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Review

Honeybee nutrition and pollen substitutes: A review

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ABSTRACT

Like other invertebrates, honey bees too are poikilothermic animals; they cannot regulate their body temperature and they have to undergo a period of inactivation when atmospheric temperature is intolerable. During this period, their nutritional requirements and metabolic activities are minimized due to highly restricted foraging activities. The egg-laying by queen and rearing of unsealed and sealed brood are decreased, however their extent is governed by the quantum of stored food available. The problems of deleterious influence of adverse weather conditions and non-availability of bee flora all round the year, in a particular locality, have been realized by the researchers/beekeepers and migration concept has been developed to solve this problem. But again, migration itself is not an easy task. The provision of artificial feeding as an alternate of migration. Scientists all over the world have formulated different artificial food recipes for bees on the basis of nutrient composition of honey and pollen, acceptability, palatability, digestibility and affordability of ingredients. This may help to maintain all colony parameters enough to derive maximum advantage of forthcoming floral rich season. However, a standard balanced diet for commercial beekeeping that is accepted worldwide is still awaited.

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1. Introduction

Apiculture is agriculture and forest based rural cottage decentralized industry. It is practiced as pollution free, subsidiary, commercial or single family based enterprise. Bees are the only livestock capable of harvesting nectar and pollen eventually

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producing honey: there is no competition of bees with other animals, and without bees, these valuable resources could not be harvested. Beekeeping is possible even in the areas where other crops have failed. Any type of land i.e. wild, cultivated, wasteland, mountains and even land-mined areas all have value for beekeeping. Bees get carbohydrates from nectar and protein from pollen; they usually take it after its fermentation, in the form of bee bread. From the history, it has been revealed that honeybees are one of the few insects that is directly beneficial to the mankind. These winged creature and honey they produce find mentioned in many religious epics. In Rigveda, Upanishad and in religious writings, there is description of honey as a valuable and necessary asset (Mishra, 1995; Kaushik, 2012).

Presently, beekeeping tends to be underplayed in many of the developing countries. The people are adopting beekeeping as 'a sideline activity', reason may be the focus towards crop production and livestock rearing or some government schemes, that are providing hands to mouth earning in rural areas. Due to lack of proper training, migration activity, bee enemies and unavailability of market for selling honey, many people are either not adopting beekeeping as full time profession or are getting annoyed towards this venture (Bansal et al., 2013; Singh et al., 2016). The efficiency of beekeeping depends upon the richness of bee flora in the vicinity of apiary during different climatic conditions. The richness or availability of bee flora varies in different season of a year in a particular region. The period of year in which flora of bee interest is scarce is known as dearth period. The scarcity of bee flora and insufficient stores of food inside bee colony affects brood rearing, honey production and overall colony growth and development. To get more benefits of beekeeping venture, proper management of honeybee colonies is necessary especially during dearth periods. Success of this small cottage industry depends upon planned bee management technology(s). Proper management of honeybee colonies can only be done if beekeepers have in depth knowledge of different management strategies (Agrawal, 2014). Management strategies in apiculture have the motive of lift up or improving upon various factors necessary for the colony growth and development. The trouble caused by adverse weather conditions as well as non-availability of flora all round the year, in a particular locality, have been realized by the researchers and the concept of migration of bee colonies to suitable bee flora rich place has been developed to solve this problem. But again, migration itself is not an easy task, it involves lot of expenses, labour and yet it is not risk-free. It has been observed that even following the concept of migratory beekeeping approximately 40% colonies perished out during scarce period of the year (Kumar and Agrawal, 2014). The provision of artificial feeding (nectar and pollen substitutes) has been considered and developed to maintain egg laying, brood rearing and foraging activities which may maintain enough bee population in the colony.

Many diet formulation have been developed by combining different ingredients and examined by various workers all over the world for commercial beekeeping (Haydak, 1967; Standifer, 1980; Herbert et al., 1980; Schmidt et al., 1987; Chhuneja et al., 1993; Mishra, 1995; Abbas et al., 1995; Nabors, 2000; Rogala and Szymas, 2004; Saffari et al., 2004; Keller et al., 2005; Madras-Majewska et al., 2005; Akyol et al., 2006; Safari et al., 2006; Sharma and Gupta, 2006; Dastouri et al., 2007; DeGrandi-Hoffman et al., 2008; Saffari et al., 2010; Sena et al., 2012; Kumar et al., 2013; Sihag and Gupta, 2013; Abd El-Wahab et al., 2016; Amro et al., 2016; Aqueel et al., 2017; Eissa et al., 2016; Gameda, 2014; Mahfouz, 2016; Pande et al., 2015; Puškadija et al., 2017a; Shehata, 2016; Stevanovic et al., 2018; Wijayati et al., 2019). In this review, efforts have been made to illustrate various methods/strategies of honeybee management especially through stimulative feeding (pollen substitutes/ supplements) during dearth periods.

2. Protein based pollen substitutes and supplements

The main source of protein for brood rearing, overall colony development, longevity of adult workers is pollen. The annual pollen requisite of honey bee colonies varies according to the variation in colony location, floral sources and strength of colony. The flora of bee interest is not available in adequate quantity round the year, so provision of pollen substitute and pollen supplements have been tries to maintain the strength of colony by enhancing brood survival and length of adult age (Haydak 1935, 1937; Doull, 1980; Saffari et al., 2004). Large number of diets including soybean flour, brewer's yeast, parched gram, guar meal, skimmed milk powder, egg yolk powder, casein, pea powder, rice bran and fish meal as major ingredients have been formulated and tested on honeybees. Various combinations of diet have been developed and described by several researchers who had got success at the specific conditions of their evaluations.

