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An Overview of Alternative Feed Sources in Honey Bee Nutrition#

ABSTRACT

Honey bee nutrition is crucial for the health, production, and longevity of their colonies. Honey bees obtain the vast majority of their carbohydrates from nectar. Pollen is a major source of macro and micronutrients, such as proteins, lipids, sterols, vitamins, and minerals. These nutrients are essential for brood development, hypopharyngeal gland function, enzyme synthesis, and reproductive efficiency. Nutritional stress can arise as a result of seasonal food scarcity, habitat loss, intensive agricultural practices, and the effects of climate change. To mitigate these stressors, researchers rigorously examine the formulation and evaluation of supplemental feeds and alternative sources, highlighting their nutritional composition, functional properties, and health benefits. This review comprehensively presents current scientific research on the nutritional requirements of honeybee colonies and the application of alternative feeds, considering evidence-based colony management strategies and ecologically advantageous beekeeping practices.

Keywords: Apis mellifera L., nutritional ecology, nutritional requirements, feed substitutes

Bal Arısı Beslenmesinde Alternatif Yem Kaynaklarına Genel Bakış

Öz

Bal arılarının beslenmesi, kolonilerinin sağlığı, üretimi ve uzun ömürlülüğü için çok önemlidir. Bal arıları karbonhidratlarının büyük çoğunluğunu nektardan elde eder. Polen, proteinler, lipitler, steroller, vitaminler ve mineraller gibi makro ve mikro besin maddelerinin önemli bir kaynağıdır. Bu besin maddeleri, yavru gelişimi, hipofaringeal bez fonksiyonu, enzim sentezi ve üreme verimliliği için gereklidir. Beslenme stresi, mevsimsel yiyecek kıtlığı, habitat kaybı, yoğun tarım uygulamaları ve iklim değişikliğinin etkileri sonucu ortaya çıkabilir. Bu stres faktörlerini azaltmak için araştırmacılar, besin bileşimlerini, fonksiyonel özelliklerini ve sağlık yararlarını vurgulayarak, ek yemlerin ve alternatif kaynakların formülasyonunu ve değerlendirmesini titizlikle incelerler. Bu derleme, kanıta dayalı koloni yönetim stratejilerini ve ekolojik açıdan avantajlı arıcılık uygulamalarını dikkate alarak, bal arısı kolonilerinin beslenme gereksinimleri ve alternatif yemlerin uygulanması üzerine güncel bilimsel araştırmaları kapsamlı bir şekilde sunmaktadır.

Anahtar Kelime: Apis mellifera L., beslenme ekolojisi, beslenme gereksinimleri, yem ikameleri



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INTRODUCTION

Honey bees are important because they help with pollination and make honey and other useful bee products for people. Recent years have witnessed a rise in colony losses attributed to climate change, insufficient high-quality nutrients (pollen and honey), habitat degradation, diseases, and parasitic infestations (Figure 1) (Stanimirović et al. 2019; Oskay & Oskay, 2023; Quinlan & Grozinger, 2023).

Social insects and other animals seek food to grow and reproduce. Honey bees must meet their own requirements and acquire food for the colony (Latshaw & Smith, 2005; Tait & Naug, 2022). In a colony, worker bees gather nectar, pollen, water, and propolis as needed. The queen bee and worker bees' genetics determine the colony's pollen-gathering behavior and whether workers collect pollen or nectar. Although they specialize in pollen and nectar, foraging bees can collect both at once (Wright et al. 2018; Lemanski, 2019; Ghosh et al. 2020; Grume, 2021). Climate change, habitat loss, the rise of monoculture farming, and pesticide use all harm the places where honey bees forage (Quaresma et al. 2026). This means that diverse food sources need to be managed and protected. Flower pollen contains proteins, lipids, vitamins, and minerals. Nectar, on the other hand, is a type of carbohydrate that has sugar in it. The quality and availability of food sources for honey bees depend on several factors. Recent studies show that finding the right balance between carbohydrates and pollen can greatly improve the health, lifespan, and strength of honey bee colonies. This is useful information for beekeepers who want to manage their bees' diets (Ansaloni et al. 2025; Najarpour et al. 2026).

