

Review Article

Nutritional requirement and its role on honeybee: a review

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ABSTRACT

Honey bees play significant role in crop pollination. As, honeybee nutrition is raising global topic in beekeeping, it's essential nutrients, nutrient sources and role in honey bees are reviewed in this paper. Like other animals, honeybees also need carbohydrate, protein, vitamins, minerals and water. These nutrients are primarily supplemented by pollen, nectar, royal jelly or water. Adequate supplement of these nutrients play significant role in growth and development in honeybees and also development of immunity in honeybees. Knowledge of bee nutrition helps to manage nutrient in bee colony and prevents them from different diseases and pests.

Keywords: Bee health, Honeybees, Nectar, Nutrition, Pollen

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INTRODUCTION

Honeybees are the important pollinating agent for both agricultural as well as natural ecosystem (Stein *et al.*, 2017; Çolak *et al.*, 2017; Pudasaini & Thapa, 2014). Bee pollination improves both quality and quantity of crop production (Stein *et al.*, 2017; Pudasaini & Thapa, 2014; Pudasaini *et al.*, 2014), and crops produced by bee pollination are important source of nutrition to people throughout the world (Eilers *et al.*, 2011). They also play key role on ecosystem balance (Klein *et al.*, 2007). Furthermore, honey mainly contains carbohydrate and also other various essential nutrients, although may be in small amount, like proteins, enzymes, amino acids, minerals, trace elements, vitamins, aroma compounds and polyphenols (e.g. reviewed by Ajibola *et al.*, 2012; Bogdanov *et al.*, 2008). Bee pollen is especially rich in protein and others several nutrients that are essential to human and they also have therapeutic application to multiple diseases (e.g. reviewed by Komosinska-Vassev *et al.*, 2015). There are others several importances of bee as royal jelly for health improvement (Morita *et al.*, 2012), bee venom as apitherapy (Wehbe *et al.*, 2019).

Since every organism needs different type of nutrients to sustain their life smoothly and bee also required various types of nutrients such as carbohydrate, protein, vitamins, minerals, water and so on (Di Pasquale *et al.*, 2013; Vaudo *et al.*, 2015). Some of them are fulfill by foraging by worker bees from outside the hive and royal jelly is secreted from hypopharynx gland of worker nurse bee (Graham, 1992). In the context of rising a global concern of bee declining (Pudasaini *et al.*, 2016; Jung, 2014; Lebuhn *et al.*, 2012); lack of nutrients also lead to colony decline or collapse in bee (Branchiccela *et al.*, 2019; vanEngelsdorp *et al.*, 2009). As nutrition plays a key role on pathogen infections, critical for immune-defense and resistance to pathogens in all animals including bees (Ponton *et al.*, 2011; Cunningham-Rundles *et al.*, 2005). Also, knowledge of bee nutrition also helpful to beekeeper to give artificial diet to bees especially in dearth period. Though the role of nutrition to health of many animals is already explored, regarding to the insects, especially in bees, is less understood (De Grandi-Hoffman & Chen, 2015). Further, in our Nepalese context, although there are a few studies in providing artificial diet in bee (e.g. Neupane and Thapa, 2005; Entomology Division, 1996), there is no any study on bee nutrition. Hence, this mini-review aims to be basis for further study of bee nutrition in our context.

Essential nutrients to bees

Adequate nutrition is the basis for growth and development of a bee colony (Brodschneider & Crailsheim, 2010). As other animals, nutrition play significant role on multiple aspects of bees as caste development (Mutti *et al.*, 2011; Patel *et al.*, 1960; Wang *et al.*, 2013); immunity against different diseases (Ponton *et al.*, 2013 Basualdo *et al.*, 2014; DeGrandi-Hoffman & Chen, 2015; DeGrandi-Hoffman *et al.*, 2010; Glavinic *et al.*, 2017; Xu *et al.*, 2013; Zheng *et al.*, 2014); increase lifespan (Knox *et al.*, 1971); hypopharyngeal gland development (Keller *et al.*, 2005a); behavioral development (Ament *et al.*, 2008, 2010; Toth *et al.*, 2005); brain development (Moda *et al.*, 2013).