Mishra et al. (1979) used brewer's yeast, soybean flour and skimmed milk powder to make moist patties as pollen substitute diet for honey bees. A large number of experiments were conducted on *Apis mellifera* colonies. After treatment, it was observed that artificial diet stimulates all colony parameters positively; however a satisfactory honey production was also reported in the results. Doull (1980) proposed composition of krayeast and skimmed milk powder as diet for honey bee colonies. The longevity, brood area and foraging activity in the colonies that were fed with pollen supplement found higher than control colonies. A significant increase in honey production was observed in experimental colonies. Black gram has been proposed as a pollen substitute instead of soybean by Abbas et al. (1995). Ten colonies were examined for the period of three months (during rainy season in summer i.e. May to July). Four colonies were treated with black gram diet combination, four with soybean meal diet and rest two were without pollen substitute (control colonies). Observation revealed that growth of treated colonies found greater in every aspect in comparison to the control colonies. The maximum yield of honey was observed in colonies fed with black gram. Yeast, soybean flour, sugar and small amount of other ingredients was mixed and tested on bee colonies. Positive effect on various colony parameters i.e. brood and honey was observed. Nabors (2000) reported that treated colonies produced more honey in the honey flow season than control colonies.

A new pollen substitute diet (feed bee) has been developed by Saffari et al. (2004) with the composition of natural pollen and of existing supplementary feeds. Feedbee (detailed description of ingredient used in diets not given by manufacturer) given to treated colonies and compared with natural pollen and Bee-Pro (supplementary diet) with respect to feed intake, sealed brood area and honey production. Consumption rate of Feedbee was statistically equal to that of natural pollen and superior to Bee-Pro in all treated colonies when feed in moist patty form. Higher honey production observed in both groups (feed with natural pollen and feedbee) in comparison to Bee-Pro treated colonies and there was no significance difference seen between the honey yield of pollen and Feedbee treated colonies. A study has been conducted to check the effect of early supplementary feeding on honeybee colonies strength (Madras-Majewska et al., 2005). Growth and development of colony was assessed on the basis brood area measurements. Two colony groups: Groups I had 10 honeybee colonies fed with candy made with drone brood (kept in freezer for 6 month) and glucose, Group II consists of 9 colonies fed upon candies made with sugar and honey. Observations revealed that early spring supplementary feeding promotes the overall growth of colony by enhancing the brood area and egg laying by queen. Positive effects of supplementary feeding before wintering on bee survival

rate, brood area and bee population were recorded in a study conducted by Akyol et al. (2006) at East Mediterranean Region. Dastouri et al. (2007) used pea powder, milk powder, soybean meal and collected pollen to make four different diets for honey bees. Significance difference recorded between the colonies fed with pea powder and other supplements, except the pollen supplement. There was no significance difference found between the pea and pollen supplement treatment. A significant increase was found in the population of colonies treated with pea powder than other colonies treated with milk powder and soybean meal. An investigation was done to check the effect of supplementary feeding on honey bee colony in Turkey. Five diets were tested on 60 (six group of 10 colonies) honey bee colonies. Different combinations of diets were: Diet 1 (honey and pollen), Diet 2 (soya flour, pollen, sucrose and water), Diet 3 (yeast, pollen, sucrose and water), and Diet 4 (yeast, sucrose, water and soy flour). Diet 1 was found very effective than other treatments as higher increase recorded in the brood area, colony weight, number of frames and honey yield in colonies of group I (Dodologlu and Emsen, 2007). Van der Steen (2007) formulated a pollen substitute with easy home preparations and checked their effect on honey bee colony development. In 2001 and 2002 experiments were conducted on free flying honeybee colonies. In the year 2001, three treatments: (i) pollen substitute (ii) bee bread and (iii) no supplement (not any pollen supplement given to colony) were given to three groups of colonies without any pollen supply (with pollen trap). In 2002, material and method was almost same, only bee bread treatment replaced with a pollen supply (without pollen trap). Bee longevity, brood rearing and pollination efficacy recorded highest in colonies fed with pollen substitute (group had pollen trap). It was concluded that pollen substitute boost up the colonies where deficiency of pollen affects the overall development of colony. Avni et al. (2009) checked the effect of different surface area of pollen supplementary patties fed to *Apis mellifera* colonies on consumption of diets, brood production and honey production. Four diets were formulated for the study, three pollen supplement diets for experimental colonies and one carbohydrate diet for control colony. Patties of equal weight (300gm) but different in size i.e. small (29,200 mm²), medium (46,248 mm²) and large (84,640 mm²) were fed to *Apis mellifera* colonies. The data revealed that consumption of large size patties was greatest in most of the colonies followed by colonies fed upon medium and small size patties. Sealed brood area was found highest in the colonies fed with large size patties during the experimental period, whereas, huge fall was recorded in the sealed brood area of control colonies. Honey yield after dearth period, in next flowing season was also better in the colonies fed with large size patties than other treated colonies. Commercially available pollen substitute diets were compared with pollen cake and high fructose corn syrup by means of their consumption, effect on brood and adult population by DeGrandi-Hoffman et al. (2010). Experiments were performed in two different seasons (winter and summer) for variable durations. In the winter season, three commercially available diet formulations (Diet-1, Diet-2 and Diet-3), pollen cakes (pollen collected from colonies) were tested for three months in the absence of natural pollen intake and two formulations (Diet-2 and Diet-3) and pollen cake were given to colonies for two months during summer season with natural pollen intake. Consumption of Diet-2 and Diet-3 was almost similar to the pollen cake in both seasons. Consumption of Diet-1 found less during each feeding interval in first trial. In trial 1, Diet-3 found to be significantly effective on brood rearing and adult bee population than other diets and pollen cake fed to colonies. In trial 2, results (brood area and adult bee population) of all the colonies fed with artificial diet were similar. It may be the results of natural pollen intake by colonies which fulfilled all the nutritional deficiencies of the colonies and all diets responded equally.

