadamia nuts (Macadamia integrifolia) and pistachios (Durant and Ponisio, 2021).

1.2.4**. Other Important Crops**

Honey bees are also essential for oilseed crops like canola (Brassica napus) and sunflowers (*Helianthus annuus*) (Sharma et al., 2023). Amro, (2021) found that honey bee pollination increased canola seed yield by 40% and oil content by 25%. For seed crops such as carrots (*Daucus carota*) and onions (*Allium cepa*), honey bees are critical for robust seed production (Negi et al., 2020).

1.3. Biological and Behavioral Aspects of Honey Bees

Honey bees possess specialized structures that make them efficient pollinators. Their bodies are covered with branched hairs that trap pollen grains, and they have pollen baskets (corbiculae) on their hind legs to transport pollen back to the hive (Wojcik, 2021). Additionally, bees exhibit flower constancy, a behavior where they visit the same type of flower repeatedly during a foraging trip. This behavior increases the likelihood of successful pollination as pollen is more effectively transferred between flowers of the same species (Yourstone et al., 2023).

1.4.Process of Pollination

When a honey bee visits a flower, it uses its proboscis to extract nectar, a primary energy source. While doing so, the bee's body comes into contact with the flower's anthers, and pollen grains adhere to the bee's hairs (Barberis et al., 2022). As the bee moves to the next flower, some of the pollen is deposited onto the stigma, enabling fertilization. This process is repeated as bees forage across multiple flowers and plants, ensuring widespread pollen distribution (Földesi et al., 2021).

1.4.1. Honey Bee-Plant Interactions

The relationship between honey bees and plants is mutually beneficial. Plants gain reproductive success through effective pollination, leading to fruit and seed production (Zarmin et al., 2022). In turn, honey bees obtain nectar and pollen, which are essential for their nutrition and hive sustenance. This mutualism is vital for the reproductive success of many agricultural crops, including apples, almonds, blueberries, and melons, which depend heavily on honey bee pollination for optimal yields (Khalifa et al., 2021).

1.4.2. Impact on Crop Yields

The efficiency of honey bees as pollinators directly affects crop yields and quality. Studies have shown that crops pollinated by honey bees produce more fruits and seeds, which are often larger and of higher quality compared to those resulting from wind or self-pollination (Khalifa et al., 2021). In addition to increasing the quantity of produce, honey bee pollination enhances the commercial value of crops by improving their quality attributes, such as size, shape, and shelf-life. In strawberries, honey bee-pollinated fruits have been found to be larger, more uniform, and have a longer shelf-life than those that are not pollinated by bees. Similarly, in the case of cucumbers, bee pollination has been linked to higher seed set and improved fruit shape (Anees et al.,2022).

Moreover, the presence of honey bees can lead to increased seed production in plants, which is essential for crops like sunflowers and canola that are grown for their seeds. Enhanced pollination by honey bees can also contribute to better oil content in crops such as oilseed rape, directly affecting the economic returns for farmers (Perrot et al., 2024). Additionally, the benefits of honey bee pollination extend to the cultivation of biofuel crops, thereby supporting renewable energy initiatives (Anees et al.,2022).

Understanding the mechanisms of honey bee pollination underscores their indispensable role in agriculture. Effective pollination not only enhances crop productivity but also maintains the genetic diversity and resilience of agricultural ecosystems. The synergistic effects of improved yield and quality underscore the necessity of protecting and promoting honey bee populations to sustain and enhance global food production (Khalifa et al., 2021).

1.4.3. Economic Impact of Honey Bee Pollination

Honey bee pollination has profound economic implications for agriculture, significantly influencing crop yields, quality, and overall profitability. The value of honey bee pollination services extends far beyond their contribution to honey production, playing a crucial role in the global agricultural economy (Khalifa et al., 2021).

1.4.4. Valuation of Pollination Services

The economic value of honey bee pollination services is substantial, with estimates suggesting that these services contribute hundreds of billions of dollars annually to global agriculture. For instance, the Pollinator Partnership (2021) estimates the annual economic value of honey bee pollination services in the U.S. alone at approximately $15 billion. This valuation encompasses a wide range of crops, including fruits, vegetables, nuts, and seeds, which benefit directly from honey bee activity (Khalifa et al., 2021).

1.4.5. Contribution to Agricultural Productivity

Honey bees enhance agricultural productivity by increasing crop yields and improving the quality of produce (Rollin and Garibaldi, 2019). This impact is evident across multiple crop categories, demonstrating the extensive influence of honey bee pollination on the agricultural sector.

1.4.5.1. Fruits

Honey bees play a vital role in the fruit industry. For instance, apple (Malus domestica) orchards benefit significantly from honey bee pollination (Khalifa et al., 2021). Mashilingi et al. (2022) reported that honey bee activity can increase apple yields by up to 20%, translating into significant economic gains for growers. Similarly, the blueberry (*Vaccinium spp*.) industry, which relies heavily on honey bees, sees a substantial boost in yield. Theimer et al. (2008) documented an 80% increase in blueberry yields with effective bee-mediated pollination, underscoring the economic value of these services (Mashilingi et al., 2022).

1.4.5.2.Vegetables

The impact of honey bees extends to vegetable crops. Cucumbers (*Cucumis sativus*), which require efficient pollination for optimal fruit development, benefit from honey bee activity. Ramello et al. (2024) found that honey bee-pollinated cucumbers produced a 33% increase in yield compared to those pollinated by other means. In pumpkins (*Cucurbita pepo*) and melons (*Cucumis melo*), honey bee pollination leads to improved fruit size and sweetness. Research by (Kumar et al. (2024) showed a 25% increase in melon fruit weight and a 30% improvement in sweetness due to honey bee pollination.

1.5.Challenges Facing Honey Bee Populations

Honey bees face numerous challenges that threaten their populations and, consequently, their essential pollination services. These challenges include pesticide exposure, habitat loss, diseases, parasites, and climate change, each of which has significant implications for bee health and agricultural productivity.

1.5.1. Pesticide Exposure

Pesticide use is a major factor contributing to honey bee declines. Neonicotinoids, a class of systemic insecticides, are particularly harmful (leska et al., 2021). Studies, such as those by Straub (2021), have shown that neonicotinoids can impair honey bee foraging behavior, reduce colony growth, and increase mortality rates. The sublethal effects of these chemicals, including altered navigation and memory, further disrupt bee health and productivity. Even non-neonicotinoid pesticides can have detrimental effects, as demonstrated by research from Lu et al. (2020), which found that pesticide exposure compromises honey bee immune systems and increases susceptibility to diseases.

1.5.2. Habitat Loss

Habitat loss is another critical issue affecting honey bee populations. Urbanization, agricultural expansion, and land use changes have led to a reduction in the availability of forage resources and nesting sites (Kline and Joshi, 2020). The decline in floral diversity and abundance reduces the nutritional options available to bees, as highlighted by studies such as those by Requier and Leonhardt (2020). This loss of habitat can lead to malnutrition and weakened immune responses, making bees more vulnerable to diseases and pests.

1.5.3. Diseases and Parasites

Honey bees are also threatened by various diseases and parasites. The Varroa destructor mite, a significant parasitic threat, infests honey bee colonies, feeding on bee blood and transmitting harmful viruses (Noël et al., 2020). Research by Morfin et al. (2023) demonstrated that Varroa infestations can lead to high colony losses and reduced honey production. Nosema spp., a group of microsporidian parasites, also adversely affects bee health by impairing digestion and reducing longevity (Galajd et al., 2021). Additionally, pathogens such as the deformed wing virus and the American foulbrood bacterium contribute to colony declines (Budge et al., 20215).

1.5.4. Climate Change

Climate change exacerbates these challenges by altering floral availability and synchrony with bee life cycles (Ali et al., 2023). Shifts in flowering patterns due to temperature changes can result in mismatches between the timing of flower availability and bee foraging periods. Research by Ali et al. (2023) indicates that climate-induced changes in floral resources can impact bee nutrition and colony health. Extreme weather events, such as droughts and floods, also affect habitat conditions and the availability of forage.

2. CONCLUSION

Honey bees are critical to global agriculture, providing indispensable pollination services that enhance crop yields, improve product quality, and bolster economic viability across numerous sectors. Their role in pollinating fruits, vegetables, nuts, and oilseeds significantly impacts agricultural productivity, as evidenced by substantial increases in yields and product quality. Scientific studies demonstrate that honey bee pollination can result in up to a 40% increase in nut set for almonds, a 25% increase in oil content for canola, and an 80% boost in blueberry yields.

However, honey bee populations face severe challenges, including pesticide exposure, habitat loss, diseases, parasites, and climate change. Addressing these issues is crucial to ensuring the sustainability of honey bee populations and, by extension, the stability of agricultural systems reliant on their pollination services. Strategic management practices, habitat restoration, and reduced pesticide use are essential to mitigate these threats and support bee health. The continued prosperity of global agriculture and food security depends on maintaining robust honey bee populations and their essential ecosystem services.

