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Managing Bee's Health During Dearth Periods: A Review of Pollen and Nectar Substitutes for Tropical Climates

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This work was carried out in collaboration between all authors. Author KS designed the outline of the review and wrote the first draft of the manuscript. Authors KA and AV final editing work. All authors read and approved the final manuscript.

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ABSTRACT

Bees are essential pollinators, playing a critical role in both ecosystems and agriculture. Aside from their well-known honey production, royal jelly and wax, the significance of pollen and nectar as essential food sources for bees cannot be overstated. In dearth periods such as those occurring between major flowering seasons or environmental factors like drought, bees may encounter difficulties in finding sufficient food for sustaining their colonies. In tropical climates, the dearth period lasts longer compared to other climatic conditions. The implementation and advancement of artificial diet involving substitutes for pollen has been explored as a means to sustain brood rearing, egg laying and foraging activities. This approach aims to ensure an adequate bee population within the colony. Additionally, these substitutes improve energy use and disease resistance by

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influencing gene expression linked to immunological responses, protein synthesis, and glucose metabolism. Therefore, providing pollen and nectar substitutes to bee colonies during dearth periods can prove advantageous in preserving the overall health and growth of the hives in tropical climatic conditions.

Keywords: Brood rearing; dearth period; foraging; nectar substitutes; pollen substitutes; tropical climate.

1. INTRODUCTION

Honey bees plays crucial role as pollinators for agricultural, horticultural and forestry crops. Honey bees (*Apis mellifera* L., *Apis cerana indica* Fab., *Apis dorsata* Fab., *Apis florea* Fab., *Trigona iridipennis* Smith.) nourish themselves by consuming the pollen and nectar from flowers. *A. mellifera* L and *A. cerana indica* Fab are domesticated worldwide to obtain honey, bee wax and various bee derived products. At present, worldwide honey production is about 1.8 million metric tonnes [1]. The decline of honeybee populations is a matter of significant concern for agricultural production and ecosystems as a whole [2]. Pollen serves as the primary source of vitamins, protein and minerals for bees while nectar meets their carbohydrate needs. Bees transform nectar into honey, which serves as primary source of carbohydrates. In addition, bees transform pollen into bee bread, a substance rich in essential protein, vitamins, fats, and minerals necessary for the growth and development of bee workers and larvae. It is important for health of the bee colony that an ample supply of high-quality pollen is accessible [3].

The effectiveness of beekeeping relies on the abundance of bee attractive plants in the vicinity of the apiary and this can vary depending on the prevailing climatic conditions. The availability and diversity of bee-friendly flora changes throughout different seasons in a specific region. The term used to describe the time of year when bee attractive flora is in short supply is known as the "dearth period." A shortage of bee flora and inadequate food reserves within the bee colony can have adverse effects on brood development, honey production and the overall growth and development of the colony. To maximize the advantages of beekeeping, effective management of bee colonies is crucial, particularly during periods of scarcity. A thorough understanding of various management strategies is essential for beekeepers to effectively oversee honeybee colonies [4].

Beekeepers frequently utilize artificial diets to compensate for the absence or inadequate quality of natural pollen, which provides protein, vitamins, fats and minerals [5]. These artificial diets without natural pollen are "pollen substitutes". Whereas, incorporating natural pollen referred as "pollen supplements" [6]. Beekeepers have the choice between purchasing pre-made diets from commercial suppliers or formulating their own [7]. Pollen substitutes are not a complete replacement for natural pollen since they lack numerous nutrients compared to natural pollen [8].

In this context, the present review, elucidates use of stimulative feeding, including nectar and pollen substitutes during periods of scarcity to the domesticated honey bees (*A. mellifera, A. cerana indica*). It also examines the impact of these practices on the productivity and physiological activity of bee colonies in tropical climatic conditions during dearth periods.

2. PRESENT STATUS OF BEE PASTURAGE IN TROPICAL CLIMATIC CONDITION

Pasturage pertains to the flora that serves as a source of pollen and nectar for bees. Examples of nectar-producing plants include tamarind and neem, while pollen-producing plants encompass sorghum, roses, maize and others. Plants that yield both pollen and nectar include apples, bananas and sunflowers [9]. Tropical climates are generally situated within the area spanning from approximately 23.5 degrees north to 23.5 degrees south of the equator, encompassing the region between the Tropic of Cancer and the Tropic of Capricorn. In these climates, temperatures remain consistently elevated throughout the year, with average monthly temperatures consistently exceeding 64°F (18°C). Successful beekeeping in these climates requires a good understanding of local conditions, adaptation to challenges, and proactive hive management [10]. Local beekeeping associations and experienced beekeepers can provide valuable insights and support.

Table 1. Bee pasturage in Tropical region

Bee pasturage		Bee species	Effect on yield	Reference
Common name	**Botanical name**			
Avocado	*Persea americana* Mill.	*A. mellifera*	High fruit set, production, and fruit weight	[11]
Citrus	*Citrus sinensis* L.	*A. mellifera*	Large fruit with low acid content	[12]
Cocoa	*Theobroma cacao L.*	*A. mellifera*	Contribute to cross pollination, Improving pod development and yield	[13]
Cocoa	*Theobroma cacao L.*	*Meliponini Tribe*	Effective pollinator, Enhance pod set and yield	[14]
Cocoa	*Theobroma cacao L.*	*Proxylocopa spp*.	Contributing to pod development and increasing yield	[15]
Coconut	*Cocos nucifera* L.	*A. mellifera*	Fruit set was increased	[16]
Coffee	*Coffea Arabica* L.	*A. mellifera*	Increased Fruit set, Yield increased by 25%, Uniform ripening	[17]
Coffee	*Coffea Arabica* L.	*Bombus spp.*	Higher fruit set and quality	[18]
Coffee	*Coffea Arabica* L.	Euglossa spp.	Contribute to pollination	[19]
Coffee	*Coffea Arabica* L.	Triepeolus spp.	Contribute to pollination	[20]
Coriander	*Coriandrum sativum* L.	*A. cerana indica*	69.51% of seed set And the yield was 14.57 q/ha	[21]
Cotton	*G. hirsutum* L.	*A. mellifera*	12% increased fibre weight and 17% increased seed number	[22]
Cotton	*Gossypium hirsutum* L.	*Tetralonia fraternal*	Yield was 953.91 kg/ha	[23]
Cowpea	*Vigna unguiculata* L. Walp	*Bombus pennyslvanicus* De Gee, *Bombus grieocollis* De Gee	-	[24]
Cucumber	*Cucumis sativus* L.	*A. mellifera*	Increased yield of 10%	[25]
Cucumber	*Cucumis sativus*	*Heterotrigona itama*	Heavier, larger, and longer fruits	[26]
Green gram	*Vigna radiata* L.	*A. mellifera*	Improved yield and quality of grains	[27]
Guava	*Psidium guajava* L.	*A. mellifera*	Increased fruit set and improved fruit quality	[28]
Mango	*Mangifera indica* L.	*A. cerana indica*	42.29% of fruit set	[29]
Mango	*Mangifera indica* L.	*A. mellifera*	Enhance mango yields by 30-40%	[30]
Mango	*Mangifera indica* L.	*Xylocopa spp.*	Contribute to efficient pollination and improved fruit quality	[31]