As it turns out, because the health and productivity of honey bee colonies depend on nutrition and honey bees are vital for global food security, providing them with adequate, balanced nutrition is crucial not only for beekeepers but also for researchers and farmers involved in agricultural production. This review focuses on the nutrition of honey bees, presenting current information from the literature on nutritional requirements and feed substitutes.

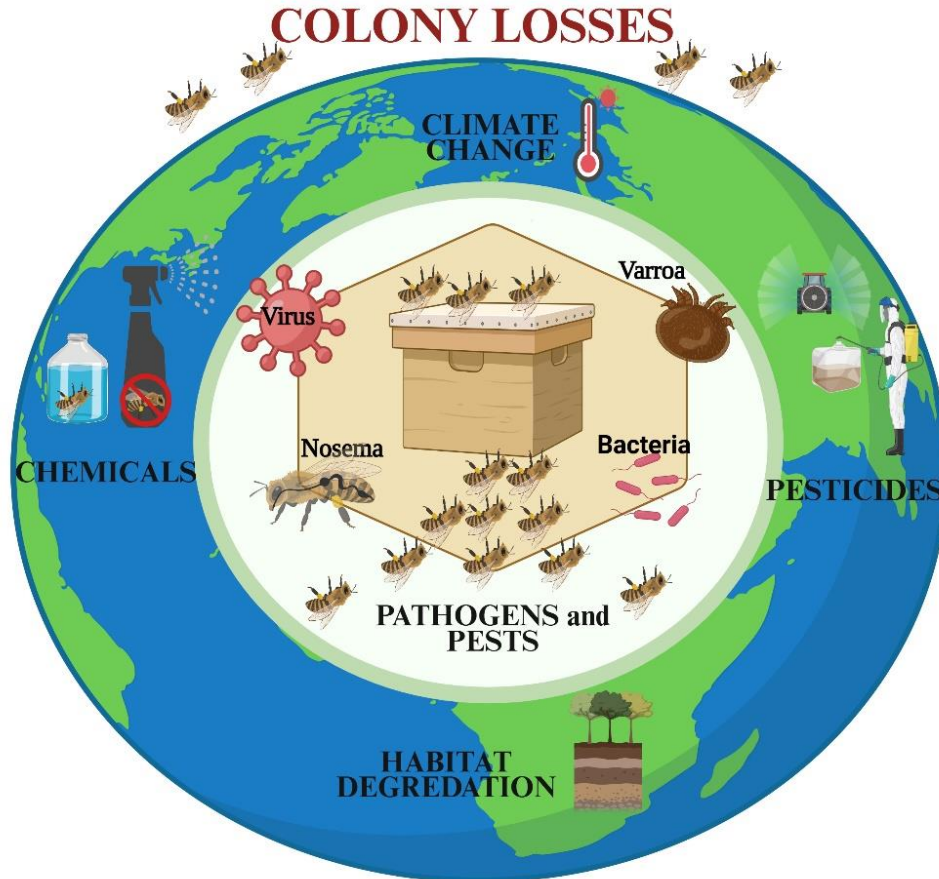


Figure 1. Determinants of colony losses (Oskay, 2026)

Şekil 1. Koloni kayıplarının belirleyicileri



Replacement Nutritional Supplements for Honey Bee Nutrition

The vegetation available to honeybees in various climates affects beekeeping production. Researchers and beekeepers utilize migratory beekeeping, which involves moving bee colonies to areas with abundant flowers due to adverse weather conditions and insufficient vegetation in some regions. This transportation process is expensive, time-consuming, and dangerous. During these periods, it is important to encourage honeybee colonies to lay eggs, raise brood, and forage for food by providing alternative food sources to increase their strength. Even though there have been a lot of studies on honey bee nutrition, we still don't know enough about what honey bees need to feed on when they are under biotic and abiotic stressors. At present, there is no superior alternative food to nectar and pollen that can adequately maintain honey bee colonies over the long term (Wright et al. 2018; Sonmez Oskay et al. 2025). Nevertheless, the combination of diverse components has led to the development and examination of numerous nutritional formulas by researchers globally for commercial apiculture (Oskay & Sonmez Oskay, 2017; Ahmad et al. 2021; Oliver, 2021; Lata et al. 2023; Oskay & Oskay, 2023; Oskay et al. 2023; Přidal et al. 2023). Figure 2 presents a visual representation of the information presented under subheadings regarding the nutritional sources covered in the formulas, the methods of administration to the colony, and the health and performance of honey bees.