The relationship between consumption of proteinic diets and hypopharyngeal gland development in honeybee workers was investigated by Al-Ghamdi et al. (2011). Group I used to measure the consumption rate of diets by worker bees and group II used to determine the effect of diet on hypopharyngeal gland development when fed upon bee bread, pollen, nectapol, mixture of yeast, gluten and sugar and traditional substitute. Consumption of all formulated diets found higher during 3–9 days after emergence and consumption by bees decreased after 9 days gradually. The lowest consumption of diet recorded in colonies fed with traditional substitutes. Hypopharyngeal gland of worker bees showed largest acinar surface area when fed with bee bread followed by yeast – gluten mixture, pollen loads, nectapol and traditional substitutes respectively.

Three diet formulations in solid, semi-solid and slurry form developed by using four pulse soybean, Mungbean, pigeon pea and chick pea in India (Sihag and Gupta, 2011). Tested colonies were equalized in terms of strength of colony, no pollen stores, sealed brood, unsealed brood and honey stores. Each of four Pollen substitute/supplement was given to set of four colonies directly into frames inside the hive, however control colonies were fed with sugar syrup only. It has been observed that addition of pollen increase the percent acceptability of all diets. Soyabean diet formulation (with pollen) in slurry form found to be best for all desired aspects including brood area, pollen store, honey area and colony strength among all other three formulations of Mungbean, gram and arhar. Honey yield in next blooming season was found three times more in colonies fed with pollen supplement and two and half times more in colonies fed upon pollen substitute than control colonies. A study has been conducted to check the feeding efficiency of pollen substitute on honey bee colony parameters (Sena et al., 2012). 18 colonies (two groups of 9 colonies) were selected for study and equalize to each other by means of population and queen's age. It has been reported that feeding the bee colonies with Feedbee, showed a slight increase on the production of honey per colony and brood rearing activity of honey bees. But there was no statistically significance differences found between the control and experimental colonies. Evaluation of protein levels and colony development of Africanized and European honey bees fed with natural and artificial diets (Morais et al., 2013). Two artificial protein diets were proposed, a high protein diet made of soy milk powder and albumin, and a lower protein level diet consisting of soy milk powder, brewer's yeast and rice bran compared with bee bread and a non-protein sucrose diet. Field experiments were conducted on Africanized and European honey bees in two apiaries located at two different places of Brazil. The colonies fed with proteinaceous artificial diets showed significant enhancements in all parameters: percent consumption of formulated diet, colony strength colony weigh and honey production, while overall productivity of control colonies declined during dearth period. Overall observations showed that these two protein diets have better potential to maintain the maximum parameters of colony during dearth period.

A study has been carried out to check the effect of high protein feeds on growth, development, performance and overwintering of honeybees (Irandoost and Ebadi, 2013). Eight different protein sources lentil flour, soybean flour, soybean meal, bread yeast, wheat gluten, skim milk powder, fish meal and pollen used in the study. Experiments were conducted on three groups of colonies: on caged bees in incubator, hive bees in fields and on overwintering bees. Among all nutritional sources, consumption of pollen was highest while lowest for fish meal. A positive relationship was found between the consumption and other colony parameters. Egg laying in colonies fed with pollen recorded highest (22636 cm²) and lowest (13052 cm²) in the colonies fed with fish meal. Similarly, honey production found higher in pollen fed

colonies and least in colonies given with fish meal. A mixture of soybean flour, yeast extract, honey, NaCl salt, vitamins, minerals etc. was used by the [Sihag and Gupta \(2013\)](#) for the formulation of different combinations of four diets. Total 15 colonies were selected for study, 12 colonies for treatment and set of three colonies as control group. All selected colonies were equalized for five colony parameters; sealed brood area, unsealed brood area, bee strength, bee bread area and honey stores. It was reported that colonies receiving diet-4 (Soybean flour + Yeast + Honey + vitamins + minerals) had significantly more sealed brood, unsealed brood, bee population and honey area than other colonies treated with diet-1, diet-2 and diet-3. However rate of all colony parameter declined gradually in the control colonies. Report showed that none of the control colony survived in dearth period. From this study, it has been revealed that it is necessary to feed honey colonies with pollen substitute or pollen supplement during the scarce period of the year to get the benefits of next honey flowing season. Supplemental diets were given on *Apis mellifera* colonies to check their effect on honey production ([Mahmood et al., 2013](#)). Pollen, soybean, grams, maize, brewer's yeast, and sugar was used to formulate four different combinations which were named as: Soybean diet (T₁), Gram diet (T₂), Maize diet (T₃) and Sugar only (T₄). After treatments, in next honey flow season 21.3 kg, 24.4 kg, 19.3 kg and 16 kg honey was extracted from the soybean diet, gram diet, maize diet and sugar treated colonies respectively. Colonies treated with gram diet showed better performance in honey production than other treated colonies. Whereas, all the colonies treated with protein supplement diets proved superior over control colonies.