Mango	*Mangifera indica* L.	*Megachile spp.*	Contribute to higher fruit set and quality	[32]
Mango	*Mangifera indica* L.	*Lasioglossum spp.*	Aid in pollination	[33]
Passion Fruit	*Passiflora edulis* Sims	*A. mellifera*	Lead to higher yields and better-quality fruits	[34]
Passion Fruit	*Passiflora edulis* Sims	*Trigona spp.*	Contributes to successful pollination	[35]
Passion Fruit	*Passiflora edulis* Sims	*Bombus spp.*	Enhancing fruit set and yield	[36]
Passion Fruit	*Passiflora edulis* Sims	*Andrena spp.*	Contribute to pollination	[37]
Papaya	*Carica papaya* L.	*A. mellifera*	Enhance fruit set and quality	[38]
Papaya	*Carica papaya* L.	*Peponapis spp.*	Improves fruit set	[39]
Papaya	*Carica papaya* L.	*Osmia spp.*	Improving fruit yield and quality	[40]
Papaya	*Carica papaya* L.	*Colletes spp.*	Contribute to pollination	[41]
Pumpkin	*Cucurbita maxima* L.	*A. mellifera*	High fruit set, weight, size of fruit and quantity of seeds	[42]
Sesame	*Sesamum indicum* L.	*A. mellifera*	202.20 kg/ha of mean seed yield	[23]
Sunflower	*Helianthus annuus* L.	*A. mellifera*	Increased the pollination efficiency up to five -fold.	[43]
Sunflower	*H. annuus*	*A. mellifera*	43% yield increased	[44]
Tomato	*Solanum lycopersicum* L.	*Anthophora urbana* Cresson and *Bombus vosnesenskii* Radoszkowski	Yield increased and improved fruits quality	[43]
Tomato	*Solanum lycopersicum* L.	*Exomalopsis analis* Spinola, *Centris tarsata* Smith	Increased fruit quality and production	[45]
Watermelon	*Citrullus lanatus* Thunb.	*A. mellifera*	Increased fruit set, numbers per plot, weight of fruit	[46]

In regions characterized by high temperatures and consistent floral resources, dearth periods present unique challenges. Beekeepers must employ proactive strategies to support their colonies during times of pollen and nectar scarcity. Supplemental feeding, habitat diversification, and hive management techniques are essential tools for sustaining bee populations through dearth periods. By integrating these insights into their practices, beekeepers can mitigate the effect of dearth periods and promote the long-term sustainability of beekeeping in tropical climates [47].

The growing need for food security is becoming more pronounced amidst challenges like climate change, alterations in habitat transformation, land use and the continuous expansion of the human population. Efficient pollination is vital for improving both the quality and quantity of various crops, including nuts, fruits, oils, and others [48]. Animal-mediated pollination contributes significantly to a substantial increase in world crop output yielding an extra USD 235–577B per annum. The regions experiencing the most pronounced economic benefits from this phenomenon include the Mediterranean, Eastern and Southern Asia and Europe [49]. The honey production of Worldwide is 1.83 million tonnes in 2022 growing at an average annual rate of 1.69%. Table 1 depicts the bee pasturage in tropical climatic condition.

3. NECTAR AND POLLEN SUBSTITUTES FOR APIARY MANAGEMENT

To ensure the well-being of bee hives around the year, it is essential to address the seasonal variability in the availability of flora that is attractive to bees. To tackle the issue, various attempts have been done to provide substitutes and supplements for pollen. A specialized pollen substitute regimen noticeably enhances colony performance in the initial stages of spring, which were visualized by boosted population levels, expanded capped brood areas, changes in colony and honeybee weights, and elevated vitellogenin levels [50]. The nutritional value of the diet might significantly influence the progression of hypopharyngeal glands [51]. Fig. 1 depicts the feeding substitutes of pollen and nectar during dearth period.

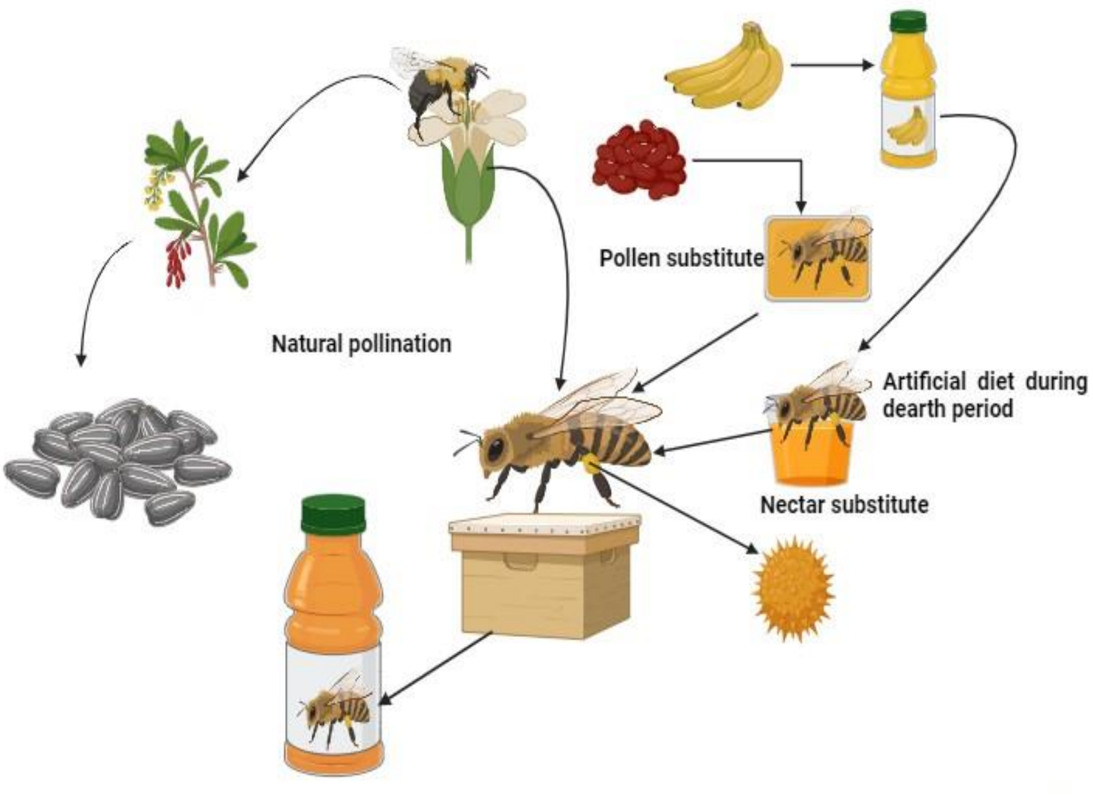

Fig. 1. Natural pollination and feeding of artificial diet at dearth period (BioRender)

Table 2. Nectar and Pollen substitutes and their impact on honey bee

S. No	Nectar and Pollen substitutes	Placement	Effects	Reference
1.	Fish	Top bars	Highly Palatable	[52]
2.	Skimmed milk powder + Krayeast		More production of honey, no effect on brood development	[53], [54]
3.	Soybean nuggets + Peanut cake		Inadequate brood rearing and consumption	[55]
4.	Lactoalbumin + torula yeast		Inadequate brood rearing	[56]
5.	Fish meal + Brewer's yeast		Lower longevity, Less brood mortality	[57]
6.	Torula yeast + Soybean flour		adequate brood rearing	[58]
7.	Torula Yeast		Adequate brood rearing	[59]
8.	Lactalbumin + Torula yeast		Adequate brood rearing	[60]
9.	Brewer's Yeast + Parched gram + Skimmed milk powder + Sugar		Adequate brood rearing	[61]
10.	Skimmed milk + Black gram		Increased honey production number of frames	[62]
11.	Caesin + Sucrose + cholesterol + Alphecel + Salt mixture + Tocopherol + Vitamin		Positive results on hive development	[63]
12.	Vitamin B-complex + Maize flour +Methionine		Increased bee frames, brood area and honey stores	[64]
13.	Feed bee		Increased brood progression, honey stores and bee strength	[65]
14.	MegaBee		Hypopharangeal gland progression	[66]
15.	Soy flour + Brewer's yeast + Soy protein		More bee strength, Adequate brood rearing	[67]
16.	Germinated pea powder + Brewer's yeast + Skimmed milk powder + Honey		Improved brood area, honey stores and pollen stores	[68]
17.	Brewer's yeast + powdered sugar + bee honey + turmeric + vitamins + mint oil + fenugreek powder + orange + juice sugar		Honey production, Adequate consumption	[69]
18.	Soy Flour + Parched Gram + Brewer Yeast + Hydrolysate Powder		Highly Palatable	[70]