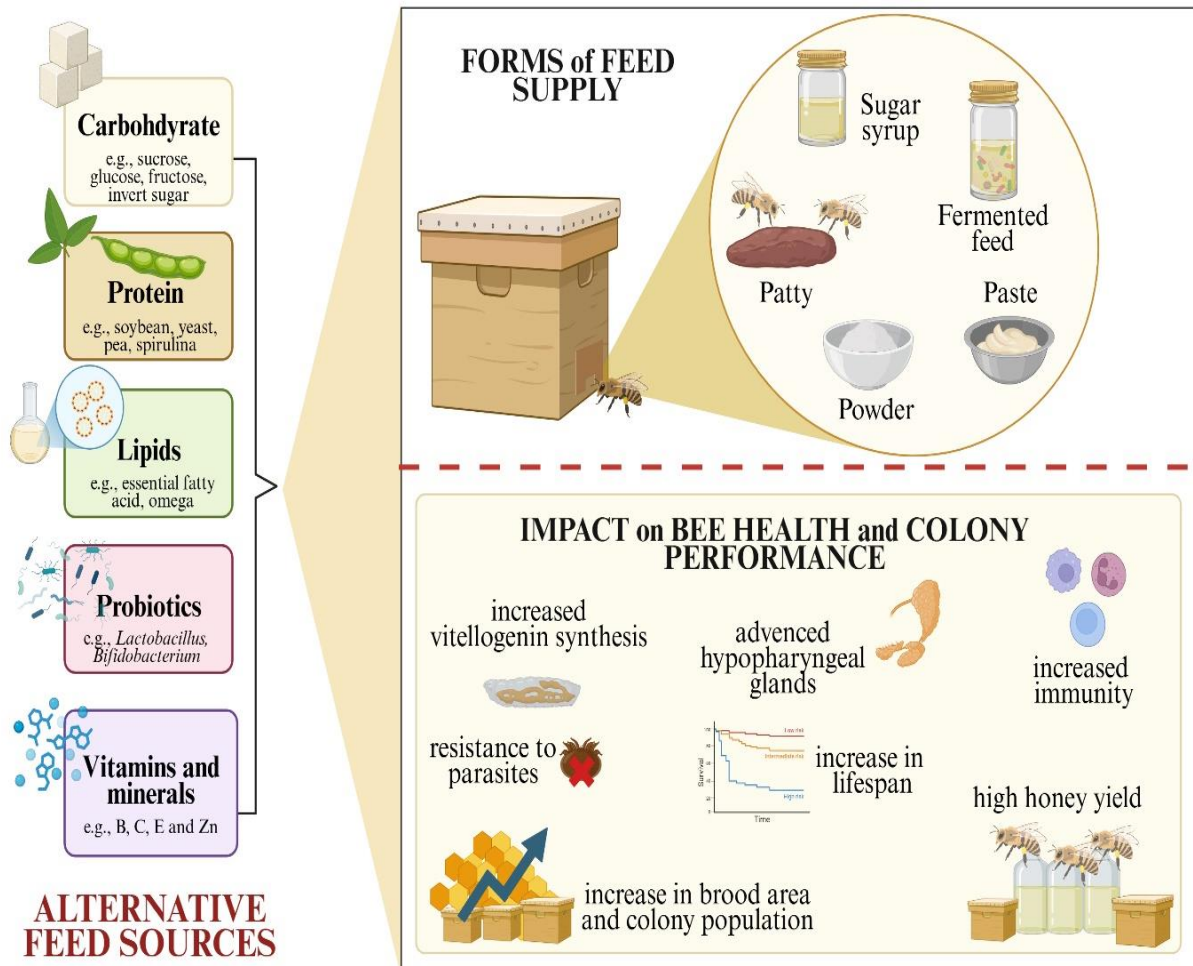


Figure 2. Alternative feed sources used in honey bee nutrition, methods of administration to the colony, and their effects on honey bee health and colony performance (Oskay, 2026)

Şekil 2. Bal arısı beslenmesinde kullanılan alternatif yem kaynakları, koloniyeye uygulama yöntemleri ve bunların bal arısı sağlığı ve koloni performansı üzerindeki etkileri.