[Pande and Karnatak \(2014\)](#) used germinated pulses as pollen substitute for pollen scarce period management of honeybee colonies. Different germinated pulses flour used for the formulation of four different diet(s) viz. ger horse gram, ger chick pea, ger green gram/ Mungbean, ger Pea. All pollen substitute diets affects the colony attributes positively including foraging activity, brood area and honey stores. Colonies fed with germinated chickpea showed significant increase in all parameters including honey store followed by colonies treated with ger green gram and ger horse gram respectively. All the desirable colony attributes were observed to be least in germinated Pea. However, all the colonies treated with pollen substitute diets were found to be superior over control colonies. [Kumar and Agrawal \(2014\)](#) carried out a comparative study to examine the performance of honeybee colonies fed with artificial diets in two different regions of India (Gwalior and Panchkula). Defatted soy flour, brewer's yeast, parched gram, spirulina, skimmed milk powder, sugar, glucose, protein hydrolysate powder and natural pollen were used to develop six different combinations of artificial diet. Trials of diet on colonies have been done during summer dearth period. Among all combinations Diet-3 (Defatted soy flour, brewer's yeast, protein hydrolysate powder, sugar and glucose) found to be best for artificial feeding of honeybees. Performance of all experimental colonies was found comparatively better than control colonies. Sealed and unsealed brood, bee population and quantity of honey stores were found higher in the colonies fed formulated diet-3 in comparison to colonies fed with diet1, diet 2, diet 4, diet 5 and diet 6. Impact of supplementary feeding on honey bee brood development and honey production was investigated by [Gameda \(2014\)](#). Comparison of pea flour and sugar syrup as a supplementary feed of honey bees was done on two groups (seven colonies in each group). The results proved that pea flour was better for overall colony growth and maintenance during dearth period and greater honey production. It was reported that after dearth period, in next honey flow season, honey produced from colonies fed with pea flour was found to be comparatively higher than honey produced from colonies fed on sugar syrup. [Wilde et al. \(2014\)](#) carried out a study to test the effect of supplement food in spring season on development and productivity of

honeybee colonies. Experiments were carried out during March-June month in the year, 2013 at University of Warmia and Mazury in Olsztyn, Poland. 120 bee colonies were divided into five groups. Honey-sugar cake with different additives was given to three groups of colonies (Group I: Honey-sugar cake with Beedine, Group II: Honey-sugar cake with Immunebee solution, Group III: Honey-sugar cake with beetonic solution). Group IV given with Honey-sugar cake without any additive solution and Group V given with honey-sugar cake only. There was no significant difference between the brood areas of all groups. But it was found higher in the colonies group II given with Immunebee solution. Similarly, recorded quantity of honey was not significantly different in all the groups. It was highest in group I (given with Beedine and lowest in the group V (no cake and no additives). [Abd El-Wahab et al. \(2016\)](#) carried out a study on honey bee colonies fed with five pollen supplement diets, composed of soybean flour, Brewer's yeast, powdered sugar, date pollen grains, honey, turmeric, fenugreek powder, vitamins, orange juice, mint oil and sugar syrup. Composition of diet E (Brewer's yeast, bee honey, turmeric, powdered sugar, fenugreek powder, vitamins, orange juice, mint oil and sugar syrup consumed by bee colonies in a higher amount/ 2 weeks interval. No residues of patties left at the end of feeding interval. It was found that honey yield of colonies fed with new pollen substituted diet significantly great in comparison to other tested diets and control. [Shehata \(2016\)](#) proposed composition of crushed panicum, crushed phalaris, soybean, mixed melon and orange shell juice, agwa and cinnamon oil for the formulation two pollen substitute diets (Diet B and Diet F) for honey bees management during dearth period. Carniolan and Italian hybrid honey bee colonies (*Apis mellifera*) were selected for study. Colonies were equalized in terms of no. of frames covered by bees and newly mated queen. Group of three colonies were used for each pollen substitute diet and group of three colonies given with sugar syrup used as a control in the study. Both pollen substitutes fed colonies found to be significantly superior to control colonies in terms of sealed brood area, pollen collection and honey yield. Composition of soybean meal, mesquite pod powder, date paste, Feedbee and corn gluten was used to formulate number of five diets ([Amro et al., 2016](#)). Palatability and effect of these proteinaceous diets was checked on brood rearing and other quality parameters of honey bee colonies in isolation condition. Composition of diets used in the study as: Diet 1 (Soybean meal, dried skimmed milk, Brewer's yeast, sugar powder, fresh mixed pollen pellets, honey and water), Diet 2 (Mesquite pods powder, dried skim milk, Brewer's yeast, sugar powder, fresh mixed pollen pellets, honey, multivitamins and minerals, coriander oil and water), Diet 3 (Date paste, dried skim milk, Brewer's yeast, sugar powder, fresh mixed pollen pellets, honey, multivitamins and minerals, coriander oil and water), Diet 4 (Feedbee, honey and sucrose solution and water) and Diet 5 (Corn gluten, sugar powder, fresh mixed pollen pellet, honey and water). Food consumption was significantly highest in the colonies fed with diet 3 (213.2 g) followed by Feedbee (173.6 g), mesquite (124.1 g), corn gluten (95.7 g) and soybean meal (87.4 g) respectively. Brood area was largest (1066.7) in the control group (free flying condition) and lowest values in the experimental group fed with corn gluten. There was no brood area recorded in the experimental group of colonies fed with soybean meal. Physical and chemical analysis of honeybees was also done by the researchers in their study. The fresh and dry weight of the control colonies which were reared under natural condition was 132.7 and 31.9 mg/larva. The results of colonies fed with artificial diets were also close to values of control colonies. The fresh and dry weight of larvae of these colonies was recorded as 123.6 and 29.5 mg/larvae. Observation revealed that all other experimental colonies had lower values of larval weight than control group and group of colonies given with Feedbee. [Puškadija et al. \(2017a\)](#) conducted a study with artificial feed

on some Carnolian honeybee colonies and found that late winter feeding stimulates the rapid spring development of Carniolan honey bee. Experiments were started from the last week of February 2016 on three groups of colonies (Group P, S and C). Colonies of experimental group P were fed with pollen candy, group S of colonies given with pollen substitute and colonies of control group C were not fed with any pollen supplement or substitute. During the experimental period effect of the pollen candy and pollen substitute on different colony parameters like weight of the bee colonies, number of bee and number of brood cells were observed. During the experimental period control group of colonies were losses their weight, whereas colonies fed with pollen supplement and substitute enhanced their weight. Number of brood cell and number of bees found higher in the colonies fed with pollen substitute. A positive significant relationship found between the brood cell and number of bees of colonies.