19.	(Anise, ginger and laura leaf) + brewer's yeast + sugar		Improved development of hypopharyngeal gland	[51]
20.	*Tenebrio molitor* patties		Overall best results	[71]
21.	Sugar mixture (1% pollen, 92% sucrose, 8% sugar)		Improved egg laying action and expansion of brood	[72]
22.	30- 50% sugar solution		Highest collection response	[73]
23.	0.5% ascorbic acid + Sugar syrup		Improved brood rearing	[74]
24.	Sugar syrup + 0.75% Vitamin C		Increased brood rearing, defensive behavior, foraging activity	[75]
25.	Sugar solution made using water enriched with soil extract		Enhanced pollen collection	[76]
26.	Sugar syrup		Expanded lifespan and Increased survival rate	[77]
27.	Sugar syrup +Yeast powder		Highest production of queen cell	[78]
28.	Brewer's yeast + powdered sugar + turmeric + vitamins + bee honey + mint oil + fenugreek powder + orange juice + sugar		Honey production, satisfactory consumption	[69]
29.	Date syrup		Improved physiological state of individual bees	[79]
30.	Powdered sweet potato + Powdered potato	Inside the colony	Adequate honey production and brood development	[55]
31.	Soybean + Mungbean + Chick pea + Pigeon pea	Feeding in frame	Increased honey production, bee strength	[67]
32.	Royal jelly + Yeast	Queen cell tumbler	Increased queen larvae growth	[80]
33.	Banana syrup	Division board	Improved honey stores, pollen stores, brood area, foraging activity	[81]
34.	*Agaricus brasilensis* extract + sugar syrup + honey	Artificial rearing tumbler	Adequate adult population, brood rearing	[82]
35.	winged bean (roasted)	-	Adequate consumption	[83]

Honeybees exhibited the highest collection response when presented with nectar and sugar solutions containing sugar concentrations ranging between 30 to 50 % [84]. Various sugars, including L-arabinose, D-fructose, D-xylose, D-galactose, D-glucose, D-mannose, maltose, lactose, melibiose, trehalose, sucrose, raffinose and melezitose [73]. Date syrup proved to be a superior option for honeybee colonies compared to conventional pollen substitutes, enhancing the physiological condition of individual honeybees during periods of pollen scarcity [79]. Nectar and pollen substitutes for apiary management and their effects on honey bee colonies during dearth periods are listed out in Table 2.

4. IMPACT OF NECTAR AND POLLEN SUBSTITUTES ON PRODUCTIVITY OF BEE COLONY

Apiarists provide substitutes of pollen and nectar to their beehives with the intention of enhancing colony vigor and productivity, aiming to achieve specific production objectives [85]. This portion delves into the impact of pollen and nectar substitutes on factors affecting colony vigor, such as the adult bee population and brood generation, along with different facets of productivity, encompassing honey yield and the queen's performance quality.

Population: A primary objective of feeding pollen supplements is to boost adult honey bees' population within the colony, often described as enhancing the hive's "strength." Population of adult bees increased when colonies were provided with specific pollen substitutes, in contrast to colonies that didn't receive any dietary supplementation [86]. Rise in the adult bee population in India during the cold season when bees were provided with a pollen supplement for nutrition in the absence of natural pollen [67]. Providing supplemental feeding in summer season, had no discernible influence on colony strength [7]. This observation suggested that regional factors may also be at play, with warmer climates showing a less pronounced effect of pollen supplements compared to regions with more severe winters and shorter periods for colony growth. Pollen substitutes are usually advantageous for population of adult honey bee when there is a scarcity of pollen resources. However, their cost-effectiveness may not be justified when natural pollen is readily available in sufficient quality and quantity.

Brood development: Apiarists anticipate that usage of nectar and pollen substitutes encourage bee colonies in increasing the production of brood. An increase in brood production is observed when bees are provided with a pollen supplement diet, compared to those without any additional dietary support, especially during periods of pollen scarcity or adverse weather conditions [86]. This suggests that, in such environmental conditions, utilizing pollen substitutes is more beneficial for enhancing colony brood production compared to taking no action at all. There was no discernible disparity in production of brood between hives that were provided with commercial pollen substitutes, whether they were lacking in natural pollen or not [87]. Spring feeding of pollen supplements has been proved to rise brood production, as indicated by studies conducted by [6]. In contrast, summer feeding does not lead to any improvement in production of brood [7]. Rearing of brood can be encouraged through the provision of pollen diet during winter in Arizona, in contrast to control colonies that did not result in any production of brood [86]. In subtropical winter, the introduction of artificial pollen supplement and brood pheromone led to an augmentation in brood rearing [88]. Colonies given with a soybean diet did not generate any brood that advanced to the closed stage [89]. Scientists have enhanced the brood production by enriching pollen supplement feeding with a range of ingredients. For example, scientists created a pollen substitute that closely resembles natural pollen and has a balanced amino acid composition [90]. Compared to conventional alternatives, this one improved bee health, increased brood production and promoted colony expansion. Incorporating natural pollen into supplementary feeding can result in enhancements in brood development [67].

The supplementation of pollen diet with 24-methylenecholesterol was found to enhance worker bees' survival, increase fat of the abdomen and boosted head protein in laboratory setting [91]. Highest rates of pupation and egg hatch occurred when diets contained a crude protein content in the range of 30-35% [92]. The usefulness of a novel pollen substitute made from algal proteins was assessed. Comparable to natural pollen in terms of nutritional value, this substitute showed promise for large-scale, sustainable production [93].

Royal jelly*:* The pollen present in the bee hive is typically consumed and processed by nurse worker bees, who distribute the proteins, vitamins, minerals and fats into brood food and royal jelly and established that brood food and royal jelly are closely associated to the nutritional intake of pollen within the hive [94]. The microbiological quality and royal jelly's physiochemical exhibited remarkable stability even when colonies were provided with various protein diets. While pollen substitutes diets may have a very less influence on royal jelly quality, future research is compulsory to gain a deeper understanding of this aspect [95].

Honey yield: Enhanced honey production is often anticipated with use of pollen substitutes, as colonies with greater numbers of honey bees and brood tends to produce high amount of honey [96]. Honey production increased by supplements of pollen [96]. Furthermore, it's worth noting that production of honey was determined by anticipating from the colonies overall weight. Consequently, factors like an adult bee population and brood weight were influenced. In contrast, in some instances, the implementation supplements of pollen had no discernible impact on production of honey [97]. There was rise in honey production when spring feeding was introduced, with this increase plateauing during the later part of the summer [98].

Queen bee: The largest queen of the colony developed through feeding either pollen or soybean flour with 10% extra oil. On the contrary, colonies that were provided with Pollen substitute diet resulted in the production of queens with moderate weight, while those supplied with a diet containing soy protein or soybean flour fed with 5% extra oil produced smaller queens [99]. Although weight can serve as queen quality indicator, it may not conclusively predict a queen's more reproductive ability for apiarists. The longevity of queen life was extended by substitutes of pollen. Colonies given with pollen substitute experienced elevated queen losses in contrast to those fed with high protein pollen supplement during the cold period [90].

