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An overview of artificial nutrition in apiculture

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KEYWORDS

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Artificial feeding

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Diet patterns

ABSTRACT

Artificial nutrition in apiculture is a long-term subject of discussion and investigation. The maintenance and boosting of bee colonies in apiculture depends on synthetic food around the globe to overcome the suppressing factors, including dearth periods. The information on types of food components and their combinations used is haphazard and hardly helpful in determining the advancements in the artificial feeding of bees. This study aimed to extract the available information on artificial feeding on honeybees and arrange it most scientifically. The information in the form of research or review articles available on every platform, *viz*., soft portals, printed journals, books and scientific proceedings, were collected and analyzed to produce a comprehensive and informative review article on the artificial nutrients in apiculture. Compilation of the available information revealed that artificial feeding of bees depends on food components and their combinations. Based on this, it can be suggested that nectar and pollen are basic foods of honey bees, and based on this, the food components were further categorized as nectar supplements and pollen supplements. These supplements were fed to bees as natural nutrients and food components. The natural nutrients include proteins, carbohydrates, vitamins, yeasts, antibiotics, amino acids, enzymes, antioxidants, etc. Meanwhile, under natural food components, cereal grains, pulses, beans, fruits, vegetables, medicinal plants, spices, condiments, and some non-traditional/ miscellaneous kinds of stuff have been included in the bee diets. On the other hand, many diet categories have been prepared using the abovementioned nutrients and food components in various forms and proportions. In general, the pollen and nectar, the main food of bees, have been supplemented under different diet combinations. These diet

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combinations used pollen and nectar substitutes or combined with other nutrition, drugs, antibiotics, etc. The present investigation provides an updated overview of the food categories and their combinations used in the artificial feeding of bees to date. These findings can help explore new food items and their effective diet combinations.

1 Introduction

The honey bee (*Apis mellifera*) is one of the most economically and ecologically significant insects providing nutritive honey, propolis, venom, wax, and pollination to the agriculturally important crops (Calderone 2012; Marcelino et al. 2022; Naz et al. 2022). The decline in bee populations may negatively affect agricultural productivity as these social insects are responsible for pollinating 3/4^{ths} of the world's angiosperm plants (Morse and Calderone 2000; Aizen and Harder 2009; Grossman 2013). The possible reasons behind this decline are the non-judicious use of unsafe agrochemicals, climate change, and the socio-economic condition of the farms. These factors, alone or in combination, may affect honeybees and their valuable products. Uncertain fluctuations in temperature, relative humidity, shortage of water, deforestation of floral plants, non-scientific apicultural practices, and pests/diseases also contribute to bee population decline and concerned production (Wakgari and Yigezu 2021).

The availability of quality food through natural resources may ensure the better survival of honeybees. However, constant and continuous natural food availability is impossible, and honeybees often face dearth periods. Apiculturists feed the bees with sugars and different artificial foodstuffs to maintain the colony and avoid losses during these food exhaustion intervals. More specifically, for an individual bee's overall development and physiological functioning, a variety of nutrients, such as carbohydrates, protein, vitamins, amino acids, minerals, lipids, etc., are needed through a single diet (Brodschneider and Crailsheim 2010). Like in other living beings, a balanced supply of nutrition plays a vital role in multiple aspects of bees as caste development (Slater et al. 2020), disease resistance (Zheng et al. 2014; Basualdo et al. 2014; Hoffman and Chen 2015; Glavinic et al. 2017), increases lifespan (Knox et al. 1971), development of hypopharyngeal glands (Keller et al. 2005a, b; Mohamed et al. 2023), behaviour and development (Ament et al. 2008, 2010; Toth et al. 2005), and neural development (Moda et al. 2013). The nutrient contents and their proportions in diets also influence bee-associated microfauna responsible for nutrient processing and boosting immunity (Hildebrandt et al. 2009; Turnbaugh et al. 2009; Ponton et al. 2013; Raymann and Moran 2018; Kešnerová et al. 2020).