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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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NATURAL AND ALTERNATIVE METHODS AGAINST VARROA DESTRUCTOR

Sadık ÇIVRACI[1*]

ABSTRACT

Varroa destructor is one of the most important problems of bee breeding in the world and is the most important honey bee parasite that negatively affects the productivity and health of honey bees worldwide. Varroa causes great damage to honey bee colonies by sucking the hemolymph of honey bees. Many studies have been conducted to eliminate the harmful effects of the varroa parasite, and genetic, chemical, mechanical, and biological control methods have been developed. It is extremely important to control varroa in all bee products, especially honey and beeswax, without leaving harmful residues to honey bees and human health. For this reason, natural and alternative methods are becoming more important than chemicals in varroa control.

Anahtar Kelimeler: *Varroa destructor, essentıal oils, plant extracts, biological control*

VARROA DESTRUCTOR'A KARŞI DOĞAL VE ALTERNATİF YÖNTEMLER

ÖZET

Varroa Destructor, Dünya'da arı yetiştiriciliğinin en önemli sorunlarından birisi olup bal arılarının verimliliğini ve sağlığını dünya çapında olumsuz etkileyen en önemli bal arısı parazitidir. Varroa, bal arılarının hemolenfini emerek bal arısı kolonilerine büyük zararlar vermektedir. Varroa parazitinin zararlı etkilerini ortadan kaldırmak için birçok çalışma yapılmıştır ve genetik, kimyasal, mekanik ve biyolojik mücadele yöntemleri geliştirilmiştir. Bal ve balmumu başta olmak üzere tüm arı ürünlerinde bal arıları ve insan sağlığına zararlı olacak kalıntılar bırakmadan varroaya karşı mücadele etmek son derecede önemlidir. Bu nedenle varroa mücadelesinde kimyasal kullanımının yerine doğal ve alternatif yöntemler giderek önem kazanmaktadır.

Keywords: *Varroa destructor, uçucu yağlar, bitki ekstraktları, biyolojik kontrol*

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1. INTRODUCTION

Varroa destructor is an extremely harmful external parasite that lives in the larval, pupal, and adult stages of honey bees and feeds by sucking their blood fluid called hemolymph and can multiply in colonies for a long time without being noticed. Varroa can persist at all stages of the bee's development. Mated adult female varroa spend the winter on the bees. During this period the bees gather tightly together in the hive to form a winter cluster. When spring comes, the queen bee starts laying eggs in the comb cells. The worker bees close the comb cells containing the larvae in about 5-6 days. Varroa enters the honeycombs just before the worker bees close the combs and feeds easily in the closed combs, because the worker bees cannot interfere with the closed comb. Varroa usually prefers the honeycomb cells of drones because they are larger, drones have a longer developmental period than others, and drone cells on the sides of the comb are cooler. These conditions are extremely favorable for Varroa to breed. (Sammataro et al., 2000; Rosenkranz, et al., 2010)

Varroatosis caused by the ectoparasitic mite *Varroa destructor* is one of the biggest problems for honey bees (*Apis mellifera*) and beekeeping worldwide. The disease causes reduced growth rate of colonies, winter loss in honey bees, reduced flight activity, reduced nectar and pollen collection capacity, body deformations, and body weight loss in adult bees. In the advanced stages of the disease, V. destructor causes the destruction of colonies by damaging honey bees (Anderson & Trueman, 2000; Amdam, et al., 2004). This parasite is also a carrier of different pathogenic microorganisms. Varroa mite is especially responsible for honey bee viruses such as Deformed Wing Virus (DWV) (Posada-Flore et al., 2020), Acute Bee Paralysis Virus (ABPV) (Erban, et al., 2015), Vesiculovirus (SBV) (Drescher, et al., 2017), Kashmir Bee Virus (KBV) (Shen, et al, 2005) and Israeli Acute Paralysis Virus (IAPV) (de Miranda, et al., 2010), Black Queen Cell Virus (BQCV) (Karapınar et al., 2018) and these diseases cause great losses in colonies.

The fact that honey bees are among the most important pollinators in the world, the usage areas of honey bee products, and economic factors (Rucker et al., 2012) reveal the importance of varroa control. Varroa control is mandatory for honey bee colonies to survive and for breeders to continue beekeeping. Chemical, biological, genetic, and hormonal control methods have been used against *V. destructor* in various countries (Anderson & Trueman, 2000; Gregorc & Planinc, 2002; Garbian et al., 2012).

One of the most common methods of controlling Varroa is using chemical compounds. While chemical treatments provide fast and effective control of the parasite, they also carry many risks. Commonly used licensed chemical drugs include Folbex-VA®, Formic Acid plates®, Perizin®, Antivarroa®, Apitol®, Apistan®, Bayvarol®, Varropol®. These synthetic acaricides contain active ingredients such as amitraz, flumetrin, promopropylate, and coumaphos. The point to be considered in chemical control is the appropriate dose and correct timing. Since varroa hiding in closed pupal eyes will not be affected by the drugs, chemical treatment should be carried out especially in periods when pupal production is less. Rotation with different active ingredients in chemical treatment is an important point to prevent the development of resistance of Varroa (Ellis & Hayes, 2009; Haber & vanEngelsdorp, 2019; Turhan, 2024).

2. Biological Control

Biological control of varroa is an environmentally approach that aims to manage pest mite populations through natural processes and organisms. Biological control is emerging as an effective alternative to minimize the long-term negative effects of chemical acaricides and avoid resistance problems. One of the most remarkable of these methods is the use of entomopathogenic fungi targeting Varroa mites. For example, fungal species such as *Metarhizium anisopliae* and *Beauveria bassiana* penetrate the exoskeleton of the mites, infecting and killing them. In order to apply these fungi effectively, it is important to ensure suitable environmental conditions and to manage them in a way that does not harm bee colonies (García-Fernández et al., 2008).

The development of genetically resistant honey bees is an important part of the biological control mechanism. The strategy here is to select bees with Varroa Sensitive Hygiene (VSH) traits and use them in beekeeping activities. These bees control the presence of varroa in the colony by cleaning the honeycombs infected with varroa (Danka et al., 2011).

Pheromone-based applications are alternative methods to chemicals in the control of varroa. Although studies on the subject are limited, this method aims to control the behavior of varroa by means of different pheromones (Park et al., 2023).

Organic acids are a powerful alternative to using chemicals in varroa control. Organic acids are a reliable method against varroa mites. When organic acids are used appropriately, they offer the opportunity to control varroa without threatening honey bees and human health. Organic acids such as oxalic acid, formic acid, and lactic acid are especially effective against varroa. Organic acids work by having a toxic effect on the respiratory system of the varroa mite (Imdorf et al., 1996; Rosenkranz et al., 2010). Oxalic acid is especially effective in the fall and early winter months as it affects varroa on adult bees. Oxalic acid used at appropriate doses during these periods has maximum effect (Gregorc & Planinc, 2002). Formic acid is mostly applied by evaporation due to its evaporation property. It is effective on varroa in open and closed pupal eyes. It is recommended to be used in periods when the number of brood is low. The most important consideration in using formic acid is the ambient temperature. At high temperatures, the high level of formic acid evaporation can cause damage to honey bees, while at low temperatures, the level of effectiveness will not be sufficient (Satta et al., 2005). Lactic acid is not preferred because it requires frequent use and creates a workload. Akyol & Özkök, 2005).

Colony or hive management interventions can be an effective way of controlling Varroa mite populations. More successful results can be obtained when these interventions are applied together. Mechanical control methods include the use of sieved floorboards, limiting drone brood production, removing drone brood from the colony, trapping in drone cells, limiting drone brood production, using young queens and sprinkling powdered sugar (Akyol & Korkmaz, 2006; Muz et al., 2014; Devi et al., 2019).

3. Use Of Plant Extracts And Essential Oils In Varroa Control

The use of natural and alternative methods instead of chemicals in varroa control is very important for both honey bees and human health. Plant extracts and essential oils have gained importance both because they are effective in controlling varroa mites and because they are alternatives to chemical acaricides. Especially essential oils such as thymol, linalool, eugenol, carvacrol, and eugenol can reduce their populations by affecting the physiological and behavioral processes of mites (Imdorf et al., 1999). Plant extracts are a promising tool in varroa control thanks to their antimicrobial and antiparasitic properties (Islam et al., 2016).

Studies have shown that essential oils obtained from aromatic plants such as tobacco, pine leaves, garlic, thyme, eucalyptus, juniper, mint, flea grass, walnut, citrus, sage, etc., show 45-70% efficacy against varroa (Imdorf & Charriere, 2002). Tobacco smoke was found to be 65-95% effective against varroa (Bakandritsons & Zabunis, 1985). Delaphane (1992) reported that menthol in mint and Shaarawi (1995) reported that mint, wormwood and eucalyptus are effective in the control of Varroa.

El-Wahab & Ebada (2006), used in their examination different concentrations of *Cymbopagon flexuosus* (Lemon grass), *Citrus aurantium* L (Sour Orange), and *Citronella volatile* oils varroa mites in honey bee colonies. The mean percentage of varroa infestation on the worker brood and adult workers reduced to 100% after the fourth week of treatment with *Citrus aurantium L*, *Cymbopagon flexuosus*, and after the third week of treatment with *Citronella oils*.