Carbohydrate sources

Carbohydrates are the main source of nutrition for honey bee colonies. Their primary role is to provide energy for the essential functions of specific organs and glands, including muscle movement, temperature regulation, and the creation of beeswax. Although the sugar concentration in plant nectar varies from 10 to 70%, it is well known that worker bees prefer plants with nectar containing 30 to 50% sugar. Research indicates that the carbohydrate nutritional requirements of honey bees escalate with age, as older worker bees ingest up to 60% more carbohydrates than their younger counterparts aged 0-7 or 8-14 days. Given that an individual worker bee needs approximately 11 mg of dry sugar per day, a colony with an average of 50.000 bees requires approximately 318 kg of sugar per year (Paoli et al. 2014; Tsuruda et al. 2021). Besides, the phytochemicals in nectar are largely beneficial to honey bees. Phenolic acids and flavonols are the most common phytochemicals. Two compounds (p-coumaric acid and quercetin) from the phenolic acids and flavonols are known to support honey bee health. Studies show that phytochemical consumption in honey bees prolongs lifespan, reduces nosema infection, modifies honey bee genes with antimicrobial properties, and eliminates pesticide stress (Tsuruda et al. 2021; Gawali & Waykar, 2025).

Beekeepers provide their colonies with carbohydrate-dense sustenance during periods of nectar scarcity, inclement weather, or after the honey harvest. The colonies are provided with liquid sugar syrup in spring and autumn, and with dry or fondant sugar in winter when honey bees are affected by low temperatures (Mogren et al. 2018; Přidal et al. 2023; Quinlan et al. 2023). Beekeepers all over the world use corn syrup, high fructose corn syrup, sucrose, and invert sugar syrups. High fructose corn syrup (HFCS) is made by breaking down maize starch. In its liquid form, it is cheaper than sucrose and requires less work to colonize. Research indicates that worker bees nourished with high fructose corn syrup had reduced lifespans compared to those provided with sugar syrup. Recent studies showed that colonies fed high-fructose corn syrup had fewer brood and fewer adult bees in the spring than colonies fed sucrose. Another one, apiculture employs maltose syrups derived from wheat starches and indigestible long-chain saccharides. Honey bees nourished with wheat starch syrup exhibit a higher incidence of Nosema disease compared to those provided with honey or sugar syrup. High glucose levels in starch syrup cause winter reserves to crystallize in honeycomb cells. Maltodextrin, on the other hand, puts stress on the bees' digestive systems, which eventually kills the colony (Wheeler & Robinson, 2014; Papežiková et al. 2020; Szczęśna et al. 2021).

The main substitute for honey for honey bees is sucrose-water syrup. In the spring, colonies get a 50% (1:1) sugar syrup, and in late autumn, they get a 66% (2:1) syrup. Depending on the needs of the colony, the syrup is made with 1:1 for brood rearing and 2:1 for winter sustenance. Before making the syrup, the water is heated to stop microbes from growing. The water is then cooled to 40°C. Add sugar and stir until it is completely dissolved. Then give the colony the syrup when it cools to 25–30 °C. Beekeepers find it not always easy to make a lot of sucrose syrup for beekeeping. It takes a long time to make, it ferments quickly, and colonies can steal from each other (Oskay & Sonmez Oskay, 2017; Hu et al. 2024).