Wijayati et al. (2019) formulated a pollen substitute for better colony development during dearth period of the year. Winged bean seeds were processed in three different forms: roasted winged bean seeds, boiled winged bean seeds and fermented winged bean seeds. Consumption of roasted winged bean seeds found better in comparison to other tested diets.

Kumari and Kumar (2020) formulated and fed a diet composed of Defatted Soy Flour, Parched Gram, Brewer Yeast and Protein Hydrolysate Powder to *Apis mellifera* in sub-tropical Himalayan region. The results obtained revealed that diet got consumed in good quantity and influenced the colony parameters positively. The effect of feeding diet was also observed on quality and quantity of honey. It was found that there is no deterioration in honey quality, also the quantity of honey was increased.

The summary of work done by various workers along with diet recipe and their effects on colony parameters are mentioned below in Table 1.

3. Carbohydrate based pollen substitutes & supplements

A variety of carbohydrate diets have been tested by a large number of beekeepers. Some feeds were consumed readily and in more quantity while others were not accepted and if accepted, the consumption reported to be very less.

Rosov (1944) reported yearly consumption of honey by a colony of honey bee *Apis mellifera* L. to be 40–45 kg during summer, 20 kg during winter and 6 kg used in wax secretion and a total of about 70 kg. per year. In India, jaggery syrup was found to be readily acceptable to bees as sugar in South India (Anonymous, 1951). However, bees do not normally take jaggery, and become dysenteric if they take it due to severe shortage of nectar, particularly in cooler climates and in winter (Muttou, 1947; Mullick, 1948). Bhatia and Pingale (1954) fed small colonies with glucose containing either (*Agave Veracruz*) juice, or pure poly-fructosan. Stute (1958) conducted various experiments in Germany by feeding an extract from fresh or dried orange peel to bees after treating it with diphenyl to eliminate its bitterness and observed that the extract sweetened with sugar or honey, which he termed as bee tea, can safely be used as bee food. Free and Spencer-Booth (1961) fed 3 groups of 7 colonies with concentrated and dilute sugar syrup and no syrup during spring, summer and autumn for 3 years. Concentrated sugar syrup was consumed in more quantity than the dilute sugar syrup and it also increased the brood rearing activity to some extent. Farrar (1963) reported that good colonies in most northern regions consume roughly 22–25 kg of honey from the time brood rearing stops in the fall until enough nectar can be collected in the spring to support the colony. Sheeley and Poduska (1968) reported that bee colonies fed on divert sugar (92% sucrose, 8% invert sugar and 1% pollen) showed enhanced egg laying by

queen and an increased brood area. Jaycox (1969) recommended that in more temperate region, 18–27 kg of honey should be present as winter food reserve in a colony. Patriot (1980) recorded colony for fourteen winters in France and found that the mean total winter loss in weight was 7.0, 7.9 and 7.2 kg for apiaries at altitude below 300, 300 to 500 and 500 to 1000 m, respectively. The mean winter weight loss taking all hives together, varied from 5 kg to 12 kg. Taking these factors into account, he concluded that at least 12 kg food reserve should be provided in winter to honey bee colonies.

Standifer et al. (1970) reported that the bee colonies fed with Bee Vert (Invert sugar plus one percent sucrose) reared more brood and produced twice as many foragers as control colonies. Waller (1972) reported that nectar and sugar solutions containing 30–50 percent sugar concentration, elicit the maximum collection response by honeybees. Nectar is manipulated and enzymatically converted to honey by bees. The colony will perish without honey as energy source, even though large amount of pollen or bee breed may be stored in the combs. Sucrose, glucose and fructose are the predominant sugar in nectar although many more have been identified usually in trace amounts (White, 1975). Barker and Lehner (1973) studied the consumption of honey syrup, sucrose and mixed sugar syrup (comprising of 13 different sugars) by bees. He further reported that consumption of honey syrup and sucrose syrup averaged 23.7 mg and 5.9 mg per bee per day. Finally, they concluded that the bees showed preference for solution with honey over sucrose or mixed sugars. Further, Barker and Lehner (1974) tested a number of sugars like L-arabinose, D-xylose, D-fructose, D-glucose, D-galactose, D-mannose, lactose, maltose, melibiose, sucrose, trehalose, melezitose and raffinose and found that sucrose was superior to other sugars in both acceptance and nutritive value. Jachimowicz and Ruttner (1974) reported that a mixture containing 70 percent powdered sugar, 15 percent honey and 10 percent invert sugar (with 1 small bottle of fumidil 'B' per 20 kg of sugar) can be fed successfully to strong active colonies as spring stimulative food. Diets formulated with sucrose were consumed in greater amounts by the colonies than formulations containing other sugars (Herbert and Shimanuki, 1978b). Rate of consumption of honey, sucrose or high fructose corn syrup under caged condition has, however, been found almost same (Barker and Lehner, 1978). No significant difference in brood rearing and honey yield was noticed by Atallah and Naby (1979) in Egypt with colonies fed on invert sugar during nectar dearth period and colonies fed on sucrose syrup or with normal honey stores. It was concluded that invert sugar was satisfactory substitute for sucrose for the colonies during nectar dearth period.