Worker bee: Worker bees typically exhibit extended lifespans when provided with substitutes of pollen as opposed to sucrose solution [100]. Colonies are given with diets 35% protein yielded worker bees with longer lifespans than colonies given with 15% protein [101]. In contrast, providing two different pollen supplements to hives actually decrease in the lifespan of honey bees [87]. Worker bees raised in hives provided with pollen supplements had longer lifespans compared to worker bees from hives with less access to pollen [98]. However, in the following year, these same worker bees had shorter lifespans. When bees were provided with a diet consisting solely of soy flour, their lifespan was shorter in contrast to bees that were given a diet containing soybean flour with extra ingredients and major risk of mortality in bees when their diet contains more than 2% oleic acid, while a reduced risk was associated with diet containing 6% linoleic acid content [102]. For beekeepers, it is advisable to thoroughly evaluate the lactose content in diets that incorporate dairy products before using in beekeeping practices. Scientists discovered a novel pollen substitute that had a wider variety of fatty and amino acids. Worker bee longevity increased and brood survival rates were improved with this new substitute [103].

Pest and diseases resistant: Seasonal shifts in nutritional needs may affect how honey bees respond to infections [104]. It is recommended that researchers working on the creation of new supplements of pollen to honey bees take into consideration the seasonal nutritional necessities of these bees. Findings suggest that disease can be prevented by providing substitutes of pollen in bee nutrition. Nevertheless, it is crucial to approach with care, considering they were acquired under controlled laboratory settings and might not completely reflect the intricate interplay of disease resistance in real-world bee populations. Scientists conducted a more current study to investigate the effectiveness of different nectar substitutes that were enhanced with vitamins and minerals. Syrups enhanced overall colony health and boosted resistance to environmental stresses, according to the study [105].

5. IMPACT OF POLLEN AND NECTAR SUBSTITUTES ON PHYSIOLOGICAL ACTIVITY OF BEE COLONY

This section explores the physiological reaction of bees to pollen substitutes. It is crucial to investigate into the behavior, development and functioning of single bee in reaction to these substitutes. The ultimate goal is to understand how improvements in the health and growth of bees resulting from pollen substitute diet may positively impact the overall productivity of the entire colony.

Bee Behaviour: Bee colonies have been observed to handle pollen supplement patties in a distinct manner in contrast to natural pollen. Some worker honey bees consumed the diet with pollen substitute [106]. However, they neither stored these patties as bee bread, nor used them to directly nourish developing larvae. Additionally, there was only a minimal loss of the patty as waste within the colony.

Artificial diets for bees often consist source of protein that aren't part of their natural forage and may pose digestion challenges [90]. According to their findings, nurse bees can digest two synthetic diets with 35% dispersible protein, whereas they could digest 70% of the dispersible protein in natural pollen. This delves that a considerable amount of protein present in artificial feed could remain undigested and be excreted as waste, posing a potential inefficiency in resources and expenses associated with beekeeping. In addition to assessing the solubility of proteins in the digestive system, different path to assess digestibility is by examining the gut enzymes presences. Rise in activity of midgut proteolytic enzymes of worker honey bees that were provided with more protein diet [92] Indicating that bees are capable of digesting substitutes of pollen, but it doesn't provide a precise measure of the extent to which they can digest these substitutes. New pollen substitute that was probiotic-enriched by microbes [107]. The gut health and general colony vitality significantly improved as a result of the study, indicating that adding beneficial bacteria can boost the nutritional content of pollen substitutes.

Enzymes: Worker bees from hives that consumes pollen substitutes with more levels of dietary protein showed rise in enzyme superoxide dismutase activity, known for its antioxidant properties [92]. In contrast, worker honey bees provided with less protein substitutes had less superoxide dismutase action. Moreover, diets containing 35% protein is identified to support optimal brood development. In honey bees action of antioxidant has not been extensively studied, and research in these aspects is required for better understanding.

Weight of bee: Worker honey bees' weight increased in a linear manner with the rising protein in substitutes of pollen [92]. There is no significant difference in the pupae weight, indicating that the impact of protein content on bee weight may vary at different stages of development. The head weight of worker bees was found to be high in bees that were provided with natural pollen, followed by those given with pollen substitute diet and soy-based substitutes suggesting that the type of diet can influence the development and size of specific body parts in worker bees, such as their heads [99]. The thorax weight of worker honey bees was greatest in those that were given with dry spirulina, as contrast to honey bees given with natural pollen [108]. The workers dry weight was not significantly influenced by their diet [98]. Diets included a substitutes of pollen, bee bread and substitutes enriched with probiotics with aim to understand how these different diets might affect the midgut structure of the worker honey bees. It appears that the body weight of bees could serve as nutritional quality indicator. The impact of pollen diet consumption on the structure of the midgut, while significant, is not entirely clear-cut and may necessitate additional research to comprehensively grasp this element [109].

6. MOLECULAR IMPACTS ON HONEY BEE PHYSIOLOGY

Genes involved in the metabolism of carbohydrates may express differently when fed nectar substitutes. To control the influx of simple sugars from substitutes, for example, genes involved in the citric acid cycle and glycolysis may become more active [110]. Pollen substitute consumption has been shown to upregulate genes that encode Anti-microbial peptides (AMPs), including abaecin and defensin. These peptides are essential for the innate immune response because they offer defense against infections [111].

Fat body: Insects rely on fat bodies for various critical functions, including endocrine regulation, immune responses, vitellogenesis (the formation of egg yolk), antimicrobial compounds synthesis, regulation and storage of nutrients [112]. The similarity between fat bodies and nutrition suggests that a high-quality diet is expected to lead to the production of huge fat bodies [108]. Bees given pollen substitutes containing amino acids developed larger fat bodies than those given substitutes without these enriched components [113]. Both natural pollen and dry spirulina caused a rise in the fat bodies size in honey bees [108].

Immunity: Molecular level, gene expression could serve as mark of how an organism reacts to nutritional changes. Bees that were given substitutes of pollen exhibited a notable increase in the immune genes' expression, leading to a substantial rise in the synthesis of the apidaecin 1, in contrast to bees that are exclusively provided a solution of sucrose [114].

Hemocyte and hemolymph: The quantity of hemocytes in worker bees kept in confinement rose as the quality of pollen substitute improved [113]. Bees provided with substitutes of pollen had more hemocyte counts in contrast to bees that ingested natural pollen. When bees were lacking protein, the structure and function of the hemolymph cellular system were adversely impacted [115]. The hemolymph protein levels in bees that consumed pollen supplements were less than those in bees that were given either pollen or bee bread [89]. Particular pollen substitutes led to bees having hemolymph levels that were either equivalent to or higher than those noted in bees provided with pollen or bee bread [90].

Bee bread is produced from fermented honey and pollen. Elevated hemolymph levels are observed in bees given with fermented diets while bees provided with non-fermented diets has less hemolymph protein [116]. This could be caused by the bees consuming a larger quantity of fermented substitute or because the process of fermentation enhanced the digestibility [117]. The investigation on hemolymph levels and the feeding supplements of pollen was conducted on bees within fully developed colonies.

Some studies that assessed the hemolymph protein of bees took an additional step by also measuring the levels of vitellogenin. Vitellogenin (glycolipoprotein) has various functions, including nutrient storage, influencing foraging and nursing behavior, affecting lifespan and plays an important role in overwintering physiology [118]. The patterns of vitellogenin levels generally followed a similar trend to hemolymph protein levels. Furthermore, it was noted that fermented diets led to more vitellogenin in bees compared to unfermented diets [117]. Based on these studies, it appears that feeding bees with substitutes of pollen can enhance vitellogenin levels, which is a positive finding in the context of bee health and nutrition.