Carbohydrate

Carbohydrate is the source of energy to honey bees which mainly fulfilled by nectar from flowers (Brodschneider & Crailsheim, 2010). According to Erler *et al.* (2014) carbohydrate supply requires energy for metabolic processes for humoral and cellular immune reactions and also give antimicrobial properties by secondary plant metabolites. An adult worker bee needs approximately 4 mg of sugar in a day for survival (Barker & Lehner, 1974) and bee fed 59.4 mg of carbohydrates to one worker larva during their larval period (Rortais *et al.*, 2005).

Protein

Pollen is the natural source of protein in bee colony which is also collected by worker bees during foraging. Royal jelly, another source of protein in hive, contribute protein supplement up to all three day's larvae and queen in a colony. Shortage of protein hamper on growth and development of body, development and function of different glands in bees (Keller, 2005b). Requirement, consumption, utilization, importance of protein in honeybee is reviewed by (Crailsheim, 1990). Protein deficiency diets during development stages resulted into smaller hypopharyngeal glands in worker bees (DeGrandi-Hoffman *et al.*, 2010).

As presented in Table 1, similar to others animals, ten different amino acids are essential to honeybee (Keller *et al.*, 2005a,b).

Table 1. Proportion of amino acid requirement of bee (DeGroot, 1953)

Amino acid	Requirement (g per 16g N)
Threonine	3.0
Valine	4.0
Methionine	1.5
Leucine	4.5
Iso-leucine	4.0
Phenylalanine	2.5
Lysine	3.0
Histidine	1.5
Arginine	3.0
Tryptophan	1.0

Several previous study reported that protein play significant role to develop resistance to pathogens in bees (Behmer, 2009; Alaux *et al.*, 2010; Mao *et al.*, 2013; Ford *et al.*, 2001; Kaminogawa & Nanno, 2004; Ritz & Gardner, 2006; Rowley & Powell, 2007).

Other nutrients

Except carbohydrate and protein others nutrients like lipids, vitamins and minerals are also essential to bees (Haydak, 1970). Pollen is the main source of lipids for bee colony. Lipids are mainly metabolized during the brood stage and considered as an important source and a precursor for further biosynthesis (Cantrill *et al.*, 1981). 2-4% more extraction of lipids from pollen increased in brood rearing (Herbert *et al.*, 1980). Vitamins are also essential to honeybees and water soluble vitamins are more common in pollen than fat soluble vitamins (Roulston & Cane, 2000). However, in a study providing with the combination of the fat soluble vitamins A, D, E and K in the artificial diet improved the amount of brood produced (Herbert & Shimanuki, 1978c). Main source of minerals to bees is pollen, but bees also get from nectar, water or the existence of endogenous mineral pools in adults (Brodschneider and Crailsheim, 2010; Imdorf *et al.*, 1998). Further, addition of 1% pollen ash in the artificial diet as a source of mineral found increased in brood rearing (Herbert and Shimanuki, 1978b).

Source of nutrients

Bees collect pollen, nectar and water from outside the hives from plants and other sources, whereas royal jelly is secreted own glands of bee (Graham, 1992). Two pairs Hypopharynx glands of nurse bee produce royal jelly (Johnson, 2010; Graham, 1992; Michener, 1969) and after 21 days of birth worker bees go out for the collection of pollen, nectar, water and resin (Young *et al.*, 2007).

Royal jelly

Royal jelly is a secretion from the two pairs of hypopharynx gland of worker nurse bee, especially sixth to ten days of life (Graham, 1992; Patel *et al.*, 1960; Johnson, 2010; Michener, 1969). It is milky white semi liquid which contains several essential nutrients to bees and feed to all caste larvae up to three days and queen from larval stage to throughout the life span (Winston, 1987). Further, if larva that hatches from fertile egg nourished with only royal jelly throughout the larval stages turns them to queens (Haydak, 1970); otherwise, they develop into sterile worker. Royal jelly contain several essential nutrients and as a result of that it turns queen shorter larval stage or developmental time, larger body size, longer life