Zmarlicki and Marcinkowski (1979) reported that bee colonies fed on various stimulative foods in spring showed approximately 6% increase in brood. Hussein (1979a) demonstrated that addition of about 0.5% ascorbic acid in sugar syrup produced rearing significant (32%) increase in brood rearing than the control. Atallah and Naby (1980) also tried sugar cane syrup, invert sugar, date extract and sucrose solution (1:1) to a group of 100 newly emerged worker bees under caged conditions. They reported that the artificial diets of unrefined sugar, in the form of cane syrup produced acid rectal contents, which were harmful to caged bees. Ibrahim (1982) fed groups of starved worker bees with seven different feeds, each containing 50 percent sugar. Rate of consumption was highest for honey syrup, followed by invert sugar solution, normal sugar syrup, pure fructose solution, commercial glucose solution and molasses solution. Verma and phogat (1982) reported that feeding sugar syrup fortified with 0.75 percent vitamin C, improved comb building (by 32%), brood rearing (by 110.37%), foraging activity and defensive behavior in *A. cerana indica* colonies. Singh and Verma (1983) found that weak colonies built more combs and reared more brood when fed with sugar syrup containing antibiotics, than

Table 1
Various honeybee diet formulations and their effects on colony attributes.

Sr. No.	Reference (s)	Feedstuff	Placement	Effects
1.	Haydak (1933)	Dried yeast, Egg white, Egg yolk, Rye flour Skimmed milk powder, Whole egg, Whole milk	In empty comb cells	Lower adult mortality, brood rearing maximum in the case of dried yeast and lowest in egg white
2.	Haydak (1936)	Commercial casein, Corn flour, Cottonseed meal, Fish meal, Meat scrap, Oat flour, Pea flour, Wheat flour	In empty comb cells	Brood development normal in all cases except fish meal, building activity normal in all diets except on fish meal and pea flour
3.	Haydak (1937)	Cottonseed meal, Linseed meal, Peanut meal, Soybean flour	In empty comb cells	Body development normal on all the materials, brood rearing normal on cottonseed meal, soybean flour and soybean meal
4.	Haydak (1939)	Cottonseed meal	In empty comb cells	Satisfactory body development, consumption and brood rearing
5.	Haydak (1945)	Soy flour + SMP Brewer yeast + SMP BY + SF + Dried egg yolk	In empty comb cells	Enhanced brood rearing
6.	Maurizio (1950)	Soy flour + SMP	Top bars	High mortality, reduced longevity
7.	Haydak (1959)	Soy flour + Brewer's yeast + Dried skimmed milk	Top bars	Enhanced brood rearing
8.	Standifer et al. (1960)	I.N.A.	I.N.A.	Increased adult longevity
12.	Wahl (1963)	Brewer yeast, Dried milk, Soy flour	I.N.A.	Soyflour resulted in higher brood rearing
15.	Doull and Purdie (1966)	Krayeast + SMP (4:1)	Top bars	Satisfactory honey production
16.	Forster (1966)	Krayeast + SMP	Outside the colony	Unsatisfactory brood rearing and honey production
18.	Haydak (1967)	Brewer's yeast + Soy flour + SMP	Top bars	Satisfactory results
19.	Stroikov (1966)	Soy flour + Brewer's yeast + Dried skimmed Brewer's yeast Dried whole milk	I.N.A.	Satisfactory brood rearing
20.	Forster (1968a,b)	Brewer's yeast + soy flour + SMP	Top bars	Unsatisfactory results
21.	Hagedom and Moeller (1968)	Soy flour	Top bars	Consumption satisfactory, Less brood rearing
22.	Haydak (1968)	Brewer's yeast + Soy flour + SMP	Top bars	Enhanced brood rearing
23.	Sheeley and Poduska (1968)	Linseed meal, Meat meal, Peanut flour, Protone Soy flour	Top bars	Satisfactory brood rearing
24.	Banby and Gorgui (1970)	Broadbean flour Roasted chickpea flour, Maize flour, Soy flour	Top bars	Excelled brood rearing, body weight, longevity
25.	Standifer et al. (1970)	Brewer's yeast + Soy flour + SMP + Meat scrap	Top bars	Unsatisfactory brood rearing
26.	Free and Williams (1971)	Baker's yeast, Active yeast, Fodder yeast Medicinal yeast	Top bars	Negligible consumption
27.	Standifer et al. (1973a)	Brewer's yeast	Top bars	Unsatisfactory brood rearing
28.	Standifer et al. (1973b)	Soy flour + Skimmed milk powder + Meat scrap Soy flour	Top bars	Consumption satisfactory
30.	Stranger and Laidlaw (1974)	Soy flour + Wheat Wheat	Top bars	Satisfactory brood rearing
31.	Barker and Lehner (1976)	Skimmed milk powder + Other ingredient	Top bars + liquid in feeder	Bee mortality
32.	Peng and Jay (1976)	Brewer's yeast + Soy flour + Skimmed milk	Top bars	Unsatisfactory brood rearing
33.	Szymas (1976)	Casein, Soybean meal, Wheat gluten Yeast	I.N.A.	Pronounced changes in midgut epithelium
34.	Alexandru et al. (1977)	Brewer's yeast + Soy flour + SMP	Top bars	Satisfactory brood rearing
35.	Barker (1977)	Soy flour	I.N.A.	Significant adult mortality
36.	Doull (1977)	Torula yeast	Top bars	Unsatisfactory brood rearing, consumption also low due to hardness of patties
37.	Standifer et al. (1977)	Brewer's yeast, Soy flour, Wheat	Hive entrance and top bars	Satisfactory brood rearing
38.	Atallah and Naby (1979)	Brewer's yeast Powdered milk Sugarcane yeast	Top bars	Heavy adult mortality, normal brood rearing
39.	Corner (1978)	Skimmed milk powder + Other ingredients	Top bar and liquid feeding	Adult mortality
40.	Taber (1978)	Soy flour	I.N.A.	Adult mortality
41.	Herbert and Shimanuki (1979a,b)	Casein, Corn gluten, Cottonseed meal, Roasted oats Soybean meal, Wheat, Wheat germ flour	Top bars	Higher level of protein toxic to bees, Supported brood rearing
42.	Mishra et al. (1979)	Brewer's yeast + Soy flour + Skimmed milk powder	Top bars	Satisfactory honey production
43.	Chalmers (1980)	Brewer's yeast, Fish meal, Potato flour, Skimmed milk powder	Top bar	Fish meal found suitable, all other diets shown poor results
44.	Doull (1980a,b)	Krayeast + Skimmed milk powder	Top bars	No effect on brood rearing but high honey production