Hypopharyngeal gland: The nurse bees hypopharyngeal glands are reason for the protein synthesis of fetal food [94]. Hypopharyngeal gland progression is assessed by measuring either gland protein content or acini size [119]. Bees that consumed pollen supplements showed improved development of their hypopharyngeal glands in contrast to bees that did not consume [120]. In addition, artificial supplements enriched with extra pollen resulted in more hypopharyngeal gland progression in bees compared to pollen-free diets [100]. Like many other health indicators, pollen supplements seem to offer advantages over a lack of protein intake. However, there is room for improvement to enhance their support for better progression of the hypopharyngeal glands. Scientists evaluated the progression of hypopharyngeal glands in honeybees equipped with pollen supplements in the presence of brood pheromone in fully populated colonies [88].

Protein content: The concentration of protein in a honey bee could indicate its capacity to effectively absorb and utilize the proteins it ingests from its diet. The protein in both newly emerged adult worker bees and larvae were greater with hives having access to pollen compared to hives that had less access to pollen and were instead fed protein substitutes [89]. Conversely, those from colonies with pollen access had less body protein levels than nurse honey bees from hives that were supplied with pollen substitutes [87]. Newly emerged bees and larvae exhibited higher levels of body protein as their dietary protein intake increased [92]. Interestingly, this trend in higher protein levels with increased dietary protein intake corresponded with a rise in the body weight bees.

7. SELF-MANAGEMENT OF BEES' IN DEARTH PERIOD

The management strategies employed by bees during dearth time are crucial for their survival and long-term well-being. Honey bees exhibits more resource conservation and colony dynamics adjustments during periods of limited floral availability [121]. By reducing brood activity and foraging activity, bees effectively conserve energy and essential food supplies, ensuring the colony's sustenance through the dearth period [122]. Worker bees play a pivotal role in this process, engaging in food storage and resource allocation to prioritize the colony's survival [123].

Furthermore, the phenomenon of robbing behavior, demonstrates the adaptive nature of honey bee colonies during dearth periods [124]. Bees resort to scavenging resources from weaker colonies or nearby sources to supplement their own dwindling supplies. Worker bees intensify their efforts to defend the hive against potential threats, showcasing a collective defense mechanism [123]. In severe situations, colonies might even abscond, deserting their nest in pursuit of better circumstances [125]

Overall, honey bees exhibit remarkable adaptability and resilience during dearth periods, employing a repertoire of strategies to navigate through challenging circumstances. Comprehending these natural methods of management is crucial for both beekeepers and conservationists to bolster bee populations amidst environmental shifts and habitat alterations. Continued exploration of the nuances of honey bee behavior during periods of scarcity will undoubtedly improve our capacity to safeguard and maintain these indispensable pollinators moving forward.

8. DISCUSSION AND FUTURE PROSPECTS

Substitutes of nectar and pollen are vital for managing domesticated bees in tropical climates, where seasonal variations can impact natural forage availability. In order to improve and optimize bee diet supplements, scientists stressed the necessity for multidisciplinary approaches integrating field research, laboratory analysis, and cutting-edge nutritional science [126]. These substitutes offer essential nutrients during dearth time, promoting colony health and productivity. They mitigate the negative effects of resource scarcity, ensuring consistent colony progression and honey production. Future prospects involve refining substitute formulations to closely match natural resources, enhancing their nutritional value, and exploring sustainable production methods to meet the demands of tropical beekeeping. Additionally, research on the particular nutritional requirements of bees in tropical climates can guide the progression of customized substitute solutions for optimal colony management.

9. CONCLUSION

Unique obstacles are posed by tropical climates, such as irregular floral availability, severe weather conditions and substitutes for nectar and pollen serve a vital role in sustaining the health and productivity of domesticated honey bee colonies. These substitutes offer essential nutrients and energy sources during scarcity, bolstering colony resilience against environmental stressors and promoting sustainable beekeeping methods. Moreover, their integration aids in fortifying honey bee populations amidst the challenges of habitat loss and climate change. However, it's crucial to recognize that while substitutes can supplement natural forage, they cannot entirely replicate the diverse nutritional benefits of natural pollen and nectar sources. Hence, a well-rounded approach that combines natural foraging with supplementary feeding strategies is imperative for comprehensive colony management in tropical climates. Continuous innovation and research will further refine our understanding and application of effective management techniques, ensuring the longevity of bee populations and the sustainability of beekeeping ventures in tropical regions. Enhancing feeding management can be achieved by researchers addressing the existing gaps in the current research and this refinement of practices will lead to a more efficient research for the enhancement of honey bee health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Shahbandeh M. Global production volume of natural honey 2000-2022. May 22, 2024.
2. Grossman E. Declining bee populations pose a threat to global agriculture; 2013. Retrieved March 5, 2020.
3. Brodschneider R and Crailsheim K. Nutrition and health in honey bees. Apidologie. 2010; 41:278–294.
4. Agrawal TK. Beekeeping industry in India: Future potential. Int. J. Res. Appl. Nat. Soc. Sci. 2014; 2(7):133–140.
5. Somerville D. Fat Bee Skinny Bees–A Manual on Honey Bee Nutrition for Beekeepers. Rural Industries Research and Development Corporation; 2005.
6. Saffari AM, Kevan PG and Atkinson JL. Consumption of three dry pollen substitutes in commercial apiaries. J. Apic. Sci. 2010; 54 (2):13–20.

