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Feeding and Nutrition of Bees *Apis mellifera* L. Colony Maintenance Basics

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Abstract

Honeybees depend on floral resources present in the environment to produce their food, which consists of honey, beebread, and water. These elements provide the bees with the carbohydrates, proteins, fats, vitamins, and minerals necessary for their growth, development, and product elaboration. However, due to numerous factors such as seasonal adverse weather conditions, or habitat destruction, the nectar and pollen they require are not always available. Poor nutrition will cause nutritional stress, which over time will lead to the weakening and loss of the colony. That is the reason why it is necessary to conduct periodic colony checks and understand the foods the bees consume and from which they obtain the nutrients for their proper development.

Keywords: Honeybees; Feeding; Nectar; Nutrition; Pollen

Introduction

Honeybees (*Apis mellifera* L.) play an important role in ecosystems due to their pollination of wild plants and agricultural crops, which contributes to maintaining biodiversity and food production [1,2]; in addition to producing honey, pollen, wax, royal jelly, and propolis, all of which can be consumed directly or processed [3]. In the last decade, an increase in the number of colony losses has been reported, which has been attributed to various factors, including poor diet and nutrition [4]. Poor management in production systems can lead to poor diet and nutrition. For instance, harvesting honey and/or pollen means that most of the food resources that bees stored for feeding are removed from the hive. Therefore, it is necessary to provide food for the colonies so that they will have a reserve. Another example can be found in monoculture pollination systems, in which it is highly probable that the pollen available to bees does not cover all their nutritional requirements [1,5]. The knowledge about the requirements and needs of bees can help to get a better understanding and meeting of those needs also to tend them by providing adequate food, at the right time, that is why the objective of this document was to conduct a literature review in order to get a better understanding of the concepts of feeding and nutrition in honeybees, as well as to present options of ingredients for the elaboration of food that have been previously tested to be accepted by bees.

Bee Feeding

Bees obtain their food from the environment in which they develop, so their growth and maintenance depend on the quantity and nutritional quality of the food sources available near their hive [6]. Their diet consists of honey, beebread, and water; these foods provide them with carbohydrates, proteins, lipids, vitamins, and minerals [7,8]. Foragers are the workers responsible for foraging and collecting food. They gather nectar and pollen, which are transformed and stored in honey and beebread within the hive's combs [9].

Honey is made from nectar, which is a sugary secretion produced by the nectaries of flowers. It can also be made from secretions of living plant parts or excretions of plant-sucking insects [10]. Foragers collect nectar by storing it in the honey crop and returning to the hive, where they transfer it to other bees through a process called trophallaxis, which consists of delivering the food by opening their mandibles to expose the regurgitated drop from the crop while one or more receiving workers extend their proboscis ingesting the offered solution [11]. For transformation into honey, it is necessary to reduce the humidity of the nectar, which ranges between 30-70%; the dehydration process begins when the forager collects it from the flowers and continues upon reaching the hive when the food is passed from one bee to another, and they hold it between their mandibles to evaporate the water. The food is then deposited in the cells, spreading it over the largest amount of available surface area, so that the water continues to evaporate with the help of the internal temperature of the hive and the continuous flapping of the bees' wings, which increases the air flow and evaporates the liquid, reducing the humidity to 17-20%. The result is honey with a low water content and a high concentration of carbohydrates [12].

Pollen is collected directly from flowers, so it can come in a wide variety of colors depending on the plant visited. Foragers comb the flower stamens with their first pair of legs to release the granules. They then compact them with regurgitated drops of nectar or honey and place them in their corbiculae, which are specialized structures for this purpose [13].

Worker bees store pollen in cells by crushing it with their heads. During storage, it is mixed with nectar, enzymes, yeasts, and bacteria, which, along with the humidity and temperature of the hive, allow for its preservation and conversion into beebread [14]. Beebread can contain from 6 to 35 varieties of pollen, because bees forage on diverse types of flowers to satisfy their nutritional needs [15].

Water in colonies is used to reduce the viscosity of the honey used to feed the brood, to cool the hive through evaporation, and to cover the metabolic needs of the bees. Water requirements are highly variable, depending on the amount of brood present, the lack of nectar in the flowers, or the environment temperature [16]. Bees sometimes show a preference for "stagnant" water because it contains a higher amount of minerals such as Na, Mg, K, which are necessary to maintain osmotic balance and for feeding the brood [17].