Table 1 (continued)

Sr. No.	Reference (s)	Feedstuff	Placement	Effects
45.	Erickson and Herbert (1980)	Peanut cake	Top bar	Unsatisfactory brood rearing and consumption
46.	Hussein (1981a)	Soybean nuggets	Inside the hive	Satisfactory brood rearing and honey production
		Potato powder		
		Sweet potato powder		
47.	Herbert and Shimanuki (1983b)	Lactoalbumin	Top bar	Unsatisfactory brood rearing
		torula yeast		
48.	Winston et al. (1983)	Brewer's yeast + Fish meal	Top bar	Less brood mortality, lower longevity
49.	Lehner (1983)	Soybean flour	Top bar	Sustained brood rearing
		Torula yeast		
50.	Peng et al. (1984)	Torula Yeast	Top bar	Satisfactory brood rearing
51.	Shimanuki and Herbert (1986)	Lactalbumin	Top bar	Satisfactory brood rearing
		Torula yeast		
52.	Chhuneja et al. (1992)	Brewer's Yeast + Dehusked parched gram + Skimmed milk powder + Sugar	Top bar	Satisfactory brood rearing
53.	Abbas et al. (1995)	Black gram + Skimmed milk	Top bar	Increased number of bee frames and honey
54.	Srivastava (1996)	Caesin + Sucrose + cholesterol + Salt mixture + Tocopherol + Alphecel + Vitamin	Top bar	Positive effects on colony development
55.	Sabir et al. (2000)	Maize flour + Methionine + Vitamin B-complex	Top bar	Increased brood area and honey stores, number of bee frames,
56.	Saffari et al. (2004)	Feed bee	Top bar	Increased brood rearing, honey stores and bee strength
57.	Lakra (2006)	Soy flour + Honey + Yeast extract + Multivitamin	Top bars	Satisfactory honey production
58.	Gloria-DeGrandi-Hoffman et al. (2010)	I.N.A.	Top bar	Developed hypopharangeal gland
59.	Sihag and Gupta (2011)	Soybean + Mungbean + Chick pea + Pigeon pea	Frame feeding	Increased bee strength, honey production
60.	Kumar et al. (2013)	Defatted soy flour + Brewer's yeast + Soy protein hydrolysate	Top bar	Satisfactory brood rearing, increased bee strength
61.	Pande and Karnatak (2014)	Germinated pea flour + Brewer's yeast + Skimmed milk powder + Honey	Top bar	Increased brood area, honey stores, pollen stores
62.	Pande et al. (2015)	Banana syrup	Division board feeder	Increased brood area, honey stores, pollen stores, foraging activity
63.	Haleem et al. (2015)	Yeast powder + Sugar syrup	Top bar	Highest queen cell production
64.	Abd El-Wahab et al. (2016)	Brewer's yeast + bee honey + turmeric + powdered sugar + fenugreek powder + vitamins + orange juice + mint oil + sugar	Top bar	Satisfactory consumption, Honey production
65.	Aqueel et al. (2017)	Yeast + Royal jelly	In artificial queen cell cups	Better growth of queen larvae
66.	Puškadija et al. (2017b)	Defatted soy flour + Brewer's yeast + Enzyme inverted syrup	I.N.A.	Enhanced weight of the bee colonies, number of bee, number of brood cells
67.	Stevanovic et al. (2018)	<i>Agaricus brasiliensis</i> extract + sugar syrup + honey	Artificial rearing cup	Satisfactory brood rearing, adult population
68.	Wijayati et al. (2019)	Roasted winged bean seeds	I.N.A.	Satisfactory consumption
70.	Kumari and Kumar (2020)	Defatted Soy Flour + Parched Gram + Brewer Yeast + Protein Hydrolysate Powder	Top bar	Highly Palatable

INA: Information not available.

when fed with simple sugar syrup. Feeding sugar syrup made with water having soil extract improved pollen collection at Bangalore, Karnataka (Raj and Basavanna, 1983). Feeding sugar syrup also resulted in higher survival rate and longer life span in the bees than when fed with other carbohydrate foods (Mishra et al., 1984). On the basis of feeding experiments on different types of carbohydrates, Herbert (1992) suggested that the ideal carbohydrate supplement for honey bees is sucrose (2 parts sugar, 1 part water). In spring, a less concentrated solution of sugar containing 1 part sugar to 1 part water is better. Khorvash et al. (1995) in Iran fed the control colonies with white refined sugar and test colonies with various unrefined sugar and obtained satisfactory results even with the unrefined sugar. However, use of unrefined sugars like gur, shaker or cane juice in feeding bee colonies has been reported to cause dysentery (Atwal, 2001).

