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Minireview

Nutrition for Honey Bee to Prevent Colony Collapse

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Abstract The honey bee is a globally important pollinator for wild plants and cultivated crops. On the other hand, beehives have been significantly affected by a variety of factors, including chemical exposure, pathogen infection, and a decrease in floral diversity. A healthy honeybee is able to withstand many of the stresses of modern apiculture. This review of previous studies demonstrates how healthy nutrients affect bee colonies. The development of an optimal honey bee diet may one day save the honey bees' future. It is anticipated that the current findings will aid in the creation of a diet with appropriate nutrients for honey bees.

Keywords Nutrition, Macronutrient, Micronutrient, pH, Role differentiation

INTRODUCTION

Honey bees as pollinators are essential to wild plants and commercial crops (Williams, 1994).

However, colony losses of up to 45% per year have been experienced by US beekeepers since 2006 (Azzouz-Olden *et al*., 2018). Globally, the colony collapse disorder (CCD) and the disappearance of honeybees during overwintering this year in South Korea caused great damage nationwide (Flores *et al*., 2021). Researchers claim that the CCD phenomenon cannot be attributed to a single source but rather to the intricate interactions of several processes (Flores *et al*., 2021). Increased losses from invasive mites, diseases like viruses and parasites, exposure to insecticides or mite pesticides, stress from mobile beekeeping, habitat changes, inadequate feed, and nutrition, decreased immunity, and stress from a variety of other factors are some of the causes (Fig. 1). According to Goulson *et al*. (2015) numerous studies on the nutrition of honey bees have suggested that malnutrition-related stress may play a significant role in CCD (Goulson *et al*., 2015). Many of the stresses of modern apiculture can be overcome by a well-nourished honey bee (Kim *et al*., 2022). Additionally, a consistent supply of pollen can help the colonies grow and encourage brood rearing (Morais *et al*., 2013). Thus, the hive's food reserve and nutrition have an impact on honey bee growth (Fleming *et al*., 2015).

Honey bees, like all other animals, require particular nutrients (Saffari *et al*., 2010). Vitamins, minerals, lipids (fatty acids and sterols), water, and proteins (amino acids) are necessary for honey bees. According to Standifer (1980), these nutrients must be included in the diet in the right quantities. Macronutrient-rich carbohydrates, proteins, and lipids are essential for honey bee growth and maintenance, while vitamins, minerals, phytochemicals, and other micronutrients are not only necessary but crucial for the preservation of honey bee health (Retschnig *et al*., 2021).

Nectar and pollen are honey bees' primary sources of nutrition (Winston, 1991). Nectar is the main source of carbohydrates. Pollen contains lipids, amino acids, starches, sterols, vitamins, and minerals, all of which have an impact on honey bees' lifespan and survival (Table 1). Pollen is the primary source of protein for honey bees. In this review, previous studies demonstrate how these