Invert sugar, similar to honey sugar, is produced by hydrolyzing sucrose into fructose and glucose derived from beet and sugarcane plants. Inversion is often achieved by heating sucrose syrup with acids, alkalis, or invertase. Honey bees that consume acid-hydrolysis invert syrup have a lot of damage to their stomach epithelium. Invertase enzymes break down sucrose into glucose and fructose in invert sugar syrup. The syrup is thick like honey and is not likely to ferment or crystallize. Enzymatically processed invert sugar syrup is the second-best food for honey bees, after honey (Oskay & Sonmez Oskay, 2017; Hu et al. 2024). Recent studies indicate that colonies provided with invert sugar throughout winter exhibit heightened activity in pollen foraging, enhanced brood rearing, and improved readiness for the onset of the active season. Invert sugar is a good sugar supplement for honey because it helps bees gather more pollen (Abdella et al. 2026).

5-Hydroxymethylfurfural (HMF) is a natural compound that doesn't hurt the quality of honey at low levels. The formation of HMF in honey bee diets depends on the type of sugar, pH, temperature, water content, and the presence of divalent cations. Research shows that the lethal dose of HMF for honey bees ranges from 150 to 750 mg/kg of diet. Field studies of bees eating HMF-infused feed show that colonies can survive 40 to 150 mg HMF/kg. The amount of HMF in syrups for feeding colonies should not be more than 20 mg/kg, which is the same as most honeys (Oskay & Sonmez Oskay, 2017; Gregorc et al. 2019; Fakhlai et al. 2020; EFSA et al. 2022).



Protein sources

Honey bee colonies require pollen for proteins, lipids, vitamins, and minerals essential for brood development and the longevity of adult worker bees. The vigor of honey bee colonies and the supply of pollen are contingent upon their geographic location and floral resources (Haydak, 1970). The protein composition of floral pollen varies from 2.5% to 61%. A colony of 20,000 honey bees gathers 57 kg of pollen each year, with 15–30% of the worker bees engaged in this activity (Tsuruda et al. 2021).

Beekeepers use pollen replacements and supplements to enhance brood survival and extend the lifespan of adult bees when local flora is inadequate throughout the year. In colonies with developing honey bees and worker bees, the diet must consist of pollen from flowers or alternative protein sources. Bees may not receive adequate nutrition due to pollen's deficiency in amino acids. Papaver somniferum pollen is an excellent option for beekeeping because of its substantial nutritious composition, as indicated by a study on protein-rich pollen sources and fall colony development and honey bee longevity in vitro (Topal et al. 2022).

Adult worker bees provided with low-quality pollen diets exhibited reduced lifespans, diminished immunity, and decreased tolerance to diseases and pests. Beekeepers give honey bee colonies pollen substitutes or supplements that contain pollen when there isn't enough pollen to keep the colonies strong. Modern pollen substitutes should be tasty, healthy, cheap for beekeepers, long-lasting, and easy to give to colonies. Beekeepers like pollen as a protein source for colony food, but getting large amounts from outside sources is expensive and can lead to disease or chemical contamination (Amro et al. 2020; Paray et al. 2021; Kim et al. 2022; Kim et al. 2024). Proteins exert considerable influence on physiological processes, including immunological response, parasite tolerance, survival, worker bee longevity, drone reproductive quality, brood rearing, adult population development, and royal jelly synthesis. The protein concentration in pollen substitute meals for honey bee nutrition varies between 5 and 25% (Fleming et al. 2015; Olgun et al. 2020; Ghramh & Khan, 2023).

These diets include protein from plants (like soy, corn, chickpeas, wheat, lentils, and sorghum), animals (like eggs and milk), and bacteria. Soy meal is the most common substitute for pollen in honey bee diets because it is cheap and easy to find. However, soy has protease inhibitors and bad carbs. Consequently, lactose-containing milk powder is an inadequate substitute for protein. Even though common animal products like eggs and whey protein can be good alternatives, their efficacy is inconsistent. When honey bees are given plant-based pollen substitutes like chickpea, corn, sorghum, and wheat flour, especially the protein-rich chickpea flour, their feeding preferences and foraging behavior change (Koru, 2018; Vrabie et al. 2019; Oskay, 2021; Darwish & Galal, 2022; Oskay & Bayrak, 2022; Oskay, & Oğuz, 2022; Khooshe-Bast et al. 2023; Migdał et al. 2024).