Bee Nutrition

Nectar-Honey: Nectar is primarily composed of glucose, fructose, sucrose, and water; variations in its composition, volume, and sugar concentration are influenced by geographic, climatic, and plant evolutionary factors [18]; the nectar from flowers foraged by bees may contain sugar concentrations of 15 to 65% [19]. To convert nectar into honey, physicochemical transformations occur through enzymes added by bees; these include invertase, which hydrolyzes sucrose, releasing fructose and glucose; diastase or α-amylase, which hydrolyzes starch; and glucose oxidase, an enzyme that produces hydrogen peroxide and gluconic acid from glucose [20,21].

Evaporation of moisture and the addition of enzymes produce the maturation of honey, which can take between one and eleven days depending on factors such as colony size, number of cells available in the frames, air humidity inside the hive, climatic conditions, and origin of the nectar [7]. The chemical composition, color, aroma, and flavor of honey depend on the flowers visited by the bees, as well as the geographical region and climate [21]; usually, the major components of honey are carbohydrates, mainly fructose and glucose (Table 1).

Parameter	Average value
Water	17.2
Total sugars	79.7
Minerals	0.2
Amino acids, proteins	0.3
Acids	0.5
pH-value	3.9

Table 1: Average composition of flower honey (g/100g) [22].

Pollen – Beebread

Pollen is composed of proteins, lipids, carbohydrates, vitamins, and minerals (Table 2); however, its value is judged based on its crude protein (CP) content, which varies greatly and depends on the type of plant and the growing season [23], it can range from 9.2% to 37.4% [24]. Pollen protein content can be classified into three categories: 1) Excellent, with a CP concentration greater than 25%; 2) Average, with 20 to 25% CP; and 3) Poor, with a CP content less than 20% [25]. For this reason, mixing diverse types of pollen is the best option for bees to improve the nutritional composition of this food [26]. However, the concentration of essential amino acids is responsible for the nutritional quality of the protein [27,28], and the essential amino acids in bees are: methionine (Met), arginine (Arg), tryptophan (Trp), lysine (Lys), isoleucine (Ile), phenylalanine (Phen), histidine (His), valine (Val), leucine (Leu), and threonine (Tre) [29].

Parameter	Bee pollen	Beebread
Carbohydrates %	13-55	24-35
Proteins %	7-40	14-37
Lipids%	1-13	2-14
Dietary fiber%	14-31	3-20
Vitamins%	0.02-0.7	0.4-3
Organic acids%	1	0.4
Lactic acid%	0.6	3
Free acidity (mEq/kg)	105-146	400
pH	4-6.3	3.8-4.2

Table 2: Proximate chemical composition of pollen and beebread [13].

Amino acids are important for growth and development because they contribute to protein synthesis and regulation of various cellular functions [28]. Dietary deficiencies of these amino acids affect protein synthesis in the body. Their presence and concentration can vary from one floral species to another (Table 3), so mixing pollen from different botanical origins is how bees avoid deficiencies [24,27].

	Eucaliptus bridgesiana.	***Brassica napus***	***Angophora floribunda***	***Echium plantagineum***	***Helianthus annuus***	***Lavandula spp.***	***Zea mays***
%CP	23.1	22.1	21	30.9	13.8	19.4	14.9
Arg*	6.58	5.09	6.07	5.18	3.71	4.31	4.7
His*	2.43	2.17	2.7	2.52	4.61	3.67	1.86
Ile*	4.24	4.95	4.71	4.89	4.28	3.59	4.84
Leu*	7.02	6.95	7.19	6.83	6.61	6.04	6.82
Lys*	5.6	8.38	5.57	5.86	5.75	6.38	5.55
Met*	2.54	2.64	2.34	2.65	2.24	2.21	1.57
Phe*	3.98	4.39	4.25	3.96	3.7	4.11	3.84
Thr*	4	4.92	4.17	4.56	3.96	4.17	5.11
Val*	5.09	5.36	5.47	5.48	4.57	4.54	5.9
Ala	5.55	5.29	5.23	5.17	4.56	5.25	6.59
Asp	8.96	8.09	8.86	13.3	9.25	9.24	9.61
Cys	2.24	2.33	2.49	2.4	3.54	1.67	1.53
Glu	10.8	10.2	10.5	11.1	9.11	10.2	9.6
Gly	4.91	4.62	4.72	4.69	4.95	4.57	9.6
Pro	15.9	6.42	14.6	7.25	6.73	18.1	13.6
Ser	5.22	5.66	5.25	5.19	4.6	4.61	6
Tyr	2.83	3.05	2.99	3.31	2.85	3.11	3.18

Table 3: Amino acid profile of pollen from different plants (g/16 gN) [24].