7. Mortensen AN, Jack CJ, Bustamante TA, Schmehl DR and Ellis JD. Effects of supplemental pollen feeding on honey bee (Hymenoptera: Apidae) colony strength and *Nosema* spp. infection. J. Econ. Entomol. 2019;112:60-66.
8. Manning R. Artificial feeding of honeybees based on an understanding of nutritional principles. Anim. Prod. Sci. 2018; 58:689–703.
9. Smith J. The Importance of Pasturage for Bees. 2022; Beekeeping Today.
10. Smith J. Beekeeping in Tropical Climates. 2019; ABC Publishers.
11. Pena JF and Carabali A. Effect of honey bee (*Apis mellifera* L.) density on pollination and fruit set of avocado (*Persea americana* Mill.) cv. Hass. J. Api. Res. 2018; 62:5–14.
12. Malerbo-Souza DT, Nogueira-Couto RH and Couto LA. Honey bee attractants and pollination in sweet orange, *Citrus sinensis* (L.) Osbeck, var. Pera-Rio. J. Venom. Anim. Toxins. Incl. Trop. Dis. 2004; 10:44–153.
13. Bourke AFG, Reddy KS, Kumar A, Thomas M. Honeybee and midge interactions in cocoa pollination. Trop. Pollinat. Sci. 2022;30(4):214-226.
14. Klein AM, Vaissiere BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C and Tscharntke T. Pollinator-friendly practices and their impact on crop yields. Agric. Ecosyst. Environ. 2022;300:77-89.
15. Reddy MS, Kumar V, Singh P. Long-horned bees in cocoa pollination. Trop. Entomol. J. 2021; 29(4): 298-310.
16. Melendez-Ramirez V, Parra-Tabla V, Kevan PG, Ramirez-Morillo I, Harries H, Fernandez-Barrera, M and Zizumbo-Villareal D. Mixed mating strategies and pollination by insects and wind in coconut palm (*Cocos nucifera* L. (Arecaceae)): Importance in production and selection. Agric. Forest. Entomol. 2004; 6:155–163.
17. Vergara CH, Morales J, Gonzalez A and Torres M. The impact of bee pollination on coffee yield. Trop. Crop Sci. 2022; 56(4):678-689.
18. Moro M, Lobo J, Silva T and Almeida P. Buzz-pollination by bumblebees for coffee plants. Bee Research. 2023; 12(2): 89-102.
19. Sabatini MA, Castro ML, Figueroa CM and Reyes AG. The effectiveness of Euglossine bees in coffee pollination. J. Apic. Sci. 2022; 56(1):123-135.
20. Dulvit R, Ramos J, Garcia M and Santos T. The role of cuckoo bees in coffee pollination. J. Trop. Pollinat. Res. 2021; 19(3):145-158.
21. Patil PN and Pastagia JJ. Effect of bee pollination on yield of coriander. *Coriandrum sativum* Linnaeus. Int. J. Plant. Prot. 2016; 9:79–83.
22. Pires VC, Silveira FA, Sujii ER, Torezani KRS, Rodrigues WA, Albuquerque FA, Rodrigues SMM, Salomao AN and Soares Pires CS. Importance of bee pollination for cotton production in conventional and organic farms in Brazil. J. Pollinat. Ecol. 2014; 13:151–160.
23. Stein K, Coulibaly D, Stenchly K, Goetze D, Porembski S, Lindner A, Konate S and Linsenmair EK. Bee pollination increases yield quantity and quality of cash crops in Burkina Faso, West African Scientific Reports. 2017; 7:17691–17700.
24. Asiwe JAN. Insect mediated outcrossing and gene flow in cowpea (*Vigna unguiculata* (L.) Walp): Implication for seed production and provision of containment structures for genetically transformed cowpea. Afr. J. Biotechnol. 2009; 8:226–230.
25. Morse RA, Calderone NW. The value of honey bees as pollinators of U.S. crops in 2000. Bee Cult. 2000; 128:1–15.
26. Azmi WA, Ghazi R, Sultan U, Abidin Z, Chuah T and Mara UT. Effects of stingless bee (*Heterotrigona itama*) pollination on greenhouse cucumber (*Cucumis sativus*). Malays. Appl. Biol. 2017; 46:51–55.
27. Kasina JM, Mburu J, Kraemer M and Holm-Mueller K. Economic benefit of crop pollination by bees: A case of kakamega small-holder farming in Western Kenya. J. Econ. Entomol. 2009; 102:467–473.
28. Rajagopal D, Eswarappa G and Raju AJS. Pollination Potentiality of Honeybees in Increasing Productivity of Guava in Karnataka. In Changing Trends in Pollen Spore Research. Today and Tomorrow's Printers & Publishers: New Delhi, India. pp. 2005; 131–141. ISBN 8173715173.
29. Deuri A, Rahman A, Gogoi J, Borah P andBathari M. Pollinator diversity and

effect of Apis cerana indica F. pollination on yield of mango (*Mangifera indica* L.). J. Entomol. Zool. Stud. 2018; 6:957–961.

30. Garibaldi LA, Aizen MA, Klein AM, Cunningham SA and Harder LD. Pollination by bees increases mango yields. Agric. Sci. Rev. 2020; 34(2): 123-135.
31. O'Neill DM, Wright P, Thompson RJ and Lee, H. Native bees and their effect on mango yield. Int. J. Trop. Agric. 2022; 40(3): 345-359.
32. Kumar V, Reddy MS and Singh P. Leafcutter bees and mango pollination efficiency. J. Agric. Sci. 2021; 58(3): 101-115.
33. Goulson D, Nicholls E, Botias C and Rotheray EL. Pesticides and their impact on bee health. Ecol. Entomol. 2023; 48(2):112-123.
34. Jones CM, Williams A, Patel S and Roberts D. Honeybee pollination services for passion fruit. Trop. Horticult. J. 2021; 33(2):345-356.
35. Williams NM, Brown HR, Davis EJ and Wilson T. Trigona bees in passion fruit pollination. Trop. Bee Res. 2023; 21(3):456-468.
36. Haidar MI, Khan SA, Patel R and Singh V. The role of bumblebees in passion fruit pollination. Hortic. Sci. 2021; 45(1):29-40.
37. Waser NM, Smith JL, Davis CA and Turner P. Mining bees and their role in passion fruit pollination. J. Agric. Entomol. 2022; 54(1): 67-79.
38. Garibaldi LA, Aizen MA, Klein AM, Cunningham SA and Harder LD. Pollination by bees increases papaya yields. Agric. Sci. Rev. 2020; 34(2):123-135.
39. LeBuhn G, Hernandez JL and Melendez M. Squash bee contributions to papaya pollination. Pollinator Ecol. 2022;15(4):212-225.
40. Miller JC, Davis AM, Thompson BR, Martinez LR and Nguyen HT. Solitary bees and their role in papaya pollination. J. Trop. Entomol. 2023; 52(1): 78-89.
41. Bertone MA, Carpenter J, Delgado J and Myers J. Pollination services of Colletes bees for tropical crops. J. Apic. Res. 2022; 61(5):745-758.
42. Nicodemo D, Couto RHN, Malheiros EB and de Jong D. Honey bee as an effective pollinating agent of pumpkin. Sci. Agric. 2009; 66: 476–480.
43. Greenleaf SS and Kremen C. Wild bee species increase tomato production and respond differently to surrounding land use in Northern California. Biol. Conserv. 2006; 133:81–87
44. Chambo ED, Garcia RC, de Oliveira NTE and Duarte-Junior JB. Honey bee visitation to sunflower: Effects on pollination and plant genotype. Sci. Agric. 2011; 68:647–651.
45. Neto S, Lima FG, Gonçalves BB, Lima Bergamini L, Araujo B, Bergamini R, Antonio M, Elias S and Franceschinelli EV. Native bees pollinate tomato flowers and increase fruit production. J. Pollinat. Ecol. 2018; 11:41–45.
46. Walters SA. Honey bee pollination requirements for triploid watermelon. HortScience. 2005; 40:1268–1270.
47. Roubik DW. Tropical pollinators in the canopy and understory: Field data and theory for stratum preferences. J. Insect. Behav. 1992; 5(6):759-783.
48. Giannini TC, Cordeiro GD, Freitas BM, Saraiva AM and Imperatriz-Fonseca VL. The dependence of crops for pollinators and the economic value of pollination in Brazil. J. Econ. Entomol. 2015; 108:849–857.
49. Potts SG, Imperatriz-Fonseca V, Ngo HT, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R and Settele J. Safeguarding pollinators and their values to human well-being. Nature. 2016; 540:220–229.
50. Kim H, Frunze O, Maigoro AY, Lee ML, Lee JH and Kwon HW. Comparative Study of the Effect of Pollen Substitute Diets on Honey Bees during Early Spring. Insects. 2024; 15(2):101. https://doi.org/10.3390/insects15020101.
51. Mohamed FR, Mohanny K and Mohamed GS. Artificial feeding of honey bee colonies by adding nutritional supplements to pollen substitutes and its effect on the development of the hypopharyngeal gland stages of honeybee workers Apis mellifera L. SVU-Int. J. Agric. Sci. 2023; 5 (2):29-41.
52. Chalmers WT. 1980. Fish meals as pollen-protein substitutes for honey bees. Bee World 61:89–96.
53. Doull KM. Relationships between consumption of pollen supplement, honey