In the last few decades, a wide range of edible materials alone or in combination with *viz*., cereals and pulses, fruits, vegetables, synthetic drugs and minerals, yeasts, vitamins, proteins, sugars, etc., have been tested as quality feed options for honey bees. These materials were used with different processing methods and varying provisions of care. A thorough literature survey has been done and analyzed in the next section of this article.

2 Information collection and analysis

The literature on artificial feeding in apiculture available on all the plate forms viz., papers on the internet, printed journals, thesis, and published books were studied. Literature in other languages was also used after their proper translation (languages mentioned against the references in the bibliography). It was observed that almost all the publications showed bee food in the form of diets. These diets were investigated for two broad categories: the types of food components and the combination pattern of different food components.

To analyse the types of food components used, the diet is segregated under pollen and nectar substitutes as they are the primary natural food sources for honey bees. The food components not falling under either pollen or nectar substitutes were classified under the miscellaneous category. After establishing the types of food components, all the possible patterns of their combinations were also investigated.

3 Components used in the artificial feeding of honey bees

Based on origin, two categories of food components are natural nutrients and natural food components.

3.1 Natural nutrients

3.1.1 Protein

Protein is an important nutrient essential for the growth and proper functioning of the body system, including the development of different bee glands (Keller et al. 2005b). In general, protein deficiency may result in the deformation or size reduction in the hypopharyngeal glands of worker bees (DeGrandi-Hoffman et al. 2010). In contrast, an optimum protein provision also plays a significant role in resistance development against pathogens in bees (Rowley and Powell 2007; Behmer 2009; Alaux et al. 2010; Mao et al. 2013), whereas deficiency of protein leads to susceptibility against harmful pathogens (Field et al. 2002; Li et al. 2007). Other immunity mechanisms like encapsulation, phenyl oxidase, and lysozyme activities are also protein-dependant (enzyme-based) (Lee et al. 2006). For this protein intake, honey bees depend on pollen grains and royal jelly for quality protein; however, the natural supply of pollen is not continuous throughout the year.

Table 1 Use of commercial and isolated proteins in artificial feeding of bees

S.N.	Commercial/isolated Proteins	References
1.	Albumin	Kumari and Kumar (2020), Morais et al. (2013), Sabir et al. (2000), Haydak (1967)
2.	Casein	Kumari and Kumar (2020), Mahfouz (2016), Pirk et al. (2010), Al-Eitby (2009), Herbert and Shimanuki (1979a),
3.	Crude protein	Zheng et al. (2014), Herbert and Shimanuki (1979a)
4.	Gevral protein	Al-Eitby (2009)
5.	Isolated soy protein	Sereia et al. (2013)
6.	Lactalbumin	Shimanuki and Herbert (1986)
7.	Protein Hydrolysate	Kumar and Agrawal (2014)
8.	Sodium caseinate	Malone et al. (2004)
9.	Tankage protein for animal feed	Haydak (1936)
10.	Whey protein flour (milk protein)	Mahfouz (2016), van der Steen (2007)