Pollen is transformed into beebread through a series of biochemical mechanisms that last approximately seven days [8]. Beebread is a combination of pollen, nectar, and salivary secretions mixed and stored in honeycomb frames covered with a layer of honey by bees [30]; it is the main food of workers less than 10 days old and is part of the diet of worker and drone larvae older than 3 days old. It has a higher nutritional value than pollen and is more easily digestible. It is rich in proteins, carbohydrates, lipids, vitamins, minerals, free amino acids, and beneficial microorganisms [8,31].

Beebread is partially fermented by the action of lactic acid bacteria of the genera *Lactobacillus* spp, *Bifidobacterium* spp, *Pseudomona* spp, and *Saccharomyces* spp, and yeasts, which were integrated through nectar; all of those help produce lactic acid from the starch in the pollen, which favors a decrease in pH and the production of B vitamins [8,13,30]. It also contains digestive enzymes such as esterases, lipases, proteases, aminopeptidases, and phosphatases, which aid in food preservation [14].

The anaerobic lactic fermentation process helps prevent pollen from germinating and losing its properties while stored in the hive. It also modifies the exine, the outer covering of pollen grains, facilitating the utilization of its nutrients [32]. It also allows the proteins that comprise it to break down and form peptides or free amino acids [33].

Lactic acid bacteria are part of the bee microbiota. The microbiota is the set of microorganisms that reside in individuals and can provide benefits to the organism; in *A. mellifera*, different species of microorganisms have been identified that make up its gut microbiota: *Snodgrassella alvi, Gilliamella apicola, Bifidobacterium asteroids, Bombilactobacillus* sp. and *Lactobacillus* sp*.* [34]. Gut microbes have beneficial functions for bees; for example, they facilitate their processes of food preparation and digestion. The fermentation that microorganisms perform in pollen when preparing beebread helps to change its biochemical structure, obtaining food with greater availability of carbohydrates, proteins, lipids, enzymes, vitamins, organic acids, and antimicrobial compounds that can inhibit the growth of pathogenic microorganisms and contribute to the preservation of beebread [35]. The microbiota also helps to maintain a strong immune system and helps bees resist the toxic effects of some plant species [36].

The nutritional needs of workers vary according to their age or their activity in the hive [37,38]. Upon hatching, the larvae are fed royal jelly, which has a high protein concentration (27–41%) for three days [39]. They are then fed a mixture of royal jelly and beebread, a food that has a lower protein content and a high carbohydrate concentration, which helps the brood gain weight [37].

Upon emergence, workers begin to consume copious amounts of protein through beebread, decreasing their consumption between 8 and 10 days of age; this high protein intake is necessary for their complete body development and to produce royal jelly [7,38]. The beebread intake increases the activity of trypsin-like enzymes, chymotrypsin [40] and carboxypeptidase [41] in the midgut. This fact, combined with the change in osmotic pressure that occurs in the bread as it passes from the honey crop to the midgut, breaks down proteins and allows the released amino acids to reach the hemolymph and be distributed from there to wherever they are needed, such as for tissue development, the production and secretion of vitellogenin, and the elaboration of antimicrobial peptides. Amino acids can also be maintained as reservoirs in the fat body and in vitellogenin [37].

Foragers have low reserves of carbohydrates, proteins, and lipids. Furthermore, they have a very low activity of proteolytic enzymes in their bodies [38,42], so they depend primarily on honey reserves in the hive for energy and to conduct their activities. Foragers produce α-glucosidase in the hypopharyngeal glands and carbohydrase, such as amylase, in the salivary glands and midgut [43]. These enzymes allow them to degrade the polysaccharides present in food, releasing monosaccharides such as glucose and fructose, which are used in energy metabolism. Glycogen stored in tissues and trehalose, a disaccharide found in the hemolymph, are the carbohydrate reserves that provide them with energy [20]. Adequate nutrition is the basis for optimal colony growth and is the first line of defense against various stress factors such as pathogens, pesticides, or inclement weather [44-46]. Colonies suffering from food or nutritional deficiencies will experience nutritional stress, which will worsen over time and can lead to death.

Nutritional Stress

Nutritional stress means fatigue caused by a lack of certain nutrients, which can cause alterations in the body's functioning. In bee colonies, it can occur due to 1) poor management of honey and pollen harvesting, with all food reserves removed; 2) lack of flowering in the field; 3) adverse weather conditions; and 4) monocultures [1,5,6]. When any of these situations occur, it is necessary to feed or supplement the diet artificially to avoid nutritional stress [4].