Damiani et al. (2009) examined the acaricidal properties of essential oils obtained from Thymus vulgaris, Laurus nobilis, Lavandula officinalis, and Lavandula hybrida. These oils, which contain linalool, 1,8-Cineole, and thymol as their primary components, were found to effectively cause mortality in Varroa destructor mites. Importantly, none of the essential oils tested caused significant harm to adult bees.

Çakmak et al. (2006) tested pollen traps, in conjunction with walnut leaf smoke or mint leaves, as a control for *V. destructor*. All treatments with pollen traps reduced the mite population by approximately 50%; the treatment without pollen traps reduced the mite population significantly more.

Çetin (2010) suggested the use of eucalyptus bark and leaves, oxalic acid, lactic acid, worker bee removal, orange peel, and drone bee removal as effective methods for combating Varroa. These approaches were proposed as practical solutions for beekeepers to implement in their efforts against the parasite..

Rafaei (2010) tested Apiguard and Thyme, Camphor, and Basil oils as control agents against V. destructor. Data showed that all four tested compounds effectively controlled Varroa and Apiguard was the most effective substance.

In a study evaluating the biological activity of herbal extracts from *Baccharis flabellata* and *M. verticillata* on V. destructor and *A. mellifera*, it was determined that these plant extracts did not harm honey bees and showed toxic effect on varroa (Damiani et al., 2011).

Abd El-Wahab et al. (2012) investigated the effects of formic acid and thyme, cinnamon, anise and lemongrass oil applications on Varroa development and grooming behavior of honey bees and found that high dose applications of formic acid and essential oils had a significant effect on Varroa. In the study, it was determined that thyme oil was the most effective substance on Varroa deformation, which was examined as a grooming behavior parameter.

Qayyoum et al. (2013) said that in their study, plant extracts, Neem oil, Mixture (Neem oil, garlic oil, and tobacco oil), and tobacco oil have obtained hopeful results. The percentage of mixture infestation is more effective in all categories. Mixture also plays a vital role in the % reduction of mites from broods, while neem oil in % reduction of bees.

Islam et al. (2016), was examined four essential oils of Thyme, Lemon grass, Rosemary, Mint, and Formic Acid (65%) used at three concentrations (25, 50, and 100%) against Varroa destructor. They determined the percentage of infestation by varroa destructor on adult workers and worker brood, percent mite mortality and their honey, and number of dead fallen Varroa yield before and after the treatments in the experimental colonies. The results of their research showed that 100% concentrations of tested essential oils and the formic acid caused important control of Varroa, whereas the invasion reduction percentage with formic acid, lemon grass, thyme, mint, and rosemary oils was recorded at more than 96% after the end of treatments on both adult workers and worker brood.

Stanimirović et al. (2017) conducted a field trial to evaluate the varroacidal efficacy of a plant-based formulation called Argus Ras. This formulation included extracts from *Sophora flavescens*, *Ginkgo biloba*, *Gleditsia chinensis*, and *Teucrium chamaedrys*. The study involved 240 *Apis mellifera* colonies, and the effectiveness of Argus Ras was assessed in combination with amitraz and oxalic acid. The results showed that Argus Ras achieved an average acaricidal efficacy of 80.89%, surpassing the effectiveness of other previously tested essential oils.

Costic acid has been isolated from the plant *Dittrichia viscosa* and its efficacy against varroa, a parasite studied by Sofou et al. (2017). They determined costic acid exhibited potent in vivo acaricidal activity against the parasite.

In their study, Tsegaye et al. (2024) investigated the effects of smoke from *Cordia Africana*, *Terminallia*, tobacco, and a mixture of barley and *Olea* leaves on *Varroa* control. They found that tobacco leaf smoke and *Terminallia* leaf smoke were particularly effective in managing *Varroa destructor*. Similarly, Raza et al. (2024) examined the efficacy of essential oils extracted from *Salvia officinalis* (sage), *Cannabis sativa* (hemp), and *Laurus nobilis* (laurel) against *Varroa*. Among these, hemp oil demonstrated the highest effectiveness, while laurel oil was the least effective. Additionally, Alsaadi et al. (2024) reported that bitter melon oil could be used as an environmentally friendly and bee-safe option for controlling varroa mites.

4. CONCLUSION

As a result of the unconscious use of acaricides used in the fight against Varroa, the parasite gradually develops immunity against such drugs (Boecking and Spivak, 1999). Drugs used against varroa and synthetic acaricides leave high amounts of residues in honey and wax, causing economic problems for beekeepers (Wehling et al., 2003). While these chemicals are generally preferred due to their high efficacy, it has been observed that varroa develop resistance to these substances in cases of misuse or overuse. This leads to a decrease in treatment efficacy and complicates future control methods. In addition, the accumulation of residues in bee products (honey, beeswax, etc.) during chemical treatments is a major concern for consumer safety and bee health. Studies have shown that especially synthetic acaricides can remain in wax for a long time and may adversely affect the hive environment (Bogdanov et al., 2004). Therefore, there has been increased interest in alternatives such as organic acids and essential oils that do not endanger honey bees and human health (Rosenkranz et al., 2010).

Biological control methods are gaining attention as a more sustainable alternative to chemical treatments. Innovative strategies such as entomopathogenic fungi, genetic resistance and pheromones allow beekeepers to maintain bee health and minimize environmental impacts. The effectiveness of these approaches can be further improved through additional research and practical application experience. In the fight against Varroa, organic acids offer an environmentally friendly and effective solution. Increasing resistance to chemical acaricides and consumer demand for organic honey production are increasing interest in these natural methods. However, proper timing, correct dosage, and environmental factors need to be considered for the successful application of organic acids. Accordingly, organic acids are considered as an important component of integrated pest management (IPM) strategies (Jack & Ellis, 2021; Vilarem et al., 2021).

Plant extracts and essential oils show efficacy with minimal toxicity to honey bees and greatly reduce residue problems. The most widely used thymol-based products have been used successfully for many years in varroa control and offer advantages in terms of low cost and easy applicability. However, the effective use of plant extracts and essential oils depends on variables such as concentration, application method and environmental factors. Further investigation of the efficacy of these natural products and their potential impact on bee health is required for wider adoption of these interventions.

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THE IMPACT OF CLIMATE AND ENVIRONMENTAL CHANGE ON HONEY BEES AND BEEKEEPING

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ABSTRACT

Climate and environmental change is one of the biggest challenges of the twenty-first century. Extreme weather conditions and natural disasters have caused great harm to honey bees. It is clear that climate and environmental change will be a very important stress factor for bee colonies and beekeepers, increasing bee colony losses and decreasing income levels.In this study, we propose the main challenges that beekeepers will face in the future due to the changing climate and some precautions that should be taken (beekeepers moving to pollen-rich areas, providing additional food supplements to colonies, providing clean water sources, changing the type of hives, afforestation in the apiary, changing the harvest time).In addition, beekeepers face serious constraints and by integrating climate conditions with existing knowledge and local practices, we can strengthen beekeepers' adaptive capacity.

Keywords: Beekeeping, climate change, environmental change, adaptation

İKLİM VE ÇEVRE DEĞİŞİKLİĞİNİN BAL ARILARI VE ARICILIK ÜZERİNDEKİ ETKİSİ

ÖZET

İklim ve çevre değişikliği yirmi birinci yüzyılın en büyük sorunlarından biridir. Aşırı hava koşulları ve doğal afetler bal arılarına büyük zarar verdi. İklim ve çevre değişikliğinin arı kolonileri ve arıcılar için çok önemli bir stres faktörü olacağı, arı kolonisi kayıplarını arttıracağı ve gelir seviyelerini düşüreceği açıktır.Bu çalışmada, değişen iklim nedeniyle arıcıların gelecekte karşılaşacağı temel zorluklar ve alınması gereken bazı önlemler (arıcıların polen bakımından zengin bölgelere taşınması, kolonilere ek gıda takviyesi sağlanması, temiz su kaynaklarının sağlanması, arıcıların iklim koşullarının değiştirilmesi) önerilmiştir. kovanların türü, arı kovanındaki ağaçlandırma, hasat zamanının değiştirilmesi).Ayrıca arıcılar ciddi kısıtlamalarla karşı karşıyadır ve iklim koşullarını mevcut bilgi ve yerel uygulamalarla entegre ederek arıcıların uyum kapasitesini güçlendirebiliriz.

Anahtar Kelimeler: Arıcılık, iklim değişikliği, çevre değişikliği, uyum

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1. INTRODUCTION

Honey bees have spread and adapted all over the world except the polar region (hot dry deserts, regions with continental climates, regions with temperate climates). Different honey bee species have adapted to different geographical regions (Figure 1).

Local ecotypes have adapted to all kinds of climate conditions of the regions they grow and have developed physiological and morphological behaviors. However, ecosystems have changed at very high rates all over the world. This change is in the form of habitat, fauna, nitrogen accumulation, biological invasions, carbon dioxide accumulation in the atmosphere and climate change. (Tylianakis, Didham, Bascompte, & Wardle, 2008).