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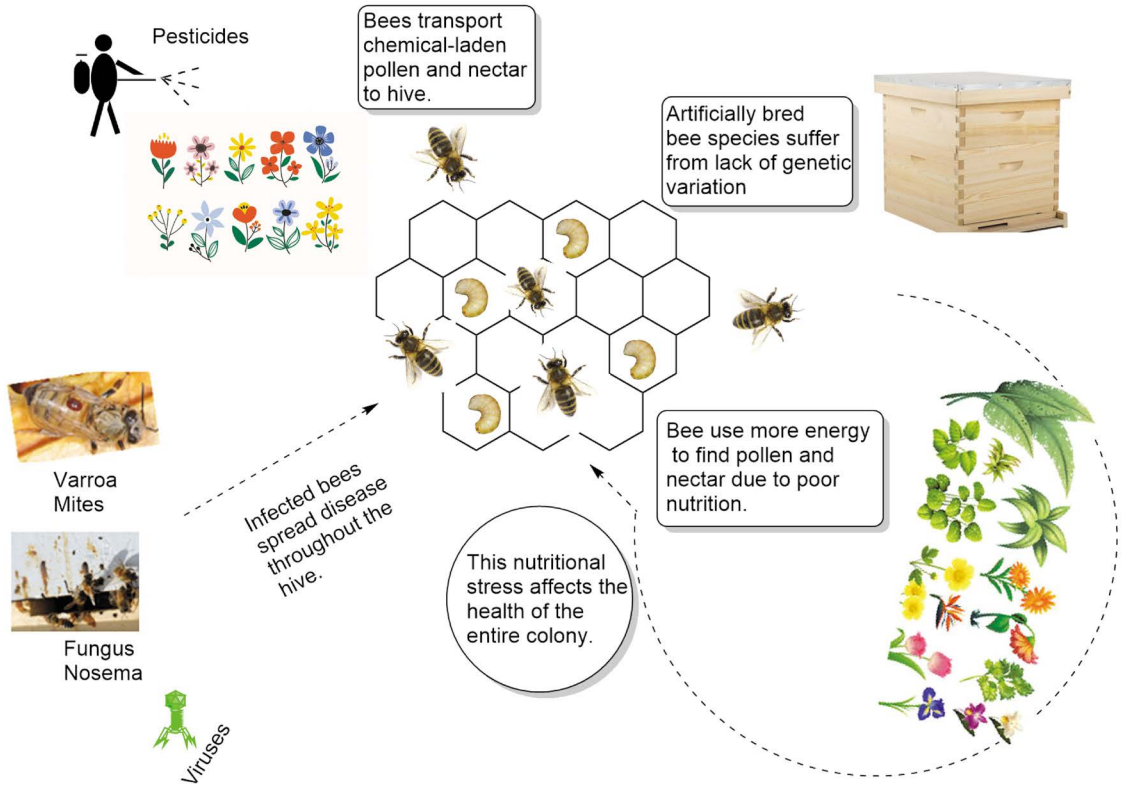

Fig. 1. There are several reasons for the increase in honey bee losses. The reason cannot be linked to a single source but rather to the complex interactions of a number of processes. A well-nourished honey bee can overcome many of the challenges associated with modern apiculture.

Table 1. Main nutrition components in pollen (Campos *et al*., 2008)

Main components	g/100 g dry weight
Proteins	10–40
Lipids	1–13
Carbohydrates	13–55
Dietary fibre	0.3–20
Ash	2–6

macronutrients and micronutrients affect bee colonies and mention the relationship between nutrition and role differentiation.

MACRONUTRIENT

1. Carbohydrates

According to Winston (1991), nectar contains 82% carbohydrates and 17% water, making it a significant source of carbohydrates for honey bees (Winston, 1991). Carbohydrates are stored in a cell within the honeycomb and consist of 38% fructose, 32% glucose, and a small amount of maltose and sucrose (Vaudo *et al*., 2016). To make honey suitable for the colony, additional enzymes are added at this time, and moisture is reduced (Oddo *et al*., 1999). When they are larvae and adults, honey bees consume different amounts of carbohydrates, but adults consume fewer carbohydrates than larvae (Standifer, 1980). Throughout its development, one worker larva is fed 59.4 mg of carbohydrates (Rortais *et al*., 2005). An adult worker honey bee needs about 4 mg of utilizable sugars each day to survive (Barker and Lehner, 1974). Honey bees' primary energy source during flight is nectar (Brodschneider and Crailsheim, 2010). Additionally, it is used to heat the environment in the winter and to produce wax for honeycomb construction (Hepburn *et al*., 2014). Honey is stored in excess. Sugar had an effect on the formation of long-term memories in honey bees (Simcock *et al*., 2018). Therefore, an adequate supply of carbohydrates is essential for bees.