Nabors (1996) tested the palatability of different mixtures of sucrose and dextrose and concluded that mixtures of sucrose with up to 60 percent dextrose could be used as food for honey bees. Chandel and Kumar (2000) found that of 1500 g sugar was required to achieve significant increase of brood area of *A. mellifera* during pollen availability from maize. It has been reported that supplementary feeding, in general, enhances food stores of the bee colonies (Free and Spencer-Booth, 1961; Nuri and Mishenko, 1970). Krol (1993) fed experimental colonies with sugar syrup (1:1) supplemented with vitamin B1 and the control colonies with sugar syrup (1:1). The experimental colonies produced more brood (by 40%) and more honey (by 30%) than the control colonies. In South India, there was no tradition of feeding bees and thus the honey yield was less. The annual honey yield of 600–800 kg in one apiary has been reported to increase to over 2,000 kg after practice of

changing old combs and sugar feeding (Olsson, 1995). Sharma (2002) reported that *A. cerana* colonies given 3 kg of supplemental sugar feeding had significantly more colony population, pollen and honey stores than those given 1 kg of feed. It has been reported that honey bees are highly responsive to phago-stimulants like sucrose (Scheiner et al., 2004) and the addition of phago-stimulants greatly affect the patty consumption (Keller et al., 2005a,b). Diets containing sucrose or pure glucose as carbohydrate sweeteners rapidly lose water, become hardened, and it becomes difficult for the bees to eat. Reduction of the glucose level to 75 percent or less and replacement of sucrose with fructose yield a soft, acceptable diet texture that lose little water and can readily be consumed by bees (Hanna and Schmidt, 2004). A sugar combination of 50% fructose and 50% glucose appears to be ideal.

A study has been conducted to check the effect of early supplementary feeding on honeybee colonies strength (Madras-Majewska et al., 2005). Growth and development of colony assessed on the basis brood area measurements. Two colony groups: Group I had 10 honeybee colonies fed with candy made with drone brood (kept in freezer for 6 month) and glucose, Group II consists of 9 colonies fed upon candies made with sugar and honey. Observations revealed that early spring supplementary feeding promotes the overall growth of colony by enhancing the brood area and egg laying by queen.

A study has been conducted to examine the effect of nectar supplement on various colony parameters viz. brood area, food stores by (Pande et al., 2015). Four different types of fruit syrups/juices were given to bee colonies by division board feeder method viz. T₁ banana, T₂ papaya, T₃ grapes' and T₄ guava and compared with the colonies fed with T₅ sugar syrup. Significant increase in brood area, foraging activity, pollen store and honey store were recorded in colonies provided with T₁ banana followed by papaya, sugar, grapes and guava respectively. Productivity of all attributes of interest found greater in colonies fed with banana syrup and least in colonies fed with guava syrup. Stevanovic et al. (2018) checked the effect of medicinal mushroom *Agaricus brasiliensis* extract on the honeybees. Honey bee colonies were given with mushroom extract once in autumn season and twice in spring season. Significant effect of supplement was observed on the brood rearing and adult population of bees.

4. Effect of feeding artificial diets on hypopharyngeal gland

Influence of pollen supplement and vitamins on hypopharyngeal gland development and brood of honey bees tested by Zahra and Talal (2008) in department of horticulture, Dohuk University, North Iraq. Results of the study revealed that brood area and dimensions of the acini of hypopharyngeal gland of worker bees fed with vitamin C were wider in comparison to bees treated with other combination of diets. Relationship between the consumption rate of proteinic diets and hypopharyngeal gland development in honeybee workers was investigated by (Al-Ghamdi et al., 2011). Hypopharyngeal gland of worker bees showed largest acinal surface area when fed with bee bread followed by yeast –gluten mixture, pollen loads, Nectapol and traditional substitutes respectively. Darvishzadeh (2015) determined the effect of proline as a nutrient on hypopharyngeal gland development of *Apis mellifera*. Diameter of acini got increased with the effect of proline.

Various properties of honey like ABTS, DPPH and FRAP have also been studied by Stagos et al. (2018), Gül and Pehlivan (2018) and Moloudian et al. (2018) respectively. An increase in all these activities have been observed in honey after feeding the colonies with artificial diets.

Diets have been fed during summer as well as winter season depending upon the severity of lean periods in different countries

(DeGrandi-Hoffman et al., 2010; Kumar et al., 2013; Kumari and Kumar, 2020). However, it has been reported that diets affect the colony parameters positively whenever fed to bees during lean periods irrespective of geographical location

5. Conclusion

Most of the research work on pollen substitute and their significance to beekeeping has been done in foreign countries, recommendations of which cannot be adopted everywhere because of vast differences in eco-climatic conditions, floral diversity and availability of raw ingredients, specific needs and economic aspects. The frequency of floral scarcity also varies in different parts of the world. Few Indian workers have also tried to investigate the influence of pollen substitute formulations on honeybee colonies, but successful formulation is still awaited. Therefore, more scientific work is required in this direction with holistic approach to improve bee colony survival during dearth period and to strengthen our national economy through beekeeping industry.

Declaration of Competing Interest

None.

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