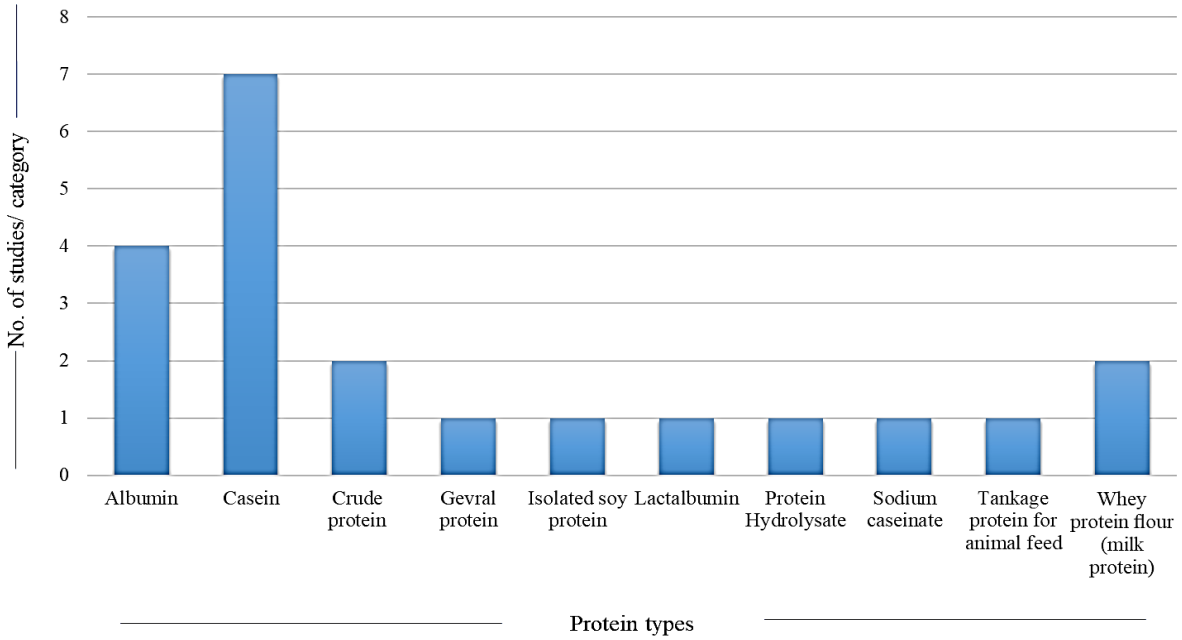

Figure 1 Comparative use of various proteins in artificial feeding of honeybees

Keeping the importance of protein in mind, researchers worldwide have used almost ten types of protein formulations, either isolated or commercial (Mahfouz 2016; Kumari and Kumar 2020). Among the reported proteins, albumin and casein have dominantly been used in the artificial feeding of bees (Table 1 & Figure 1). The economy of such a diet, however, exceeded.

3.1.2 Vitamins

A wide range of vitamins are also required for the development and physiology of bees. Along with others, water-soluble vitamins B and C are more commonly found in floral pollen grains. However, fat-soluble vitamins (A, D, E, and K) encourage more brood production (Herbert and Shimanuki 1978b; Roulston and Cane 2000). To date, overall, 14 different vitamins, *viz*., A, B, B1, B2, B6, B12, C, D, etc., have been utilized in the artificial feeding of honey bees (Akyol et al. 2006; Abd El-Wahab et al. 2016; Tawfik et al. 2020; Kumar et al. 2021) (Table 2). Among all the utilized vitamins, a mixture of multivitamins has been the most extensively used form (Figure 2).

3.1.3 Lipids

Lipids are also essential to bees, but for their supply, they depend on pollen grains (Haydak 1970). Specifically, lipids are needed during the brood stage and are considered an important precursor

Table 2 Utilization of synthetic vitamins in honey feeding

S.N.	Name of Vitamin	References
1.	Multivitamin mixtures	Kumar et al. (2021), Abd El-Wahab et al. (2016), Sihag and Gupta (2013), Amro et al. (2016)
2.	Vitamin A (Retinol)	Islam et al. (2020), Abd El-Wahab et al. (2016), Akyol et al. (2006)
3.	Vitamin B-complex	Al-Shammary and Al-Gerrawy (2017), Sabir et al. (2000),
4.	Vitamin B 1 (Thiamine)	Akyol et al. (2006), Omar (2006)
5.	Vitamin B2 (Riboflavin)	Akyol et al. (2006), Omar (2006)
6.	Vitamin B6 (Pyridoxine)	Akyol et al. (2006)
7.	Vitamin B12 (Biotin, folic acid, and the cobalamins)	Colibar et al. (2011), Akyol et al. (2006)
8.	Vitamin C (Ascorbic)	Ahmad et al. (2021), Tawfik et al. (2020), Zahra and Talal (2008), Akyol et al. (2006)
9.	Vitamin D (Calciferol)	Islam et al. (2020), Abd El-Wahab et al. (2016)
10.	Vitamin D3 (Cholecalciferol)	Akyol et al. (2006)
11.	Vitamin E (Tocopherol)	Islam et al. (2020), Abd El-Wahab et al. (2016), Akyol et al. (2006), Şahinler et al. (2005)
12.	Vitamin K3 (Menadione)	Akyol et al. (2006)
13.	Ca-d-Pantothenete	Akyol et al. (2006)
14.	Vitamix Formula- Topkim	Akyol et al. (2006)