Current environmental change affects both bees and beekeepers. Environmental change affects the physiology and ecology of bees (Shelley ER Hoover et al., 2012).

Environmental change affects honey bee colonies directly by affecting their physiology, development and immune system, and indirectly by affecting plant flowering periods and populations of parasites and pathogens (Bowler et al., 2017; Shelley ER Hoover & Hoover, 2014; Leemans & Eickhout, 2004) (Figure 2).

Climate is defined as the average weather conditions that do not change over many years in a fairly large area. Climate is an extremely important factor for the activities of the honey bee (Apis mellifera) (Le Conte & Navajas, 2008).

Chemicals used in agricultural activities, environmental pollutants resulting from industrial activities, pathogens and climate change can negatively affect plant and animal life (Cunningham et al., 2022).

Additionally, these pollutants accumulate throughout the environment in soil, water and air, accumulating in body tissues and causing reproductive failure (Leemans & Eickhout, 2004), neurotoxic damage and even death. (Moroń, Szentgyörgyi, Skórka, Potts, & Woyciechowski, 2014; Williams et al., 2015).

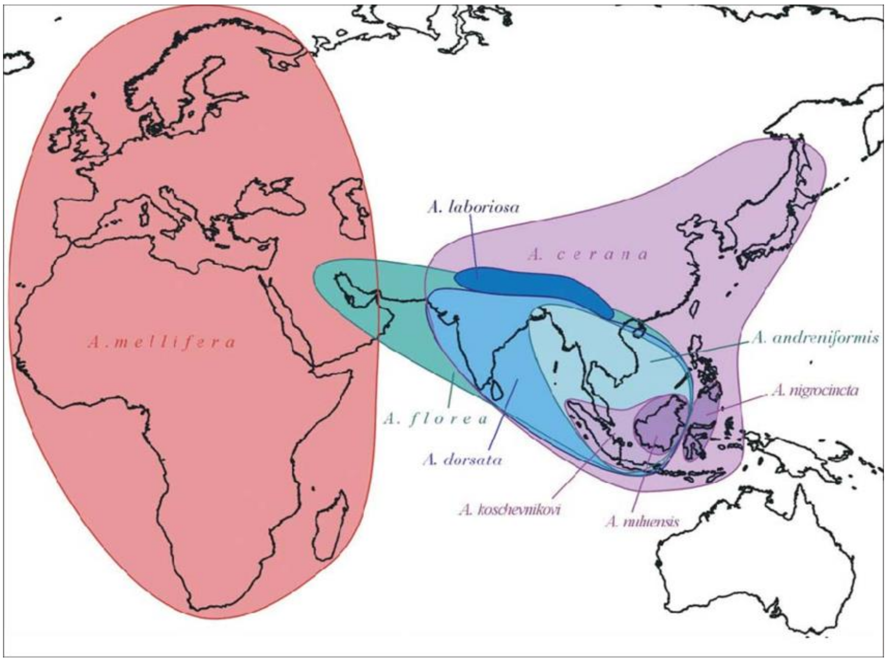

Figure 1: *Apis mellifera* habitats (Franck, Garnery, Solignac, & Cornuet, 2000)

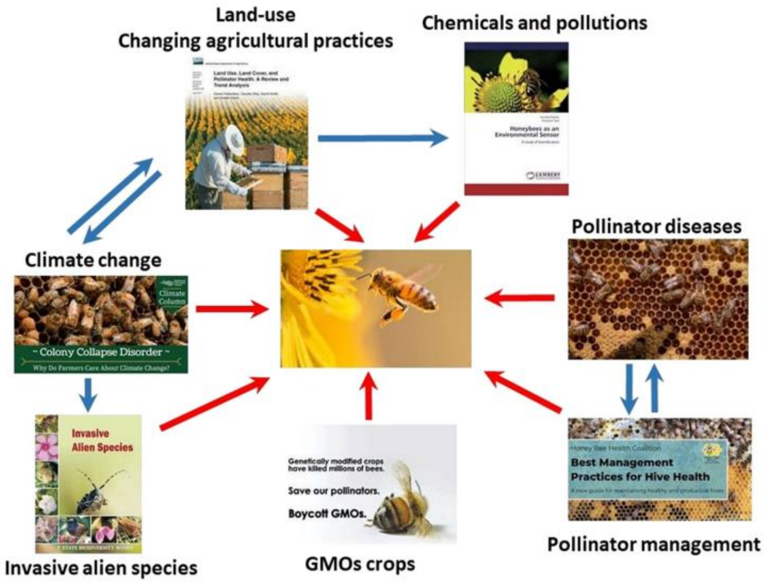

Figure 2. The impact of environmental change on honey bees (Neov, Shumkova, Palova, & Hristov, 2021)

The harms of these chemicals that cause environmental pollution are not limited to the natural environment and climate change. They can also cause respiratory diseases and many other ailments such as cancer in humans (Briffa, Sinagra, & Blundell, 2020; Lambert et al., 2012).

Determining the future effects of climate change on humans, honeybees and all other living things is a very difficult situation. According to the latest reports of the United Nations Intergovernmental Panel on Climate Change and scientific studies, climate change will cause temperatures to increase, precipitation patterns to change and seasons to shift. It will also cause excessive rainfall, extreme droughts and major floods. (Garnaut, 2008; Hov et al., 2013; Myhre et al., 2019; Van Aalst, 2006)

These environmental changes will affect all agricultural activities and will have painful consequences. Diseases and pests will increase in animal and plant production and yields will decrease significantly (Becklin et al., 2016; Lacetera, 2019; Nelson et al., 2009).

2. The İmpact Of Climate And Environmental Change On Honey Bees And Beekeeping

It is unthinkable that honey bees and beekeeping will not be affected by environmental change. These effects will certainly be in the form of reduced honey yield and reduced pollination (Le Conte & Navajas, 2008; Malisa & Yanda, 2016). Pollination is the movement of the male reproductive units of plants from flower to flower. Pollination is most intensively carried out by flies, butterflies, moths, some wasps, beetles, tobacco aphids and of course honeybees. (Forrest, 2017). There are 20,000 species of bees in the world, divided into seven families (Winfree, 2010) most of these are located in the northern hemisphere (Conrad, Peters, & Rehan, 2021). Beekeeping is a form of agricultural production that is responsible not only for honey production but also for pollinating 30% of global food production (Khalifa et al., 2021). Therefore, bees and beekeeping are vital to world food security.

The most cultivated bee race in the world is Apis mellifera. The reason why Apis mellifera is so widespread all over the world is not only because of its high honey yield but also because of the extremely high adaptability of this race (Arias & Sheppard, 2005).

Apis mellifera's high survival ability is also affected by its determination to collect nectar and its ability to enter the long winter periods with a strong honey stock and to come out strong in the spring by consuming little. Therefore, it is not a coincidence that Apis mellifera's pollination and honey production ability has been successfully introduced to the whole world. Despite the ability of all honey bees, especially Apis mellifera, to adapt to climate change and environmental changes, it is certain that this change will also affect beekeeping quite a lot. (Flores et al., 2019).

Although all wild and cultivated bees are affected by climate change, the destructive effect on wild bees is greater due to reasons such as intervention and relocation of cultivated bees. (Balfour, Gandy, & Ratnieks, 2015; Dubois, Pasquaretta, Barron, Gautrais, & Lihoreau, 2021).

Protecting wild bees is much more difficult due to limited human control and intervention (Alger, Burnham, Boncristiani, & Brody, 2019; Novelli, Vercelli, & Ferracini, 2021).

But by implementing more climate-smart methods, beekeepers and entomologists can make coping with climate change an easier and more realistic process for farmed bees (Gajardo-Rojas et al., 2022; Vercelli, Novelli, Ferrazzi, Lentini, & Ferracini, 2021). Honey bees are currently at the top of the list of endangered animals for agricultural production organization. (Landaverde, Rodriguez, & Parrella, 2023).

The reason for these concerns is that studies have shown an extreme decline in bee populations (Bartomeus et al., 2014; Forrest, 2017).

Recently, extensive information has been gathered showing how climate change is affecting the lives of bees and limiting their ability to provide their services in the ecosystem (Le Conte & Navajas, 2008; Soroye, Newbold, & Kerr, 2020).

The biggest indicators of environmental change are extreme weather conditions (excessive rain, excessive snow, excessive wind and extreme temperatures). These extreme weather conditions affect beekeeping extremely (Gray et al., 2023).

Floods and forest fires have increased exponentially today (Dorey et al., 2021; Insolia et al., 2022). In this case, bee colony losses increase. Due to increasing temperatures, the broodless period of bee colonies will shorten and perhaps disappear completely.