A diet brewer's yeast enhances egg and larval production, honey yield, and the growth of pharyngeal glands in honey bee colonies (Shawer & Mousa, 2016; Shurjeel et al. 2023). The incorporation of high-protein and high-fiber grain remnants from beer production as a protein supplement in the honey bee diet enhances hemolymph protein levels (Omar & Amro, 2023). Furthermore, algal species, microalgae (such as *Spirulina* and *Chlorella*), and processed insect larvae (e.g., yellow mealworm *Tenebrio molitor*) are emerging as promising alternatives to pollen (Ricigliano et al. 2022; Pavlović et al. 2023). Adding algal products to honey bees' diets improves queen oviposition, increases colony density, and boosts honey and beeswax production. *Spirulina* is currently used as a pollen substitute and prebiotic to improve honey bee health (Ricigliano et al. 2018; Ricigliano, 2020; Ricigliano & Simone-Finstrom, 2020; Noordyke & Ellis, 2021; Dostálková et al. 2022; Nichols & Ricigliano, 2022; Ricigliano et al. 2022; McMenamain et al. 2023). A recent pilot study indicated that colonies supplemented with a new fish protein hydrolysate exhibited enhanced foraging activity, expanded brood areas, and increased reserves of honey and bee bread (El-Din et al. 2025).

Lipids

The lipid content of pollen ranges from 1 to 20% by weight. Recent research indicates that the lipid content and omega-6:3 ratio in honey bees' bodies vary according to their dietary composition (Branchiccela et al., 2026). Furthermore, the optimal survival rate was observed in a diet comprising 4% fat and an omega-6:3 ratio of 1. An increased lipid concentration in the diet (8%) augmented brood production; however, a high omega-6:3 ratio resulted in elevated mortality and reduced brood rearing. The results indicate that both the amount and quality of dietary lipids affect colony performance (Arien et al. 2020). Sterols are lipid molecules that perform essential physiological functions in insects, acting as precursors for significant molting hormones and



constituting the fundamental components of cellular membranes. The most essential phytosterol for honey bees is 24-methylenecholesterol. Studies have shown that honey bees fed diets containing 24-methylenecholesterol have longer lifespans and higher brood production (Gawali & Waykar, 2025).

Probiotics

The intestinal microbiota in insects has an effect on their growth, reproduction, and metabolism. It enhances nutrient absorption and essential chemical synthesis. The gut microbiome conveys information regarding cell survival, apoptosis, proliferation, and inflammation through cellular receptors (Tlak Gajger et al. 2020).

Young worker bees acquire gut microbiota through oral trophallaxis with caregiver worker bees within 3-5 days. The hindguts of honey bees harbor a stable bacterial community, including 6-9 species that constitute the gut microbiota, are integrated into the host's physiological ecology, and may change with age. *Bombella apis* and *Lactobacillus kunkeei* are found in the foreguts of honey bees, while *Snograssella alvi* is found in the midgut. The hindgut of the honey bee comprises an ileum and a rectum. The ileum houses *Snograssella alvi*, *Gliamella apicola*, *Lactobacillus Firm-4 and 5*, *Bifidobacterium*, and *B. asteroides*. *Lactobacillus Firm-4 and 5*, *Bifidobacterium*, *B. asteroides*, *Bartonella apis*, and *Commensalibacter* are some of the bacteria that live in the rectum. Microbial diversity increases from the gastrointestinal tracts to the rectums of honey bees (Lyubimov et al. 2021; García-Vicente et al. 2023; Smriti et al. 2024).

More and more studies are showing that lactic acid bacteria (LABs) could be a long-term, environmentally friendly alternative to chemical methods for preventing and treating honey bee diseases. These methods are promising and eco-friendly ways to improve the health and resilience of colonies (Albanese et al., 2026). Moreover, in honey bees, probiotics improve vitellogenin signaling, increase weight, and increase gut size (Borges et al. 2021; Brown et al. 2022; Damico et al. 2023).