2. Amino acid

Pollen is the primary source of honey bees' natural protein (Brodschneider and Crailsheim, 2010). In 1953, De Groot stated that the essential amino acids for honey bees are arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine (De Groot, 1953). They are necessary for reproduction, growth, and development because they cannot be produced on their own and must be obtained through diet (De Groot, 1953). Leucine controls protein turnover through cellular mTOR signaling and gene expression, while lysine is directly involved in the synthesis of nitric oxide, a neurotransmitter that is known to improve memory in bees and moths (Gage *et al*., 2020). The hypopharyngeal gland's development depends on tryptophan, which also affects honey bees' food intake, digestion, and feeding habits (Fengkui *et al*., 2015). Consequently, it might be useful as a supplement (Kim *et al*., 2022). Methionine is essential for organism growth and development, immune enhancement, antioxidant capacity enhancement, detoxification, and methylation, and it enables worker bee larvae rather than queen bees to develop (Chen *et al*., 2020). Many of the non-essential compounds, it was said, aren't necessary for growth but boost or have a "stimulatory effect" when added. In the honey bee brain, tyrosine is a precursor for dopamine, a neurotransmitter involved in memory and learning (Agarwal *et al*., 2011). Proline is an important amino acid for the queen bee to lay eggs. It is also essential for the wing muscles of insects. Additionally, it is thought to be a honey bee-favored ingredient (Kim *et al*., 2020). Bumble bee workers' foraging activity has been connected to the amount of protein in pollen, and bumble bees can taste and distinguish between diets with different amounts of protein or pollen (Vaudo *et al*., 2016). Therefore, a balanced supply of protein containing essential amino acids is necessary for honeybees.

3. Lipid

Lipids are typically employed as energy sources to create reserve fats, glycogen, and cell membranes (Manning, 2001). Plant pollen contains between 1–20% of lipids (oil and fats) (Manning, 2001). Additionally, lipids' fatty acids and sterols play a significant role in honey bee development, nutrition, and production. And among them, honey bees' diets must include fatty acids as a necessary component (Manning, 2001). Linoleic acid (LA) (C18 : 2n-6) and alpha-linolenic acid (ALA) (C18 : 3n-3) is the primary omega-3 and omega-6 fatty acids for insects, including honey bees (Arien *et al*., 2015). Arien *et al*. (2015) claim that, insects require these fatty acids (Arien *et al*., 2015). Learning performance may suffer when fatty acids are lacking, which may have an effect on foraging activities (Arien *et al*., 2015). Olfactory and tactile functions deteriorated, and the hypopharyngeal glands became smaller when the animal was fed a diet low in omega-3 for 6 weeks (Arien *et al*., 2015). Fatty acids such as oleic acid improve the learning and survival rate of honey bees, and the ratio of omega-6: omega-3 affects the learning performance of honey bees (Muth *et al*., 2018). According to Manning (2016), honey bees with a deficiency in the essential fatty acid linolenic have been found to have impaired learning and hypopharyngeal gland development (Manning, 2016). Insects use sterols, which are lipids, to make important cell membrane components and act as precursors to important ecdysis hormones. Since insects can't make cholesterol on their own, they have to eat plant sterols. According to Standifer (1980), 24-methylene cholesterol is a major sterol found in pollen and the body tissues of queen bees, brood rods, and larvae. Bumble bee larval size and growth were boosted by high sterol pollen content (Vaudo *et al*., 2016). Therefore, it is necessary to supply the appropriate amount of lipid to bees.

MICRONUTRIENT

1. Organic acid

Organic acids are the major component of the taste and flavor of pollen (Park *et al*., 2017). Citric acid can be used to properly supplement food with minerals, making it an important part of diet and nutrition (Park *et al*., 2017). Lactic acid is one of the main fermentation products of the metabolism of carbohydrates (Quinto *et al*., 2014). Organic acids have recently been discovered to be an alternative to antibiotics for the stimulation of growth and the preservation of food (Kim and Rhee, 2015). The diet of honey bees contains a high concentration of organic acids, making it an effective antibiotic (Dranca *et al*., 2020). Therefore, an adequate supply of organic acids would be beneficial to honeybees.