It is certain that climate and environmental change will catastrophically increase the impact of bee mites on colonies (de Jongh et al., 2022; Hillayová, Korený, & Škvarenina, 2022; Le Conte & Navajas, 2008; Neumann, Yañez, Fries, & de Miranda, 2012; Noël, Le Conte, & Mondet, 2020; Novelli et al., 2021). In other words, it is estimated that pests such as small hive beetles (Aethina tumida) and wasps (Vespa spp.) will be positively affected by climate change (Barbet-Massin et al., 2013.

Varroa destructor is one of the most important and dangerous pests for bees and beekeeping worldwide (Flores et al., 2021; Hillayová et al., 2022). This pest significantly reduces the life span and productivity of bee colonies. Studies show that the density of Varroa destructor and therefore its damage increases significantly depending on the air temperature (Garcia & Rodriguez, 2011; Hillayová et al., 2022; Mendoza, 2024).

This will affect bee health and economic contributions. Seasonal change and the extension of the dry period will affect the flowering periods and even cause a long dry period (Flores et al., 2019). Inadequate nutrition of honey bees will weaken their immune system and make them vulnerable to diseases. (Castle, Alkassab, Bischoff, Steffan-Dewenter, & Pistorius, 2022; Dolezal & Toth, 2018; Kerr et al., 2015).

Such gaps in flowering periods may result in the spread of invasive plant species, which are increasing due to global and environmental change (Dietzsch, 2009; Liu et al., 2017).

Although there is a perception that invasive plant species may benefit beekeeping, this situation is definitely not sustainable. Plant invasion jeopardizes the availability of essential nutrients provided by floral resources, thus causing a food deficit and endangering beekeeping.

3. Temporary Measures That Can Be Taken

Bee breeds that are more resistant to the stress brought on by climate change can be developed. Natural disasters are not a situation that beekeepers can control, and studies and planning can ensure that honeybees are least affected by this situation (O'Brien, O'keefe, Rose, & Wisner, 2006). One of the most important planning that beekeepers need to do is choosing the location of the apiary.

Minimizing floods and forest fires by increasing public and manager awareness reduces bee colony losses (Faux & Kane, 2021).

It should be noted that in the event of climate change, much more effective methods of combating mites, small hive beetles and other invasive species must be found (Dall’Olio et al., 2022).

Rations that include protein, carbohydrates, micronutrients and microbiota required for the nutrition of bee colonies should be developed for future famine situations (Brodschneider & Crailsheim, 2010; Brown et al., 2022; Paray et al., 2021).

Studies have shown that food supplements to bee colonies increase the amount and speed of egg laying by queen bees (Shelley E Hoover, Ovinge, & Kearns, 2022; Ullah, Shahzad, Iqbal, & Baloch, 2021).

Today, additional feeding of bee colonies is usually done in the early spring and late autumn periods when flowers are limited (Shelley E Hoover et al., 2022; Vercelli et al., 2021).

It is necessary to produce queen bees that are adapted to the region and have high adaptation to difficult conditions (Meixner, Kryger, & Costa, 2015).

If we look at it from another perspective, increasing environmental differences and changes may lead to the emergence of new breeds that can better adapt to these conditions and provide efficiency (Blacquière et al., 2019). However, it does not seem possible to predict this situation exactly now.

Even small measures such as afforestation of apiaries to protect bee colonies from high temperatures or moving colonies to high plateaus by migratory beekeeping will perhaps be life-saving for beekeeping (Gajardo-Rojas et al., 2022).

In addition to these measures, establishing bee pastures in the region and choosing strong plants in the creation of these pastures can reduce the possible negative effects in the future (Kaiser-Bunbury et al., 2017). Additional studies should be carried out and measures should be taken to minimise the damage and destruction caused by climate change and environmental change.

More efforts should be made to apply scientific studies to the field, and all beekeeping-related unions, associations and cooperatives should be made aware of this issue.

As a result, there are significant gaps in our knowledge about beekeeping under climate change. Therefore, more coordinated efforts by all relevant stakeholders globally will be required to provide adequate responses to this epic challenge.

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ARI EKMEĞİNİN (PERGA) FONKSİYONEL ÖZELLİKLERİ AÇISINDAN İNCELENMESİ

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ÖZET

Bu makalede, arı ekmeği (perga) adlı değerli arı ürününün kimyasal, biyolojik ve besinsel özellikleri incelenmiştir. Perga, polenin arılar tarafından fermantasyona uğratılmasıyla oluşan ve hem arılar hem de insanlar için önemli faydalar sağlayan zengin bir besin kaynağıdır. Arılar için enerji ve bağışıklık desteği sunarken, insanlar için probiyotik, antioksidan, antimikrobiyal ve antiinflamatuar etkileriyle öne çıkmaktadır. Makalede, pergadaki fenolik bileşikler, amino asitler, vitaminler ve minerallerin etkileri ile apiterapi ve fonksiyonel gıda alanındaki kullanımları ele alınmıştır. Ayrıca, pergadaki probiyotik özelliklerin arı sağlığına ve fermantasyonun besin değerine olan katkıları detaylı bir şekilde açıklanmıştır. Perganın gelecekteki araştırmalarda daha kapsamlı şekilde ele alınarak modern sağlık ve beslenme sistemlerinde daha yaygın kullanılabileceği vurgulanmıştır.

Anahtar Kelimeler: Perga, Arı Ekmeği, Apiterapi

INVESTIGATION OF BEE BREAD (PERGA) IN TERMS OF ITS FUNCTIONAL PROPERTIES

ABSTRACT

This written, the chemical, biological and nutritional properties of the valuable bee product called bee bread (perga). Perga is formed by the fermentation of pollen by bees and has a rich nutritional environment that provides significant benefits for both bees and humans. While it provides energy and health support for bees, it stands out with its probiotic, antioxidant, antimicrobial and anti-inflammatory effects for humans. In the article, the effects of phenolic pictures, amino acids, vitamins and minerals in perga and their uses in apitherapy and functional food fields are taken. In addition, the contributions of probiotic properties in perga to bee health and the nutrients of fermentation are explained in detail. It is emphasized that modern health and nutrition systems can be used more widely by addressing the records of perga more comprehensively.

Keywords: Perga, Bee Bread, Apitherapy

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1. GİRİŞ

Perga, halk arasında arı ekmeği olarak bilinen ve arılar tarafından polenin fermantasyonuyla oluşan benzersiz bir arı ürünüdür. Arıların hayatta kalma ve koloni sağlığını koruma stratejilerinin bir sonucu olarak ortaya çıkan bu ürün, gerek besin değeri gerekse terapötik etkileriyle dikkat çekmektedir. Perga, özellikle fenolik bileşikler, biyolojik aktif maddeler, proteinler, vitaminler ve mineraller gibi çok sayıda faydalı bileşen içermesi nedeniyle insan ve arı sağlığı açısından önemli bir yere sahiptir (Kieliszek ve ark., 2018). Arılar için enerji ve protein kaynağı olarak kritik bir rol oynayan perga, insanlar tarafından ise apiterapide ve fonksiyonel gıda olarak değerlendirilmektedir.

Perga, özellikle apiterapide kullanılmasıyla bilinen diğer arı ürünlerinden farklı olarak, fermantasyon yoluyla hem sindirilebilirliği artmış hem de besinsel değeri çoğalmış bir formdadir. Bu benzersiz fermantasyon süreci, polen taneciklerinin duvar yapısını yumuşatarak biyoyararlanımını artırırken, probiyotik özellikler de kazandırır (Olofsson ve Vásquez, 2008). Bu sayede, perganın insan sindirim sistemi üzerinde olumlu etkiler bıraktığı ve mikroflora dengesini desteklediği bilinmektedir (Gilliam ve ark., 1974).

Bu derleme makalede, perganın oluşum süreci, kimyasal bileşimi, besinsel özellikleri, terapötik etkileri ve biyolojik faydaları detaylı bir şekilde ele alınmıştır. Bunun yanı sıra, arı ve insan beslenmesindeki önemi ile diğer arı ürünleriyle birlikte kullanılabilirliği de kapsamında incelenmiştir. Perganın apiterapideki potansiyeli, geleneksel ve modern tıptaki rolü ve bilimsel araştırmalardaki yeri bu yazının çekirdek temalarından biri olarak vurgulanmıştır. Özellikle son yıllarda artan bilimsel ilgi, bu ürünün daha geniş bir yelpazede uygulanabilirliğini gözler önüne sermektedir.

2. Perga (Arı Ekmeği) Nedir ve Nasıl Oluşur

Perga, arıların toplanan poleni bala ve arı salgılarına karıştırıp petek gözlerine yerleştirerek fermantasyona bıraktıkları bir arı ürünüdür. Fermantasyon sürecinin temelini, arıların salgıladığı enzimler ve laktik asit bakterileri oluşturur. Bu süreçte polenin sert eksin tabakası yumuşar, biyoyararlanımı artar ve perga dayanıklı bir besin haline gelir (Olofsson ve Vásquez, 2008). Bu benzersiz dönüşüm, perganı hem arılar hem de insanlar için değerli kılan temel özelliklerden biridir.