span, well development of reproductive organ than worker bees (Page & Peng, 1995). This also shows the nutritious value of royal jelly. It is reported that royal jelly is highly nutritious substance that contain 12-15% proteins, 10-12% sugars, lipids 3-7%, amino acids, vitamins and minerals (Graham, 1992; Takenaka, 1982). 10-hydroxy-2-decenoic acid (10-HDA) is a bio-active compound, which is the main acid that contain in royal jelly and has antibacterial properties (Sediva & Klaudivy, 2015; Vezetu *et al.*, 2017; (Barker *et al.*, 1959). Yang *et al.* (2018) also reported that 10-HAD found in royal jelly shows bactericide and anti-inflammatory activity in human colon cancer cells. Furthermore, royal jelly also shows multiple pharmacological activities as antitumor (Townsend *et al.*, 1960), anti-oxidant (Nakajima *et al.*, 2009), anti-inflammatory (Kohno *et al.*, 2004), antibacterial (Tseng *et al.*, 2011), anti-allergic (Okamoto *et al.*, 2003), anti-aging (Park *et al.*, 2012), and antihypertensive properties (Tokunaga *et al.*, 2004).

Pollen

Except to the queen and all three days larvae, pollen is the primary source of nutrient, especially protein, for growth and development to honeybees. The protein contain is varies according to the flower sources as from 2.5% to 61% (Roulston *et al.*, 2000). Pollen also contains 0.8% to 18.9% lipid in different species of plant flower which is only source of lipid (Roulston & Cane, 2000). It has fundamental effect on nutrient metabolism in bee (Basualdo *et al.*, 2014; Zheng *et al.*, 2014). Honeybee collect pollen from flower of different plant and bee significantly depend on pollen for their nutrition (Dimou & Thrasyyoulou, 2009). Pollen is important source of protein for bee colony and play significant role in proper development of body parts of honeybee (Keller *et al.*, 2015). For example, development of hypopharyngeal gland depends on pollen quality (Keller, 2005a,b), which produce royal jelly. Furthermore, deficiency of protein causes cannibalism in bees by eating eggs and broods in colony (Haydak, 1935; Myser, 1952; Newton & Michl, 1974). Feeding of sufficient pollen also increases the life span in honeybee (Manning *et al.*, 2007), physiological changes in young bees (Hersch *et al.*, 1978). Honey bees mix nectar and some glandular secretions with pollen to make bee bread which have lower pH and less starch (Herbert & Shimanuki, 1978a; Ellis & Hayes, 2009) and also contain higher nutrients than fresh pollen (Cremonez *et al.*, 1998; Pernal & Currie, 2000).

Pollen is major source of proteins as well as vitamins, minerals, lipids and other several nutrients that are essential for health, proper growth and development of brood as well as adult (Todd & Betherick, 1942; Nicolson, 2011); physiological development, resistance to parasites and pathogens (Alaux *et al.*, 2011). Pollen requirement is maximum during nurse age and a worker bee needs 3.4-4.3 mg pollen per day (Crailsheim *et al.*, 1992). Further 2-4% more lipid extracts from pollen resulted to increased in brood rearing (Herbert *et al.*, 1980). Neupane & Thapa (2005) reported that unavailability of pollen causes to colony severe decline or collapse in honeybee.

Nectar

Worker bees collect nectar from flower which is the main source of carbohydrate to colony but also may contains small amount of amino acids and lipids (Percival, 1961; Baker & Baker, 1975). Carbohydrates provide energy for metabolic processes and other activities to bees. Honeybees change nectar to honey through regurgitation, adding some enzymes, and

water evaporation (Crane, 1990; Crane *et al.*, 1984) and stored it for the future use. Bee reduced the water content from approximately 80% to around 16-20% and added different enzymes like invertase, diastase and glucose oxidase (Doner, 1977).

Water

Worker bee forage water for multiple purposes as to dilute the honey and regulate temperature and humidity (Kühnholz & Seeley, 1997; Winston, 1987), metabolic needs (Louw & Hadley, 1985). Further water is essential to prepare food to larva as well as to supply minerals (Nicolson, 2009; Piscitelli, 1959). It should be collected as per requirement because it is not stored as pollen and honey in hive (Lindauer, 1954). Honeybees need salts (Herbert *et al.*, 1978), and they prefer foraging water that contains salts (Butler, 1940).

Nutrition and bee health

Nutrition play significant role for the outcome of pathogen infection in animals (Ponton *et al.*, 2013; Ponton *et al.*, 2011). Proper availability of all essential nutrients supports proper growth and development which booster up the development of immunity. By contrast, poor nutrition causes infection by several diseases (Cunningham-Rundles *et al.*, 2005; Ponton *et al.*, 2011). It is vital for the development of immunity and resistance to pathogens (Cunningham-Rundles *et al.*, 2005), whereas deficiency or improper diet causes susceptibility to the pathogens (Field *et al.*, 2002; Li *et al.*, 2007).