2. Inorganic ions

Minerals are essential nutrients for physiological processes and metabolic pathways. Minerals like K, P, Mg, Ca, S, Fe, Cu, Mn, Zn, Cr, and Se can be found in pollen, making daily consumption necessary (Smith *et al*., 2019). Because they cannot be produced by the body, inorganic ions must be taken in through food. In order to compensate for nutritional deficiencies in the floral diet, honey bees prefer to feed on water and soil sources (Lau and Nieh, 2016; Khan *et al*., 2021). Honey bees prefer to feed on inorganic ions for physiological activities and functions like muscle movement (Chakrabarti *et al*., 2020). While Na^+ ions are required for osmoregulation, Fe (iron ions) accumulate at the periphery of the abdomen and play a role in honey bee navigation (Khan *et al*., 2021). However, very little research has been done on the role of micronutrients like Na^+, Mg^{2+}, and Ca^{2+} ions in honey bee diets (Khan *et al*., 2021). According to Khan *et al*.'s research, honey bees prefer sodium chloride (NaCl), potassium chloride (KCl), and magnesium chloride ($MgCl_2$) salt concentrations between 0.1–1.5% (Lau and Nieh, 2016; Khan *et al*., 2021). K^+ was found to be the most common inorganic ion in bee bread. Pollen and bee bread samples contained the highest concentrations of K^+, ranging from 3.6 to 6.03 mg/g (Stanciu *et al*., 2009). It is recommended that a final diet formulation for honeybees contains 0.1% K^+, 0.05% Ca^{2+}, 0.03% Mg^{2+} and less than 0.005% each of Na^+, Zn^{2+}, Mn^{2+}, and Cu^{2+} (Herbert Jr and Shimanuki, 1978). Therefore, supplying the appropriate amount of inorganic ions required by bees will help bee health.

3. Polyphenolic

Polyphenolic compounds, particularly flavonoids and phenolic acids, are abundant in pollen (Kieliszek *et al*., 2018). According to Smetanska *et al*. (2021), phenolic acids are a large group of plant secondary metabolites that can be utilized as food additives, nutraceuticals, and pharmaceuticals (Smetanska *et al*., 2021). Due to their positive effects on health, particularly their antioxidant activity, the phenolic compound content of foods has become the focus of numerous studies. High antioxidant activity indicates a high content of phenolic antioxidants and flavonoids, which protects an organism from the harmful effects of reactive oxygen species (Kieliszek *et al*., 2018).

Table 2. Contents of vitamins in pollen (Campos *et al*., 2008)

Vitamins	mg/kg
β - Carotene	10–200
B_1; Thiamine	6–13
B_2; Riboflavin	6–20
B_3; Niacin	40–110
B_5; Pantothenic acid	5–20
B_6; Pyridoxine	2–7
C; Ascorbic acid	70–560
H; Biotin	0, 5–0, 7
Folic acid	3–10
E; Tocopherol	40–320

4. Vitamin

Vitamins play a variety of roles in the body and are necessary for healthy growth and development. Pollen contains almost all vitamins and is rich in B-complex (thiamine, niacin, riboflavin, pyridoxine, pantothenic acid, folic acid, biotin) and carotenoids (Table 2). Bees require a diet high in vitamins to produce royal jelly for their queen bees and larvae. Nurse bee need the vitamin B complex for brood rearing. Pantothenic acid is required for the differentiation of nurse bees and queen bees (Standifer, 1980). In addition to these vitamins, ascorbic acid (vitamin C) appears to be essential for brooding. Vitamin C is a water-soluble vitamin that is involved in the metabolism of fats, carbohydrates, and proteins (Kieliszek *et al*., 2018). Chestnut trees are major honey plants in many countries, and the vitamin C content of their pollen is around 0.10 mg/g (Ivanišová *et al*., 2015). The vitamins naturally present in pollen and bee bread are difficult to estimate due to their low concentrations, the presence of many disturbing factors, and the complexity of the matrix (Kieliszek *et al*., 2018). Twelve domestic pollens had an average vitamin C content of 0.56 mg/g, whereas imported pollens from China, Vietnam, and Spain had an average vitamin C content of 0.06 mg/g (Lee and Ahn, 2019). In general, the vitamins needed by a honey bee colony are met when abundantly stored in the colony's pollen or when fresh pollen is available from the field.