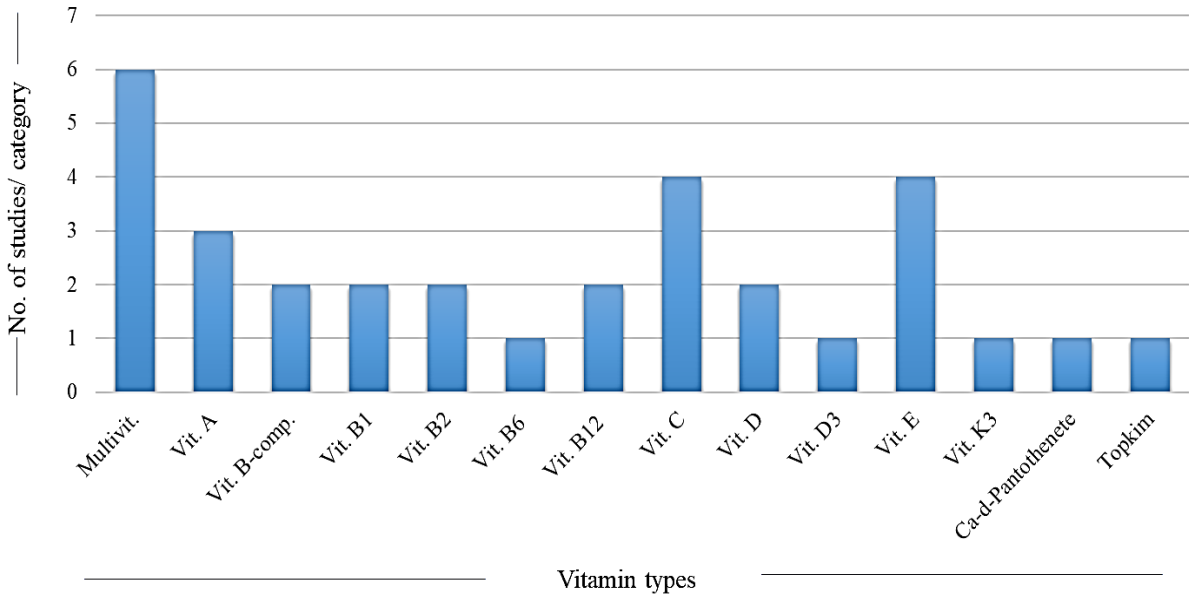

Figure 2 Comparative use of various vitamins in artificial feeding of honeybees

for further bio-molecular synthesis in honey bees (Cantrill et al. 1981). At the brood stage, the actual extraction of lipids from pollen inside the bee brood stomach increases by 2-4% (Herbert et al. 1980). When available literature was studied, no evident use of isolated lipids could be traced; however, many oilseed grains and essential oils rich in lipids have been used in bee feeding.

3.1.4 Minerals

Minerals are another important constituent of honey bee nutrition (Haydak 1970). Naturally, the main sources of minerals to bees are pollen, nectar, water, or the existing mineral pools in adult honeybees (Imdorf et al. 1998; Brodschneider and Crailsheim

2010). However, any artificial addition of minerals, *viz*., 1% pollen ash, increases brood production (Herbert and Shimanuki 1978a).