production and brood rearing in colonies of honeybees (*Apis mellifera* L.). I. Apidologie. 1980a;11(4):361–365.
54. Doull KM. Relationships between consumption of a pollen supplement, honey production and brood rearing in colonies of honeybees *Apis mellifera* L. II. Apidologie. 1980b;11(4):367–374.
55. Erickson EH and Herbert EW. Soybean products replace expeller processed soy flour for pollen supplements and substitutes. Am. Bee. J. 1980; 120:122–126.
56. Herbert EW and Shimanuki H. Effects of mid-season change in diet on diet consumption and brood rearing by caged honey bees. Apidologie. 1983; 14 (2):119–125.
57. Winston ML, Chalmers WT and Lee PC. Effects of two pollen substitutes on brood mortality and length of adult life in the honeybee. J. Api. Res. 1983;22:49–52.
58. Lehner Y. Nutritional consideration in choosing protein and carbohydrate sources for use in pollen substitutes for honey bees. J. Api. Res. 1983; 22:242–248.
59. Peng TS, Marston JM and Kaftanoglu O. Effect of supplemental feeding on honey bee (Hymenoptera: Apidae) population and the economic value of supplemental feeding for production of package bees. J. Econ. Entomol. 1984; 77:632–636.
60. Shimanuki H and Herbert EWJ. An artificial protein diet for bee colonies. In: Proceeding of XXX International Congress on Apiculture, Nagoya, Japan, pp. 1986; 330–334.
61. Chhuneja PK, Brar HS and Goyal NP. Studies on some pollen substitute fed as moist patty to *Apis mellifera* L. colonies. 1: Preparation and consumption. Indian Bee J. 1992; 54:48–57.
62. Abbas T, Hasnain A and Ali R. Black gram as a pollen substitute for honey bees. Anim. Feed. Sci. Technol. 1995; 54:357–359.
63. Srivastava BG. Nutritional requirements of honey bees: preparation of a pollen substitute diet. In: National Beekeeping Exchange Conference. 29-30 May, 1996 Punjab Agriculture University, Ludhiana, 1996; pp. 17–18.
64. Sabir AM, Suhail A, Akram W, Sarwar G and Saleem M. Effect of some pollen substitutes diets on the development of *Apis mellifera* L. colonies. Pak. J. Biol. Sci. 2000; 3 (5):890–891.
65. Saffari AM and Kevan PG, Atkinson JL. A promising pollen substitute for honey bees. Am. Bee. J. 2004; 144 (3):230–231.
66. DeGrandi-Hoffman G, Chen Y, Huang E and Huang MH. The effect of diet on protein concentration, hypopharyngeal gland development and virus load in worker honey bees (*Apis mellifera* L.). J. Insect. Physiol. 2010; 56 (9):1184–1191.
67. Sihag RC and Gupta M. Development of an artificial pollen substitute/supplement diet to help tide the colonies of honeybee (*Apis mellifera* L.) over the dearth season. J. Apic. Sci. 2011; 55 (2):15–28.
68. Pande R and Karnatak AK. Germinated pulses as a pollen substitute for dearth period management of honey bee colonies. Current Biotica. 2014; 8 (2): 142–150.
69. Abd El-Wahab TE, Ghania AMM and Zidan EW. Assessment a new pollen supplement diet for honey bee colonies and their effects on some biological activities. Int. J. Agric. Technol. 2016;12(1):55–62.
70. Kumari I, Kumar R. Pollen Substitute Diet for *Apis Mellifera*: Consumption and Effects on Colony Parameters in Sub-Tropical Himalaya. Indian. J. Agric. Res. 2020;54 (2):147–153.
71. Pavlovic R, Dojnov B, Sokarda Slavic M, Pavlovic M, Slomo K, Ristovic M and Vujcic Z. In pursuit of the ultimate pollen substitute (insect larvae) for honey bee (*Apis mellifera*) feed. J. Api. Res. 2022; 62(5):1007–1016. https://doi.org/10.1080/00218839.2022.2080950.
72. Sheeley B, Poduska. Supplemental feeding of honey bees-colony strength and pollination results. Am. Bee. J. 1968;108:357–359.
73. Barker RJ and Lehner Y. Acceptance and sustentative values of naturally occurring sugars fed to newly emerged adult workers of honey bees (*Apis mellifera* L). J. Exp. Zool. 1974;187:277–286.
74. Hussein MH. Brood rearing activity and honey productivity of honey bee colonies in relation to feeding with Vit. C. In: Bee symposium, Third Arab Pesticide Conference, Tanta University, Egypt, 1979; pp. 9–15.
75. Verma SK and Phogat KPS. Studies on the effect of the water soluble vitamin C on brood rearing and comb building activities

of worker honey bee (*Apis cerana indica* F.). Indian Bee J. 1982; 44:73.

76. Raj J and Basavanna GPC. Queen recognition, rearing and colony building by the Indian honey bee (*Apis cerana indica*). In: Proceeding, 2nd International Conference on Apiculture and Tropical Climates, New Delhi, 1983; pp.378–384.
77. Mishra, RC, Rather AJ and Kumar J. Laboratory experiments on acceptance and sustenance value of sugar, apple juice and brown sugar to *Apis cerana indica*. Indian Bee J. 1984; 46:13–14.
78. Haleem N, Kumar NR and Kaur R. Effect of nutritional supplements on queen cell production in honey bee (*Apis mellifera*). J. Appl. Nat. Sci. 2015; 7 (1):400–403.
79. Eslam MO and Abdulraouf MA. Improving pollen substitutes to maintain development and hemolymph parameters of honey bees (*Apis mellifera* L.) during pollen dearth periods. J. Api. Res. 2023; 62(4): 777-786. DOI:10.1080/00218839.2023.2229111.
80. Aqueel MA, Abbas Z, Sohail M, Abubakar M, Shurjeel HK, Raza ABM, Afzal M and Ullah S. Effect of Varying Diets on Growth, Development and Survival of Queen Bee (*Apis mellifera* L.) in Captivity World Academy of Science, Engineering and Technology. Int. J. Agric. Biol. Eng. 2017; 10(12):888–891.
81. Pande R and Karnatak AK, Pandey N. Development of nectar supplement for dearth period management of honey bees (*Apis mellifera* L.) colonies in foothills of Shivalik range of Himalayas. The Bioscan. 2015;10 (4):1599–1603.
82. Stevanovic J, Stanimirovic Z, Simeunovic P, Lakic N, Radovic I, Sokovic M and Griensven LJV. The effects of *Agaricus brasiliensis* extract supplementation on honey bee colonies. Ann. Acad. Bras. Cienc. 2018; 90(1):219–229.
83. Wijayati N, Hardjono DS, Rahmavati M and Kurniawati A. Formulation of winged bean seeds as pollen substitute for outgrowth of honeybees (*Apis mellifera* L.). J Phys Conference Series. 2019.
84. Waller GW. Evaluating responses of honey bees to sugar solution using an artificial flower feeder. Ann. Entomol. Soc. Am. 1972; 65:857–862.
85. Crailsheim K, Schneider LH, Hrassnigg N, Buhlmann G, Brosch U, Gmeinbauer R and Schoffmann B. Effect of pollen and nectar substitutes on productivity and quality of honey bee (*Apis mellifera* L.) colonies. Apidologie. 1992; 23(1):74-86.
86. DeGrandi-Hoffman G, Wardell G, Ahumada-Segura F, Rinderer T, Danka R and Pettis J. Comparisons of pollen substitute diets for honey bees: consumption rates by colonies and effects on brood and adult populations. J. Api. Res. 2008; 47 (4):265–270.
87. Lamontagne-Drolet M, Samson-Robert O, Giovenazzo P and Fournier V. The impacts of two protein supplements on commercial honey bee (*Apis mellifera* L.) colonies. J. Api. Res. 2019; 58:800-813.
88. Pankiw T, Sagili RR and Metz BN. Brood pheromone effects on colony protein supplement consumption and growth in the honey bee (Hymenoptera: Apidae) in a subtropical winter climate. J. Econ. Entomol. 2008; 101:1749–1755.
89. Amro A, Omar M and Al-Ghamdi, A. Influence of different proteinaceous diets on consumption, brood rearing, and honey bee quality parameters under isolation conditions. Turk. J. Vet. Anim. Sci. 2016; 4:468–475.
90. DeGrandi-Hoffman G, Chen Y, Rivera R, Carroll M, Chambers M and Hidalgo. Honey bee colonies provided with natural forage have lower pathogen loads and higher overwinter survival than those fed protein supplements. Apidologie. 2016; 47:186–196.
91. Chakrabarti P, Lucas HM and Sagili RR. Evaluating effects of a critical micronutrient (24-methylenecholesterol) on honey bee physiology. Ann. Entomol. Soc. Am. 2020; 113:176–182.
92. Li C, Xu B, Wang Y, Feng Q, Yang W. Effects of dietary crude protein levels on development, antioxidant status, and total midgut protease activity of honey bee (*Apis mellifera* L.). Apidologie. 2012; 43:576-586.
93. Johnson AR, Smith BE and Brown LC. Evaluation of a new pollen substitute derived from algae proteins for honey bee nutrition. J. Api. Res. 2024; 63(2):255-267.
94. Wright GA, Nicholson SW and Shafir S. Nutritional physiology and ecology of honey bees. Annu. Rev. Entomol. 2018; 63:327–334.
95. Sereia MJ and de Toledo VAA. Quality of royal jelly produced by Africanized honeybees fed a supplemented diet. Food. Sci. Technol. 2013; 33:304–309.
96. Bhusal SJ and Thapa RB. Response of colony strength to honey production:

regression and correlation analysis. J. Inst. Agric. Anim. Sci. 2006; 27:133–137.

97. Goodwin RM, Houten AT and Perry JH. Effect of feeding pollen substitutes to honey bee colonies used for kiwifruit pollination and honey production. N. Z. J. Crop. Hort. Sci. 1994; 22:459–462.
98. Mattila HR and Otis GW. Influence of pollen diet in spring on development of honey bee (Hymenoptera: Apidae) colonies. J. Econ. Entomol. 2006; 99:604–613.
99. Manning R. Artificial feeding of honeybees based on an understanding of nutritional principles. Anim. Prod. Sci. 2018; 58:689–703.
100. Alqarni AS. Influence of some protein diets on the longevity and some physiological conditions of honeybee *Apis mellifera* L. workers. J. Biol. Sci. 2006; 6:734–737.
101. Li C, Xu B, Wang Y, Yang Z and Yang W. Protein content in larval diet affects adult longevity and antioxidant gene expression in honey bee workers. Entomol. Exp. Appl. 2014; 151:19–26.
102. Manning R, Rutkay A, Eaton and Dell B. Lipid-enhanced pollen and lipid-reduced flour diets and their effect on the longevity of honey bees (*Apis mellifera* L.). Aust. J. Entomol. 2007; 46:251–257.
103. Standifer LN, Moeller FE, Kauffeld NM, Herbert EW and Shimanuki H. Development of a new pollen substitute for honey bees. Apidologie. 2023; 54(1): 45-58.
104. DeGrandi-Hoffman G, Gage SL, Corby-Harris V, Carroll M, Chambers M and Graham H. Connecting the nutrient composition of seasonal pollens with changing nutritional needs of honey bee (*Apis mellifera* L.) colonies. J. Insect. Physiol. 2018; 109:114–124.
105. Tarpy DR, Keller JJ and Grozinger CM. Evaluation of enriched nectar substitutes for honey bee colonies. J. Api. Res. 2022; 61(3):325-333.
106. Noordyke ER, van Santen E and Ellis JD. Tracing the fate of pollen substitute patties in Western honey bee (Hymenoptera: Apidae) colonies. J. Econ. Entomol. 2021; 114:1421-1430.
107. Zhang X, Li Y, Huang Q and Wu J. Effects of a novel pollen substitute enriched with microbial probiotics on honey bee gut health and colony vitality. J. Api. Res. 2024; 68(2):183-197.
108. Ricigliano VA and Simone-Finstrom M. Nutritional and prebiotic efficacy of the microalga Arthrospira platensis (spirulina) in honey bees. Apidologie. 2020; 51:898-910.
109. Szymas B, Langowska A and Kazimierczak-Baryczko M. Histological structure of the Midgut of honey bees (*Apis Mellifera* L.) fed pollen substitutes fortified with probiotics. J. Apic. Sci. 2012; 56:5–12.
110. Alaux C, Ducloz F, Crauser D and Le Conte Y. Diet effects on honeybee immunocompetence. Biol. Lett. 2010; 6(4): 562-565.
111. Rinderer TE, Harris JW, Hunt GJ and de Guzman LI. Breeding for resistance to Varroa destructor in North America. Apidologie. 2013; 41(4): 409-424.
112. Arrese EL and Soulages JL. Insect fat body: energy, metabolism, and regulation. Annu. Rev. Entomol. 2010; 55:207–225.
113. Rogala R and Szymas B. Nutritional value for bees of pollen substitute enriched with synthetic amino acids part II. Biological methods. J. Apic. Sci. 2004; 48:29–36.
114. Danihlik J, Skrabisova M, Lenobel R, Sebela M, Omar E and Petrivalsky M. Does the pollen diet influence the production and expression of antimicrobial peptides in individual honey bees? Insects. 2018; 9:79.
115. Szymas B and Jedruszuk A. The influence of different diets on haemocytes of adult worker honey bees, *Apis mellifera*. Apidologie. 2003; 34:97–102.
116. Almeida-Dias JM, Morais MM, Francoy TM, Pereira RA, Turcatto AP and De Jong D. Fermentation of a pollen substitute diet with beebread microorganism increases diet consumption and hemolymph protein levels of honey bees (Hymenoptera, Apidae). Sociobiol. 2018; 65:760 –765.
117. Paiva JPLM, Esposito E, Morais Honorato, de Souza GI, Francoy TM and Morais MM. Effect of ensiling on the quality of protein supplements for honey bees *Apis mellifera* L. Apidologie. 2019; 50:414-424.
118. Amdam GV, Fennern E and Havukainen H. Vitellogenin in honey bee behavior and lifespan, in Honeybee Neurobiology and Behavior, eds C. Galizia, D. Eisenhardt, and M. Giurfa (Dordrecht: Springer). 2012; 17–29.
119. Corby-Harris V and Snyder LA. Measuring hypopharyngeal gland acinus size in honey bee (*Apis mellifera* L.) workers. J. Vis. Exp. 2018; 139:58261.

120. Pernal SF and Currie RW. Pollen quality of fresh and 1-year-old single pollen diets for worker honey bees (*Apis mellifera* L.). 2000; Apidologie 31:387 – 409.
121. Free JB. The behaviour of honeybees visiting apple blossom. J. Appl. Ecol. 1969; 6(1):79-95.
122. Seeley TD. Honeybee ecology: a study of adaptation in social life. 1985; *Princeton University Press*.
123. Winston ML. The biology of the honey bee. 1987; *Harvard University Press*. Cambridge.
124. Seeley TD. The wisdom of the hive: the social physiology of honey bee colonies. 1995; *Harvard University Press.* Cambridge.
125. Morse RA. The behavior of honey bees (*Apis mellifera* L.) during the swarming process. Bee World. 1985; 66(3):125-138.
126. Williams GR, Alaux C, Costa C, Csaki T, Doublet V, Eisenhardt D and Neumann P. Refined nutritional strategies for honey bee health: A multi-disciplinary approach. Annu. Rev. Entomol. 2024; 69:211-232.

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