As discussed in the previous sections, pollen is the source of amino acids that is essential for the synthesis of peptides which develop immunity in bees (Chen *et al.*, 2014). Similarly, carbohydrate from nectar also contributes in immunity by providing energy for metabolic processes associated with innate humoral and cellular reactions (Chen *et al.*, 2014). Similarly, other nutrients also have role in proper growth and development of bees and development of immunity (Haydak, 1970).

The nutrient content in diets also influences the population of bee micro-biome (Turnbaugh *et al.*, 2009; Hildebrandt *et al.*, 2009; Ponton *et al.*, 2013) and micro-biome play important role on nutrient processing and immunity (Raymann & Moran, 2018). Kešnerová *et al.* (2020) also reported that diet play important role gut microbiota in bees.

The immune-competence, capacity of an organism to increase an immune response (Wilson-Rich *et al.* 2008), was also found affected by protein diet and its diversity in *Apis mellifera* (Alaux *et al.*, 2010). Further, authors reported as haemocyte concentration was higher in control bee, whereas phenoloxidase activity, relative mass of fat body and glucose oxidase activity were recorded higher in poly-floral and more protein diet feeding bees. Further, Encapsulation, phenyloxidase, and lysozyme activities are enzyme based immune response to foreign invaders like virus and wounding which is depend on protein (Siva-Jothy *et al.*, 2005; Lee *et al.*, 2006).

There are number of studies that show the relationship between nutrition and immunity in bees (Cotter *et al.*, 2011; Franca *et al.*, 2009; Alaux *et al.*, 2010). Nutrition play significant roles on development of immunity to various pathogen like *Nosema* in bees (Basualdo *et al.*, 2014; DeGrandi-Hoffman & Chen, 2015; DeGrandi-Hoffman *et al.*, 2010; Glavinic *et al.*,

2017; Xu *et al.*, 2013; Zheng *et al.*, 2014). Nutritional stress resulted to higher infection of *Nosema* spp. and also lowers down the brood and adult bee population (Branchiccela *et al.*, 2019). Numbers of spores of *N. ceranae* were found more in protein fed bees; however, protein fed bees more survive as compared to with sugar fed bees. They also reported that feeding of protein resulted significant negative impact on virus infections (Tritschler *et al.*, 2017; Jack *et al.*, 2016; Porrini *et al.*, 2011). Similar results were found in *N. apis*, although protein feeding result more spore development, it increased the longevity of infected bee host (Rinderer & Elliott,1977).

Table 2. Summary of effect of different nutrients on bee health

Experiment	Effects	References
Dietary protein quantity and diet diversity	Immune-competence level; Phenoloxidase activity, Relative mass of fat body; Glucose oxidase activity were increased Haemocyte concentration decreased	Alaux <i>et al.</i> , 2010
Nutritional stress	Higher infection of <i>Nosema</i> spp.	Branchiccela <i>et al.</i> , 2019
Protein feeding	More <i>Nosema ceranae</i> spore Higher survival	Tritschler <i>et al.</i> , 2017 Jack <i>et al.</i> , 2016
Protein feeding	Significant negative impact on virus infections More spore <i>Nosema apis</i> of development Increased longevity of infected bee	Rinderer & Elliott,1977
Protein and sugar syrup feeding	hypopharyngeal glands were small, deformed wing virus concentration was increased in less protein fed bees.	DeGrandi-Hoffman <i>et al.</i> , 2010
Pollen feeding	Development of <i>Nosema</i> parasite was found influences by host condition; development was quicker; longevity of infected bees was affected by quality of diet	Porrini <i>et al.</i> , 2011
Pollen nutrition	Pollen diets promoted ovarian activation Higher survival Higher vitellogenin levels in the hemolymph	Frias et al. 2016

CONCLUSION

Honeybees need carbohydrate, protein, vitamins, minerals and water, which are fulfilled by pollen, nectar, royal jelly or water. Adequate supplement of these nutrients play significant role in development of immunity as well as overall growth and development of honey bee. Knowledge of bee nutrition helps to manage nutrient in bee colony and prevents them from different diseases and pest. In our Nepalese context study on bee nutrition seem essential.

Authors' Contributions

All authors have equal contribution in writing this review paper.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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