Laktik asit fermantasyonu, pergaya probiyotik özellikler kazandırır ve bu da arı kolonilerinin mikrobiyal dengesine katkı sağlar. Perganın mikrobiyal yapısında Lactobacillus, Bifidobacterium ve Saccharomyces gibi bakteriler ve mayalar bulunur. Bu mikroorganizmalar, fermantasyon sırasında laktik asit ve diğer organik asitleri üreterek hem poleni korur hem de besin değerini zenginleştirir (Gilliam ve ark., 1974).

Fermantasyon süreci boyunca polenlerin yapısal bileşenleri olan karbonhidratlar, proteinler ve fenolik bileşikler dönüşüme uğrar. Laktik asit bakterilerinin etkisiyle pH düşer, bu da patojenik mikroorganizmaların gelişimini engeller. Aynı zamanda, fermantasyonun sonucunda perganın antioksidan özellikleri artar ve arıları hastalıklara karşı daha dirençli hale getirir.

Perganın oluşum sürecinde, polene arı salgıları ve bal eklenmesi, fermantasyonu başlatır. Petek gözlerinde ortalama iki hafta boyunca devam eden bu süreçte, polenlerin sert yapıları yumuşarak daha sindirilebilir hale gelir. Fermantasyon tamamlandıktan sonra perga, koyu kahverengi veya sarımsı bir renge ve kendine has bir aromaya sahip olur. Bu ürün, arıların enerji ihtiyacını karşılamakla kalmaz, aynı zamanda koloninin genel sağlığına da katkı sağlar.

Son olarak, pergada meydana gelen biyokimyasal dönüşümler, ürünün besleyici içeriğini arttırır ve uzun süre dayanıklılık sağlar. Bu nedenle perga, hem arılar hem de insanlar için çok yönlü ve değerli bir besin kaynağı olarak kabul edilir.

Perga, polenin arılar tarafından toplanması, bala ve arı salgısına karıştırılması ve petek gözlerinde fermantasyona bırakılması sonucu oluşur. Bu süreç, laktik asit bakterilerinin etkisiyle gerçekleşir ve polen, daha uzun süre dayanıklı ve besleyici hale gelir (Olofsson ve Vásquez, 2008). Laktik asit fermantasyonu sayesinde pergada probiyotik özellikler kazanılır ve bu da insan sindirim sistemi üzerine olumlu etkiler sağlar (Gilliam ve ark., 1974).

Perganın yapısında bulunan bakteriler (Lactobacillus, Bifidobacterium gibi) ve maya türleri (Saccharomyces, Candida) fermantasyon sürecine katkı sağlar. Fermantasyon sırasında polenin duvar yapısı yumuşar ve biyoyararlanım artar (Campos ve ark., 2010). Bu sürecin sonunda, perga dayanıklı ve zengin besin içeriğine sahip bir ürün haline gelir.

3. Arı Beslemesinde Perganın Önemi

Perga, arı kolonileri için yalnızca bir protein ve enerji kaynağı değil, aynı zamanda sağlıklı bir koloni için vazgeçilmez bir yapı taşıdır. Larvaların büyümesi, işçi arıların dayanıklılığı ve ana arının üreme kapasitesi gibi koloninin temel süreçlerinde perga hayati bir rol oynar. Pergada bulunan temel besin maddeleri, genç arıların hızlı büyümesini sağlarken, yaşlı arıların metabolik süreçlerini destekler. Özellikle larvaların sağlıklı gelişimi, perganın zengin protein ve amino asit içeriği sayesinde mümkün olur (Gümüs ve Karslı, 2024; Kieliszek ve ark., 2018).

Arı kolonileri, çevresel koşullara uyum sağlama yetenekleri ile bilinir, ancak bu uyumun temelinde güçlü bir beslenme rejimi yatar. Perga, arıların enerji gereksinimlerini karşılamak için ideal bir kaynaktır. Yüksek karbonhidrat içeriği sayesinde arılar, enerji ihtiyaçlarını karşılar ve petek içi aktivitelerde bulunur (Gilliam ve ark., 1974). Aynı zamanda lipitler, dokuların yenilenmesi ve enerji rezervlerinin artırılması için kritik bir rol oynar. Kış aylarında, perganın sağladığı enerji, koloninin düşük sıcaklıklarda hayatta kalmasına yardımcı olur ve kış uykusu döneminde arıların hareketliliğini sürdürmesini sağlar (Pascoal ve ark., 2014).

Perganın önemi yalnızca enerji ve protein sağlamasıyla sınırlı değildir. İçeriğinde bulunan fenolik bileşikler, arıların bağışıklık sistemini destekler ve patojenik mikroorganizmalara karşı koruma sağlar (Markiewicz-żukowska ve ark., 2013). Fermantasyon sürecinde oluşan laktik asit ve diğer organik asitler, arıların bağırsak florasını dengeler ve hastalıklara karşı dirençlerini artırır. Bu, özellikle stresli dönemlerde ve hastalık salgınlarında kolonilerin hayatta kalma oranını artıran önemli bir faktördür (Bakour ve ark., 2017).

Polenle karşılaştırıldığında, pergada biyoçeşitlilik ve besin içeriği çok daha yüksektir. Fermantasyon süreci, polenin sindirilebilirliğini artırır ve biyoyararlanımı maksimum düzeye çıkarır (Campos ve ark., 2008). Arı salgılarından gelen enzimler ve laktik asit bakterileri, polenin sert eksin tabakasını parçalayarak içerdiği besinlerin daha kolay sindirilmesini sağlar. Ayrıca, pergada bulunan probiyotik mikroorganizmalar, arıların genel sağlığını destekleyen mikroflorayı güçlendirir (Olofsson ve Vásquez, 2008).

Sonuç olarak, perga, yalnızca bir besin kaynağı değil, aynı zamanda arı kolonilerinin uzun vadeli sağlığını ve sürdürülebilirliğini koruyan bir bileşendir. Perganın arı sağlığı üzerindeki etkileri, modern arıcılık uygulamalarında giderek daha fazla dikkat çekmektedir. Günümüzde pergaya olan ilginin artması, bu değerli ürünün potansiyelini daha geniş bir şekilde anlamamıza olanak tanımaktadır. Gelecekteki araştırmalar, perganın kolonilerin dayanıklılığı ve üretkenliği üzerindeki etkilerini daha ayrıntılı şekilde ortaya koyabilir.

4. İnsan Beslenmesinde Perganın Önemi

Perganın insanlar için besinsel faydaları, çeşitli bilimsel çalışmalarda kapsamılı bir şekilde ortaya konmuştur. Zengin kimyasal bileşimi, güçlü antioksidan, antimikrobiyal ve antiinflamatuar etkileri ile insan sağlığına katkı sağlayan çok yönlü bir gıdadır. Perganın öne çıkan besin özellikleri şunlardır:

- **Amino Asitler:** Pergada bulunan temel amino asitler, protein sentezi ve kas onarımında önemli rol oynar. Başta valin, izolösin ve lösin gibi dallı zincirli amino asitler, fiziksel aktivite sonrası kas toparlanmasına yardımcı olur (Pascoal ve ark., 2014).
- **Vitaminler:** B grubu vitaminleri (B1, B2, B6) metabolik aktiviteleri desteklerken, C ve E vitaminleri güçlü antioksidan etkiler göstererek serbest radikallerin neden olduğu hücre hasarını azaltır.
- **Mineraller:** Kalsiyum, demir, magnezyum, potasyum ve çinko gibi mineraller kemik sağlığı, kan dolaşımı ve sinir sistemi için hayati önem taşır. Demir, kırmızı kan hücrelerinin üretimine katkıda bulunarak anemi riskini azaltabilir.
- **Fenolik Bileşikler:** Pergada bulunan fenolik asitler ve flavonoidler, antioksidan etkileri ile oksidatif stresi azaltır. Bu bileşenler ayrıca iltihapı azaltmaya ve kronik hastalık risklerini düşürmeye yardımcı olabilir (Markiewicz-żukowska ve ark., 2013).

Perganın probiyotik etkileri de öne çıkan bir diğer özelliğidir. Fermantasyon sürecinde üreyen laktik asit bakterileri, sindirim sistemi mikroflorasını düzenler ve zararlı mikroorganizmaları baskılar. Bu da sindirim sağlığını destekler ve bağışıklık sistemini güçlendirir.

Ayrıca, pergadaki karbonhidratlar, enerji kaynağı olarak metabolizma tarafından hızla kullanılabilir. Bu özellik, fiziksel yüksek performans gerektiren durumlarda enerji seviyelerini destekler. Lipit içeriği ise hücre membranı yapısı ve hormonal denge için kritik önem taşır.

Apiterapide yaygın olarak kullanılan perga, antioksidan ve antiinflamatuar etkileri nedeniyle kardiyovasküler hastalıkların önlenmesinde faydalı olabilir. Bağışıklık sistemini destekleyen özellikleri ise enfeksiyonlara karşı korunmada önemlidir. Sindirilebilirliğinin yüksek olması, pergayı hem genel sağlığı destekleyen bir gıda hem de modern beslenme rejimlerinde yer bulabilecek bir fonksiyonel ürün haline getirmektedir.