3.1.5 Carbohydrates

Carbohydrate is a universal energy source for honey bees, obtained from the flower nectar of different plants (Brodschneider and Crailsheim 2010). The needed energy is derived from carbohydrates for various physiological activities viz., physiological metabolism, immune reactions, and microbial resistance (Erler et al. 2014). Adult worker bees generally require an average of 4 mg of sugar per day for survival (Barker and Lehner 1974), and around 59.4 mg of carbohydrates are needed during their larval period (Rortais et al. 2005). Honey bees collect nectar from flowers, turn them into honey, and store them in hexagonal eyes, which are the primary source of carbohydrates, essentially required for natural growth and development and to generate energy for movement, body heat, and other functions. It has been estimated that the amount of food in the colonies should not be less than 9-12kg or the equivalent of 3-4 honey frames to keep brood rearing at a high level. Honey bee colonies are also fed with supplementary carbohydrates, *viz*., sugars in warm countries to stimulate queens to lay eggs (even if the sects have abundant honey). In the literature, no use of synthetic carbohydrates was witnessed here. However, Sugars have been used extensively in feeding.

Over 14 types of sugars in different forms have been utilized in artificial food for honey bees (Hoover et al. 2006; Rashid et al. 2018; Khan et al. 2021; Szczęsna et al. 2021). Sucrose is the most commonly used sugar as a solution, syrup, candy, and in-ground form (Gemeda et al. 2018; Kumar et al. 2021). These sugar forms are either used as a single component or in addition to other ingredients. The common sugar was followed by honey, which was utilized in