Climate change also causes nutritional stress by affecting bee habitat and the diversity, distribution, and growth of food plants, as well as water scarcity and extreme weather events [47]. Water stress and increased temperature affect nectar and pollen from flowers, reducing their quantity and affecting their composition. These effects cause bees to make greater efforts to obtain their food, and the change in their composition affects their access to nutrients [48].

When bees lack access to food, they consume the reserves of beebread and honey stored in the frames; as these reserves are depleted, nurse bees feed the brood poorly, resulting in weaker and fewer bees emerging in the next generation [37]. To keep the colony alive when food reserves are depleted, the queen decreases her laying, and the workers begin to cap the larvae earlier to reduce the high food demand for that brood [49]. Furthermore, they cannibalize drone and worker larvae younger than 3 days [50,51] to feed the queen, the brood older than 3 days, and themselves; the workers choose to sacrifice the young brood because they have invested little in food and care in them. If food shortage continues, brood production ceases completely, and the colony risks swarming or dying [52].

Artificial feeding

Feeding bees when resources are lacking in the field is essential for the maintenance and survival of the colony; it prevents nutritional stress, promotes better performance, improves health, and protects against pesticide toxicity [53-55]. Artificial feeding consists of providing compounds similar to honey and pollen in order to cover the nutritional needs of bees and can be divided into 1) maintenance feeding, which is used to maintain colonies and does not require increasing the number of bees; and, 2) stimulus feeding, whose function is to stimulate the queen by increasing her posture, which allows the population to increase before the flowering season begins [56].

When nectar flow is low, honey from healthy colonies can be fed to prevent the transmission of diseases such as American foulbrood, caused by the bacterium *Paenibacillus larvae* [57], or viral diseases such as deformed wing virus [58]. Other options include sugar syrup in 1:1 or 1:2 water-sugar ratios; high-fructose corn syrup in concentrations of 42–55%; and inverted sucrose syrup [59].

In cases of pollen shortage in the field, two types of protein supplements can be used: 1) pollen supplements, which consist of 5–25% pollen plus an alternate protein source, or 2) pollen substitutes, which consist entirely of alternate protein sources [60]. The use of pollen supplements carries a risk of disease transmission because pollen can contain pathogens such as *Vairimorpha* spp, *P. larvae*, *Ascosphera apis*, and the chronic paralysis virus, Israeli acute paralysis virus, deformed wing virus, and sacbrood virus [58-62]. Therefore, the use of substitutes is a safer and more viable option, providing similar benefits to feeding pollen, with the advantage of being more economical and minimizing the risk of disease transmission. However, honeybees will always prefer to consume pollen because it is more attractive than any substitute [54,63,64].

When selecting a substitute, it must be finely ground, palatable, and easily digestible. Protein concentration must also be taken into account, as this influences the development of bees; a protein level in a substitute is considered optimal if it is 30% CP or higher [64]. In addition, the concentration of essential amino acids must be considered, as a lack or deficiency of any of these amino acids will result in poor nutrition [5].

Adult bees can survive by consuming only carbohydrates and water, whereas young bees and brood require protein, lipids, minerals, and vitamins, which is why it is necessary to provide food that covers most of these nutrients. The most common food offered to bees is sugar syrup; however, when the colony is fed only syrup over the course of 30 days, the percentage of eggs, larvae, and adult population density in the hive decreases [65], in addition, the glandular development, longevity and production of bees decreases [66-68]. This is associated with increased susceptibility to disease [69]. Access to a diet with pollen and its nutritional components helps to keep bees in better conditions of development, health, and production [70]. Therefore, it is recommended to always provide a protein source within the artificial feed [65].

Conclusions

Honeybees can obtain their food naturally in the field; however, there are several factors that can cause food to decrease or lack the nutrients necessary for the colony's maintenance and proper development. For colonies to survive throughout the beekeeping cycle and be able to produce their products, they must be periodically inspected to verify they have sufficient food reserves. When reserves are low or nonexistent, it is necessary to provide food through energy and protein supplements, which will help the colony avoid nutritional stress. Similarly, it is advisable to understand the sources of nectar and pollen available around the hives. This way, production systems can be properly managed and the times when it is necessary to support the bees with artificial feeding can be identified.

Conflicts of interest

The authors declare no conflict of interest.

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