5. Perganın Kimyasal Bileşimi ve Besin İçeriği

Perganın kimyasal bileşimi, onu diğer arı ürünlerinden ayıran çok yönlü bir yapıya sahiptir. Coğrafi bölge, bitki çeşitliliği ve mevsimsel farklılıklar gibi etkenler pergada bulunan besin maddelerinin miktarını etkileyebilir. Ancak genel olarak perganın ana bilesenleri şunlardır:

5.1.Makro ve Mikro Besinler

Perganın kimyasal bileşimi oldukça zengindir ve insan sağlığına faydalı olan makro ve mikro besinleri içerir. Bu besinler, hem enerji sağlayıcı hem de metabolizmayı destekleyici özelliklere sahiptir. İşte pergada bulunan temel makro ve mikro besinler:

- **Proteinler:** Pergadaki protein oranı %20-25 arasında değişiklik gösterir ve bu proteinler, özellikle esansiyel amino asitler açısından zengindir. Valin, izolösin ve lösin gibi dallı zincirli amino asitler, kas protein sentezini destekler ve fiziksel dayanıklılığı artırır (Pascoal ve ark., 2014; Kieliszek ve ark., 2018). Bu proteinler, bağışıklık sistemini güçlendirmeye de yardımcı olur.

- **Karbonhidratlar:** Enerji sağlamak için pergadaki karbonhidratlar kritik bir rol oynar. Genellikle %35-50 oranında bulunan glikoz ve fruktoz gibi basit şekerler, hızlı enerji kaynağıdır. Fermantasyon sürecinde bu şekerlerin bir kısmı laktik asit bakterileri tarafından organik asitlere dönüştürülerek pergaya probiyotik özellikler kazandırır (Campos ve ark., 2008; Gilliam ve ark., 1974).
- **Yağlar:** Pergada %1-5 oranında yağ bulunur ve bu yağlar, doymamış yağ asitleri açısından zengindir. Omega-3 ve omega-6 yağ asitleri, hücre zarlarının yapısını korur ve anti-inflamatuar etkiler sunar (Markiewicz-żukowska ve ark., 2013).
- **Vitaminler:** Perga, B1, B2, B6, C ve E vitaminlerini içerir. Bu vitaminler, metabolik süreçleri destekler, antioksidan koruma sağlar ve genel sağlığı iyileştirir. Özellikle C vitamini, bağışıklık sistemini güçlendiren önemli bir bileşendir (Bakour ve ark., 2017).
- **Mineraller:** Pergadaki mineraller arasında kalsiyum, magnezyum, potasyum, demir ve çinko öne çıkar. Kalsiyum kemik sağlığını desteklerken, demir kansızlık riskini azaltır. Çinko ise bağışıklık sisteminin düzgün çalışmasını sağlar (Ciric ve ark., 2022).

Sonuç olarak, perganın içerdiği makro ve mikro besinler, hem enerji üretimini destekleyen hem de bağışıklık sistemini güçlendiren özelliklere sahiptir. Bu zengin besin profili, pergayı hem insan sağlığı için değerli bir gıda hem de apiterapide kullanılan önemli bir ürün haline getirir.

5.2.Fenolik Bileşikler ve Antioksidanlar

Pergadaki fenolik bileşikler, antioksidan ve antiinflamatuar etkileriyle öne çıkan temel bilesenlerdir. Bu bilesenler, serbest radikalleri etkisiz hale getirerek hücre hasarını önler ve kronik hastalıkların riskini azaltır. Fenolik bileşiklerin etkinliği, polenin fermantasyonu sırasında artar ve bu durum pergaya benzersiz bir antioksidan potansiyel kazandırır (Markiewicz-żukowska ve ark., 2013; Bakour ve ark., 2017).

5.2.3 Fenolik Asitler ve Etkileri

- **p-Kumarik Asit:** Antioksidan kapasitesi yüksek olan bu fenolik asit, serbest radikalleri etkisiz hale getirir ve oksidatif stresin azaltılmasında kritik bir rol oynar. Ayrıca, iltihaplanmayı azaltarak dokularda iyileşme sürecini hızlandırabilir (Campos ve ark., 2008).
- **Cinnamik Asit ve Türevleri:** Bu bileşikler, lipid peroksidasyonunu engelleyerek hücre zarlarının korunmasına katkı sağlar ve kardiyovasküler hastalıkların riskini azaltabilir (Kieliszek ve ark., 2018).

5.3.Flavonoidler ve Antioksidan Kapasiteleri

Flavonoidler, pergadaki temel bilesenlerden biridir ve güçlü antioksidan etkileriyle bilinir. Şu flavonoidler öne çıkar:

- **Kaempferol:** Antioksidan ve antikarsinojenik etkiler gösterir. Araştırmalar, kaempferolün kanser riskini azaltabileceğini ve oksidatif stresin düşürülmesine yardımcı olduğunu göstermiştir (Zerdani ve ark., 2011).
- **Quercetin:** Bu bileşik, antiinflamatuar etkiler sunarak bağışıklık sistemi üzerine olumlu katkı sağlar. Ayrıca, DNA hasarını önler ve hücre yenilenmesini destekler (Pascoal ve ark., 2014).

5.4.Antioksidan Etkiler ve Kronik Hastalıklar

Pergadaki fenolik bileşiklerin antioksidan etkileri, oksidatif stresle bağlı rahatsızlıkları azaltabilir. Kardiyovasküler hastalıklar, diyabet ve nörodejeneratif hastalıklar gibi rahatsızlıklarda perganın destekleyici bir rol oynadığı bildirilmektedir (Campos ve ark., 2008; Markiewicz-żukowska ve ark., 2013).

5.5.Biyoaktif Bileşenlerin Sinerjisi

Fenolik bileşiklerin antioksidan etkileri, pergada bulunan diğer biyoaktif bilesenlerle sinerjik bir şekilde çalışarak toplam etkinliği artırır. Karotenoidler, vitamin C ve E gibi antioksidanlar bu sinerjiyi destekleyen önemli bileşenlerdir (Bakour ve ark., 2017). Bu kombinasyon, perganı hem fonksiyonel bir gıda hem de apiterapide kullanılabilir değerli bir ürün haline getirir.

5.6.Gelecekteki Araştırmalar

Fenolik bileşiklerin pergadaki konsantrasyonu ve etkinliğinin coğrafi kaynağa, çiçek çeşitliliğine ve fermantasyon sürecine bağlı olarak değişiklik gösterebileceği bilinmektedir. Bu faktörlerin daha detaylı araştırılması, perganın insan sağlığı için daha etkin bir ürün olarak geliştirilmesine olanak tanıyacaktır (Kieliszek ve ark., 2018; Pascoal ve ark., 2014).

5.7.Perganın Besin İçeriği ve Fonksiyonel Gıda Potansiyeli

Perga, büyük bir fonksiyonel gıda potansiyeline sahiptir. Antioksidan, antiinflamatuar ve probiyotik etkileri, onu insan sağlığı için benzersiz bir gıda haline getirir. Bu özellikler, perganın apiterapideki rolünü pekistirirken, aynı zamanda modern beslenme rejimlerinde daha geniş bir yer edinmesini sağlar.

6. Perganın Fiziksel ve Biyolojik Özellikleri

6.1.Fiziksel Özellikler

Perga, sert ve kompakt bir yapıya sahiptir ve genellikle koyu kahverengi, sarı veya turuncu tonlarında görülür. Fermantasyon sürecinde polenin fiziksel yapısında meydana gelen değişiklikler, pergaya kendine has bir tat, koku ve doku kazandırır. Bu benzersiz fiziksel özellikler, pergayın hem arılar hem de insanlar tarafından kolayca tanınmasını sağlar (Gilliam ve ark., 1974).

Fermantasyonun sonucunda ortaya çıkan laktik asit, pergaya hafif asidik bir lezzet verirken dayanıklılığını da artırır. Bu özellik, perganın uzun süre bozulmadan saklanabilmesine ve gıda olarak tüketimine uygun hale gelmesine katkı sağlar. Perganın sert ve yoğun dokusu, şekil ve boyutunun polenin orijinal kaynağına bağlı olarak değişiklik göstermesine neden olur (Olofsson ve Vásquez, 2008).

Perganın fiziksel özellikleri, onun dayanıklılık sürecinde ve mikrobiyal bozulmalara karşı korunmasında kritik rol oynar. Laktik asit bakterilerinin fermantasyon sürecinde oluşturduğu organik asitler, perganın sert yapısını koruyarak patojenik mikroorganizmaların yerleşmesini engeller (Kieliszek ve ark., 2018). Ayrıca, fermantasyon sırasında meydana gelen biyokimyasal değişimler, pergayı fiziksel açıdan daha kararlı bir hale getirir.

Perga ayrıca kendine has bir aromaya sahiptir. Bu aroma, içeriğindeki fenolik bileşikler, flavonoidler ve organik asitlerden kaynaklanır (Markiewicz-żukowska ve ark., 2013). Fermantasyon sļrecinin yoğunluğu, polenin bitkisel kaynağı ve arıların bu fermantasyona katılım oranı, pergadaki aroma ve tat profilini etkileyen temel faktörlerdir.