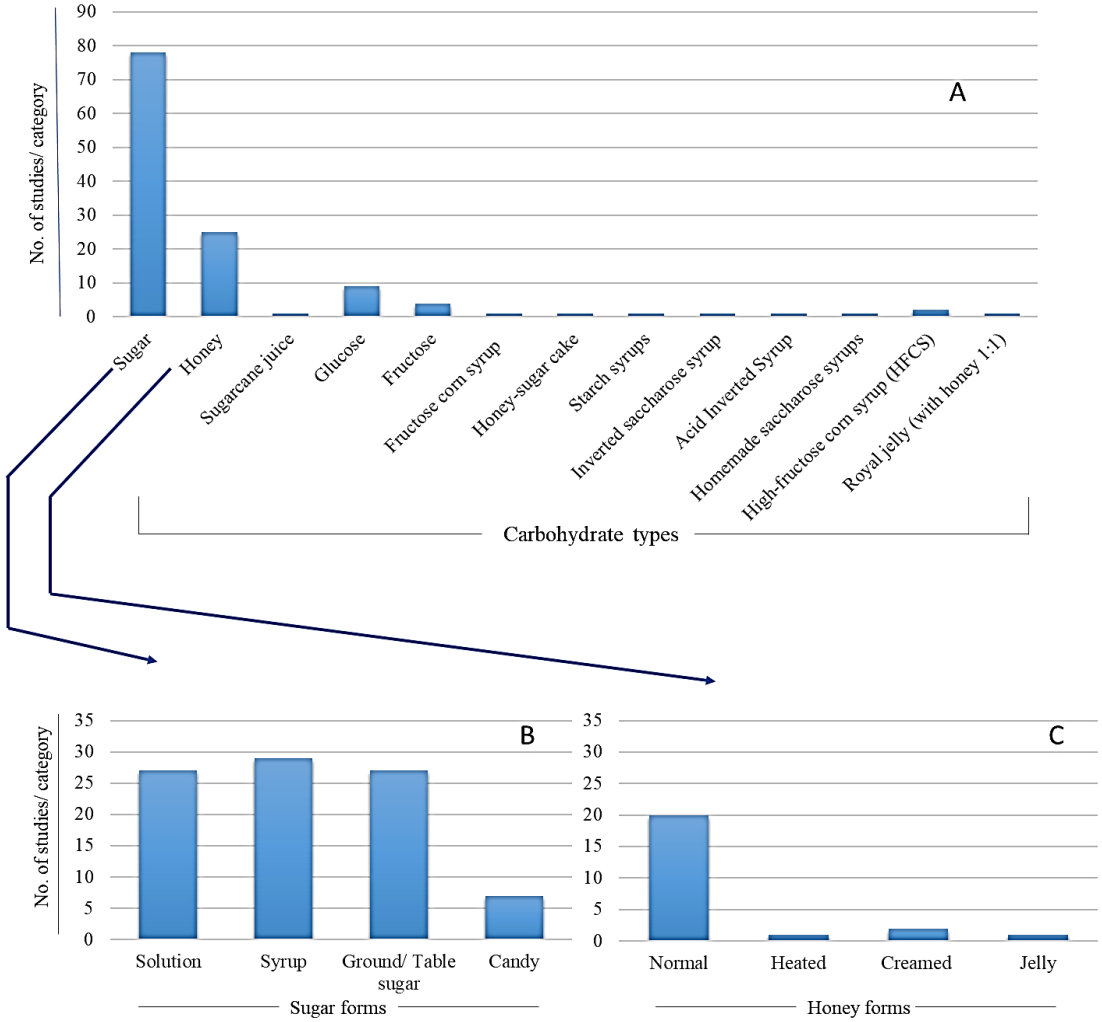

Figure 3 Comparative use of- A- various carbohydrates, B- various forms of sugar, C- various forms of honey in artificial feeding of honeybees

normal, creamed, heated, and jelly forms (Abou-Shaara 2017; Ullah et al. 2021). The third dominant sugar is glucose and fructose (DeGrandi-Hoffman et al. 2010; Guler et al. 2018) (Figure 3). In addition to this, various syrups (fructose corn, inverted saccharose, starch, acid inverted, homemade saccharose, etc.), honey-sugar cake, mixtures of sucrose and dextrose, and royal jelly have been tested for artificial feeding of honey bees (Hoover et al. 2006; Mirjanic et al. 2013; Wilde et al. 2014; Szczęsna et al. 2021) (Table 3, Figure 3).

Table 3 Different sugar forms used in feeding honey bees

S.N.	Sugar	Form	References
1.	Sugar	Solution	Gemeda et al. (2018), Rashid et al. (2018), Omar et al. (2017), Carrillo et al. (2015), Rezaei et al. (2015), Zhang et al. (2015), Somerville (2014), Usha et al. (2014), Ghazala and Nowar (2013), Singh and Singh (2012), Fasasi (2011), Al-Maktary (2009), Al-Sarhi (2008), Shehata and Nafea (2006), Diemer (2005), Aupinel et al. (2005), Al-Jubouri (2005), Abd El-Wahab and Gomaa (2005), El-Sherif (2002), Al-Hammadi (2001)
		Syrup	Khan et al. (2021), Tawfik et al. (2020), Islam et al. (2020), Younis (2019), Balkanska and Salkova (2018), Guler et al. (2018), Stevanovic et al. (2018), Abou-Shaara (2017), Abd El-Wahab et al. (2016), Haleem et al. (2015), Mirjanic et al. (2013), Anđelković et al. (2011), Colibar et al. (2011), Fasasi (2011), Sihag and Gupta (2011), De-Grandi-Hoffman et al. (2010), Saffari et al. (2010), Versluijs (2010), Bodla et al. (2009), Skubida et al. (2008), Fasasi et al. (2007), Akyol et al. (2006), Omar (2006)
		Ground/ Table sugar	Mohamed et al. (2023), Kumar et al. (2021), Islam et al. (2020), Younis (2019), Abou-Shaara (2017), Al-Shammary and Al-Gerrawy (2017), Zaghloul et al. (2017), Abd El-Wahab et al. (2016), Abd El Hamid and Abou-Shaara (2016), Amro et al. (2016), Kishan and Srinivasan (2016), Wheeler and Robinson (2014), Johnson (2014), Sammataro and Weiss (2013), Ghazala and Nowar (2013), Li et al. (2012), Al-Ghamdi et al. (2011), Fasasi (2011), Al-Eitby (2009), Avni et al. (2009), Al-Maktary (2009), Dodologlu and Emsen (2007), Keller et al. (2005a, b),
		Candy	Al-Ghamdi et al. (2021), Abou-Shaara (2017), Aly et al. (2014), Anđelković et al. (2011), Skubida et al. (2008), Akyol et al. (2006), Beota et al. (2005)
2.	Honey	Normal	Ullah et al. (2021), Islam et al. (2020), Younis (2019), Stevanovic et al. (2018), Zaghloul et al. (2017), Abd El-Wahab et al. (2016), Amro et al. (2016), Kishan and Srinivasan (2016), Taha (2015), Pande and Karnatak (2014), Usha et al. (2014), Wheeler and Robinson (2014), Sihag and Gupta (2013), Mirjanic et al. (2013), Anđelković et al. (2011), Al-Eitby (2009), Skubida et al. (2008), Hoover et al. (2006), Omar (2006)
		Heated	Barker and Lehner (1978)
		Creamed	Abou-Shaara (2017), Abd Elhamid and Abou-Shaara (2016)
		Jelly	Abou-Shaara (2017)
3.	Sugar cane juice		Beota et al. (2005)
4.	Glucose		Ullah et al. (2021), Guler et al. (2018), Abd El Hamid and Abou-Shaara (2016), Kaftanoglu et al. (2011), Beota et al. (2005)
5.	Fructose		Kaftanoglu et al. (2011), Peng et al. (1992), Vandenberg and Shimanuki (1987), Rembold and Lackner (1981)
6.	Fructose corn syrup		DeGrandi-Hoffman et al. (2010)
7.	Honey-sugar cake		Wilde et al. (2014)
8.	Mixtures of sucrose and dextrose		Nabors (1996)
9.	Starch syrups		Szczęsna et al. (2021)
10.	Inverted saccharose syrup		Szczęsna et al. (2021)
11.	Acid Inverted Syrup		Mirjanic et al. (2013)
12.	Homemade saccharose syrups		Szczęsna et al. (2021)
13.	High-fructose corn syrup (HFCS)		Guler et al. (2018), Wheeler and Robinson (2014)
14.	Royal jelly (with honey 1:1)		Hoover et al. (2006)