Research indicates that probiotics in spring sugar syrup enhance brood development, foraging behavior, and the production of honey and royal jelly. Probiotics are used in honey bee nutrition in various ways, such as in cakes, sucrose syrup suspensions, and spraying. Adding probiotics to the sugar syrup in hive feeders is the most popular method because it is easier to use, but it can cause the breakdown of bacterial cells under osmotic stress. Another method involves mixing very weak probiotics with a phosphate buffer and putting them in a spray bottle. This method is used to spray the solution throughout the hive, helping to distribute the food evenly and slow down the breakdown process (Brown et al. 2022; Damico et al. 2023; García-Vicente et al. 2023). To determine the best effects and how much honey bees feed, different amounts of probiotics can be given. The best results from using probiotics in honey bee nutrition depend on the concentration or dosage, the duration of use, and safety. Also, research is ongoing to better understand the different ways probiotics work in honey bees.

Vitamins and minerals

Vitamins and enzymes facilitate metabolic processes. Pollen contains water-soluble vitamins such as ascorbic acid, inositol, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, and biotin. B vitamins are very important for taking care of young bees. The eight essential B vitamins, which honey bees cannot synthesize, are needed for fatty acid synthesis (biotin, vitamin B7) and nucleic acid biosynthesis (folic acid, vitamin B9). Pyridoxine (vitamin B6) is necessary for honey bee brood development. In addition, worker bees lacking thiamine (B1) or riboflavin (B2) cannot develop hypopharyngeal glands (HPGs). Recent research shows that B vitamins improve colony performance. B vitamins feed colonies, build them, minimize nutritional stress, and help honey bees fight diseases (Bonoan et al. 2018; Jovanovic et al. 2021, Elsayeh et al. 2022).

Spring feedings supplemented with vitamin C (1:1 sugar syrup) enhance brood area, population size, worker bee body mass, and protein levels. Worker bees emerging from honeycomb cells have elevated levels of protein, glutathione, peroxidase, catalase, and glutathione transferase activity in conjunction with vitamin C. Vitamin C in the food of honey bees moderately reduces mite populations and enhances glucose metabolism in worker bees infested with varroa mites (Farjan et al. 2012; Andi & Ahmadi, 2014; Łopieńska-Biernat et al. 2019).

Vitamin E, which dissolves in fat, is also very important for the growth of brood. Bee bread and pollen do have some vitamins A, E, and K, but not a lot (Herbert Jr et al. 1977; Elsayeh et al. 2022; Cengiz & Erdoğan, 2023).



Administering vitamin E to honeybees enhances queen bee oviposition, colony size, and average royal jelly production each harvest (Şahinler et al. 2005; Darat et al. 2017).

Pollen comprises between 2.9-8.3% minerals (Cengiz & Erdoğan, 2023). Especially, zinc minerals are very important for honey bee nutrition. The synthesis of royal jelly proteins and metabolic processes significantly differ in colonies fed with zinc, it enhancing nutrition and maintenance (Zhang et al. 2015; de Barros et al. 2021; Behjatian-Esfahani et al. 2023; Camilli et al. 2023).

CONCLUSION

The growth and survival of a colony depend on factors such as the climate, flora, that is, the number of different types of flowers available and how often they bloom. Colonies need supplemental nutrition, especially when they have difficulty finding nectar and pollen. Recent studies show that probiotics, pollen substitutes, and vitamin and mineral supplements are effective. These bee feed additives shall be designed to satisfy the physiological and nutritional needs of honey bees without affecting honey composition, bee products quality or consumer safety. Plant-based ingredients with proven bioavailability and digestibility, such as legume proteins, yeast-derived products, microalgae and selected medicinal plant extracts are promising candidates for future bee nutrition programs. However, more research is needed to determine the long-term effects of these solutions, their appropriate formulations, and their safety and effectiveness under various environmental stresses. Beekeepers should use additional feeding sparingly when nutrition is lacking, particularly in early spring, when colonies need to build up, queens need to be raised, and colonies need to prepare for winter. Substitute and/or alternative diets should serve as supplements rather than supplanting natural and diverse nutrients. Future research should aim to assess the effects of alternative feed components on honeybee physiology, gut microbiome, immunological responses, stress resistance, productivity, and the quality of bee products. Development of scientifically proven and economically viable feed formulations will encourage sustainable beekeeping practices, strengthen colony resilience, and improve pollination services amid changing environmental conditions.

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