Sonuç olarak, perganın fiziksel özellikleri, onun hem arılar için besin kaynağı olarak etkinliğini hem de insanlar için fonksiyonel bir gıda olarak değerini artırmaktadır. Bu özelliklerin bilimsel açıdan daha detaylı incelenmesi, perganın depolama ve kullanım olanaklarının daha iyi anlaşılmasına katkı sağlayacaktır.

6.2.Antimikrobiyal ve Antiviral Özellikler

Perganın antibakteriyel ve antiviral etkileri, içeriğindeki fenolik bileşikler, flavonoidler, organik asitler ve laktik asit bakterilerinden kaynaklanmaktadır. Laktik asit bakterileri, pergadaki fermantasyon sürecinde laktik asit üreterek pHı düşürür ve patojen mikroorganizmaların çoğalmasını engeller (Gilliam ve ark., 1974; Olofsson ve Vásquez, 2008). Perganın düşük pH değeri, bakteri ve mantar enfeksiyonlarına karşı etkili bir koruma sağlar.

Fenolik bileşikler, özellikle flavonoidler ve fenolik asitler, mikroorganizmaları baskılama potansiyeline sahiptir. Yapılan çalışmalar, pergada bulunan bu bileşenlerin Escherichia coli, Staphylococcus aureus ve Candida albicans gibi patojenlere karşı etkili olduğunu ortaya koymuştur (Zerdani ve ark., 2011; Pascoal ve ark., 2014). Flavonoidler, mikroorganizmaların hücre zarına zarar vererek üremelerini engelleyebilir. Ayrıca pergadaki tanenlerin antimikrobiyal etkisi, patojenik bakterilerin büyük bir kısmına karşı etkili olduğunu göstermiştir.

Virüsler üzerindeki etkileri ise özellikle RNA ve DNA tabanlı virüsler üzerinde gözlemlenmiştir. Pergada bulunan fenolik asitler ve flavonoidler, virüslerin hücre içine girişini engelleyebilir veya replikasyon sürecini baskılayabilir. Bu etkiler, influenza ve herpes simpleks virüsleri gibi yaygın patojenler üzerine odaklanılan çalışmalarla desteklenmiştir (Bakour ve ark., 2017; Campos ve ark., 2008).

Pergadaki antimikrobiyal etkilerin bir diğer önemli kaynağı da organik asitlerdir. Laktik asit, asetik asit ve propiyonik asit gibi bileşenler, zararlı mikroorganizmaların çoğalmasını engelleyerek hem arı sağlığı hem de insanlar üzerinde koruyucu bir etki sağlar (Kieliszek ve ark., 2018).

Sonuç olarak, pergadaki fenolik bileşikler, laktik asit bakterileri ve organik asitlerin sinerjik etkisi, onu hem antimikrobiyal hem de antiviral potansiyel taşıyan doğal bir ürün haline getirmektedir. Bu özellikler, pergayın apiterapide ve fonksiyonel gıda uygulamalarında geniş çapta kullanılmasını desteklemektedir.

6.3.Antioksidan Özellikler

Perga, zengin antioksidan içeriği ile serbest radikalleri etkisiz hale getirerek hücre hasarını önleyen çok yönlü bir gıdadır. Fenolik asitler, flavonoidler, karotenoidler ve C vitamini gibi antioksidan bileşenler, pergadaki temel aktif maddelerdir. Bu bileşenler, oksidatif stresi azaltmada ve hücre yenilenmesini desteklemede çok önemli bir rol oynar (Campos ve ark., 2008; Kieliszek ve ark., 2018).

Fenolik bileşikler, vücuttaki serbest radikallerin nötrleştirilmesine katkı sağlayarak kardiyovasküler hastalıkları, diyabet ve nörodejeneratif hastalıklar gibi kronik rahatsızlıkların riskini azaltabilir (Markiewicz-żukowska ve ark., 2013). Ayrıca, fenolik asitlerin antiinflamatuar etkileri, dokularda iyileşme sürecini hızlandırabilir ve vücudun genel enflamasyon seviyesini azaltabilir.

Flavonoidler arasında yer alan kaempferol ve quercetin gibi bilesenler, perganın antioksidan kapasitesini daha da artırmaktadır. Bu bileşenler, lipid peroksidasyonunu engelleyerek hücre zarlarını korur ve DNA hasarını önler (Zerdani ve ark., 2011; Pascoal ve ark., 2014). Karotenoidler ise göz sağlığını destekleyen önemli bir bileşendir ve cilt korumasında etkili rol oynar.

Pergada bulunan antioksidanlar ayrıca bağışıklık sistemini destekleyerek enfeksiyonlara karşı direnci artırabilir (Gilliam ve ark., 1974). Antioksidan içeriğinin coğrafi kaynaklara ve bitki türlerine bağlı olarak değişiklik göstermesi, pergayın zengin biyoaktif potansiyelini vurgular. Genel olarak, perga, modern beslenme ve apiterapi uygulamalarında kritik bir bileşen olarak dikkat çekmektedir.

6.4.Perganın Biyolojik Faydaları

Perga, sadece fiziksel ve kimyasal özellikleri ile değil, aynı zamanda biyolojik faydaları ile de dikkat çekmektedir. Probiyotik içeriği sayesinde, insan ve hayvan sindirim sistemini destekler. Laktik asit bakterilerinin etkisiyle, sindirim kanalındaki yararlı bakterilerin sayısı artarken zararlı mikroorganizmaların büyümesi baskılanır. Bu durum, sindirim sistemi sağlığının korunması ve genel bağışıklık sisteminin güçlenmesi için önemlidir.

Ayrıca, pergadaki besin maddeleri, enerji seviyelerini destekleyerek fiziksel dayanıklılığı artırabilir. Kronik yorgunluk, stres ve düşük enerji gibi durumların tedavisinde destekleyici bir rol oynayabilir. Bu biyolojik faydalar, pergayı hem insanlar hem de arı kolonileri için benzersiz bir besin kaynağı haline getirir.

7. TARTIŞMA

Perganın kimyasal ve biyolojik özellikleri, hem arılar hem de insanlar için eşsiz bir besin kaynağı olduğunu açıkça göstermektedir. Arılar için enerji, protein ve bağışıklık desteği sağlarken, insanlar için fonksiyonel bir gıda ve terapötik bir ürün olarak potansiyel taşımaktadır. Laktik asit fermantasyonu süreci, pergaya probiyotik özellikler kazandırmakla kalmaz, aynı zamanda fenolik bileşiklerin etkinliğini artırarak antioksidan, antiinflamatuar ve antimikrobiyal etkileri de güçlendirmektedir (Olofsson ve Vásquez, 2008; Gilliam ve ark., 1974).

Bilimsel araştırmalar, pergadaki fenolik bileşiklerin ve flavonoidlerin oksidatif stresin azaltılmasında etkili olduğunu ve böylece kardiyovasküler hastalıklar, diyabet ve nörodejeneratif rahatsızlıklar gibi kronik hastalıkların riskini azaltabileceğini göstermektedir (Markiewicz-żukowska ve ark., 2013; Bakour ve ark., 2017). Bu özellikler, pergayı modern beslenme yaklaşımlarında ve apiterapi uygulamalarında kritik bir unsur haline getirmektedir.

Arı beslenmesinde pergaya olan ihtiyaç, özellikle stresli çevresel koşullarda ve hastalık salgınlarında daha belirgin hale gelir. Araştırmalar, pergadaki probiyotik mikroorganizmaların arıların bağırsak sağlığını desteklediğini ve patojenlere karşı koruma sağladığını doğrulamaktadır (Campos ve ark., 2008; Kieliszek ve ark., 2018). Bununla birlikte, pergadaki biyoaktif bileşenlerin insan sağlığı üzerindeki olumlu etkileri, onu yalnızca bir besin kaynağı değil, aynı zamanda tedavi edici bir ürün olarak konumlandırmaktadır.

Perganın tıbbi ve besinsel potansiyelinin tam anlamıyla anlaşılması için daha fazla araştırmaya ihtiyaç vardır. Özellikle coğrafi köken, bitkisel kaynaklar ve fermantasyon sürecinin pergadaki biyoaktif bileşikler üzerindeki etkileri daha derinlemesine incelenmelidir. Ayrıca, pergayla ilgili daha fazla klinik çalışma, bu ürünün insan sağlığı üzerindeki uzun vadeli etkilerini anlamak için önemlidir.

Sonuç olarak, perga hem geleneksel hem de modern uygulamalarda geniş bir kullanım alanı sunmaktadır. İnsan beslenmesinde fonksiyonel bir gıda olarak sunduğu fırsatların yanı sıra, apiterapi ve tıbbi uygulamalarda da dikkat çekici bir rol oynamaktadır. Gelecekte yapılacak kapsamlı araştırmalar, pergayı daha geniş bir perspektiften anlamamıza ve kullanmamıza olanak sağlayacaktır.

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