pH

Although pH is not nutritional, it is considered an important factor to consider when feeding bees. The literature showed that the pH values of bee pollen varied from 3.8 to 6.3 and bee bread from 3.8 to 4.4 (Kieliszek *et al*., 2018). Royal jelly is crucial for the development of a honey bee larva into a queen (Buttstedt *et al*., 2018). In the natural system, hypopharyngeal gland secretion has a pH of 5.1, and just after the addition of the mandibular gland secretion (pH 3.9), the pH of the final product is lowered to around pH 4.0 (Jantakee and Tragoolpua, 2015). Thus, royal jelly is the mixture of the hypopharyngeal and mandibular gland secretions that reduce the pH levels to around pH 4.0 (Jantakee and Tragoolpua, 2015). It has been reported that the pH value of royal jelly (3.6 to 4.1) and honey (3.4 to 4.1) varies (Adaškevičiūtė *et al*., 2019; Mureşan and Buttstedt, 2019). Because the pH of bee bread, royal jelly, and honey, the main food for honey bees, is around 4.0, one should consider adjusting the pH to around 4.0 when developing honey bee artificial diets (Adaškevičiūtė *et al*., 2019; Mureşan and Buttstedt, 2019).

NUTRITION AND ROLE DIFFERENTIATION

When the foraging bee is removed, the 5-day-old nurse bee becomes a foraging bee. Even if the bee doesn't have enough pollen or honey stored in it, it becomes an early foraging bee. Schulz *et al*. (1998) conducted research on role differentiation and nutrition, and the results showed that food-deprived bees foraged earlier than well-fed bees (Schulz *et al*., 1998). Baby bees store fewer lipids than adults, but after a few days, the amount of lipids increases and stays high during brooding. In honey bees, lipid storage in the abdomen is cut in half during the transition from the nurse bee to the foraging bee (Ament *et al*., 2010). Interestingly, this did not decrease due to flight behavior. These well-fed bees showed earlier foraging activity than the control group when the lipid content was reduced experimentally (Toth and Robinson, 2005). It was found that changes in lipid content induce behavioral changes in honeybees. Similar to the storage of lipids, vitellogenin, a stored protein, was abundant in the nurse bee and decreased prior to foraging activity (Ament *et al*., 2010). Experimentally, inhibition of vitellogenin synthesis induced early foraging activity (Marco Antonio *et al*., 2008) (Fig. 2). Thus, the timing of honey bee behavioral maturation is influenced by the body's stored protein and lipid content.

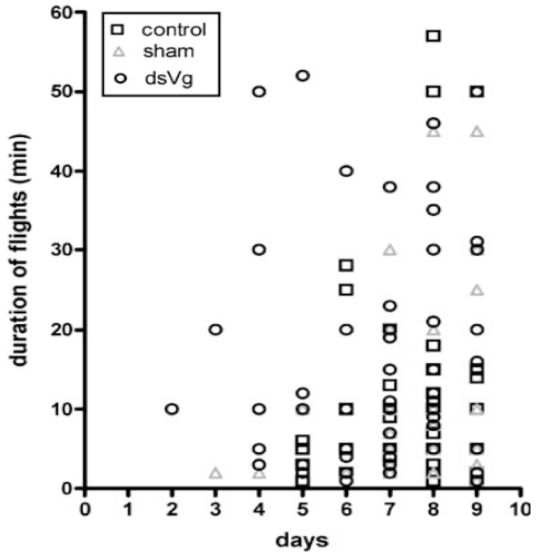

Fig. 2. Plotting age versus duration of flights performed by the three groups. It demonstrated that vitellogenin-depleted bees showed the earlier onset of long-term flight activity (Marco Antonio *et al*., 2008).

CONCLUSION

Honey bees need an adequate supply of carbohydrates and lipids and balanced amino acids. And the supply of organic acid, inorganic ions, polyphenolics, and vitamins could be beneficial to the honey bee. Insufficient nutrition resulted in an abnormal division of roles in bees, resulting in weak colonies. A healthy diet is essential for a healthy colony. Stressors like pathogens, pesticides, and a decrease in floral diversity can be overcome by well-nourished honeybees. Providing bees with a diet rich in the nutrients they require at just the right time is critical. It is regarded as a pressing necessity to develop a bee-friendly diet rich in well formulated nutrients. It is anticipated that by providing bees with a diet rich in the necessary nutrients, it will be possible to aid in the prevention of bee colony decay.

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