Table 4 Use of essential/ non-essential amino acids/ enzymes/ anti-oxidants/ drugs/ antimicrobial agents in artificial feeding of bees

S.N.	Essential/ Non-essential amino acids/ Enzymes/ Anti-oxidants/ Drugs/ Antimicrobial agents	References
1.	Glysine amino acid	Sabir et al. (2000)
2.	Methionin	Sabir et al. (2000)
3.	Biotin B7	Gençer et al. (2000)
4.	Niacin	Akyol et al. (2006)
5.	Pantothenic acid	Gençer et al. (2000)
6.	Cholesterol	Srivastava (1996)
7.	Folic acid	Gençer et al. (2000)
8.	Anicotinic acid	Omar et al. (2016)
9.	Essential amino acids (EAA)	Hendriksma et al. (2019)
10.	Nonessential amino acids (NAA)	Hendriksma et al. (2019)
11.	Creon (Enzyme based drug)	Al-Eitby (2009)
12.	Enzyme Invert Syrup	Mirjanic et al. (2013)
13.	Alphacel drug	Srivastava (1996)
14.	Antioxidants	Li et al. (2012)
15.	Multivitamin drug (Becosule)	Haleem et al. (2015)
16.	Fumagillin (Antibiotic)	Akyol et al. (2006)
17.	Tetracycline (Antibiotic)	Al-Shammary and Al-Gerrawy (2017), Omar et al. (2016)

3.1.6 Use of amino acids/enzymes/anti-oxidants/drugs/ antimicrobial agents

Apart from protein, vitamins, lipids, and carbohydrates, few studies used essential and non-essential amino acids, enzymes, antioxidants, drugs, microbial formulations, and antimicrobial agents. Among the available information, it was reported that 17 essential and non-essential amino acids were used in the artificial feeding of honey bees (Table 4). Proper development, physiological functioning and immunity against different diseases of an individual bee depend on a balanced diet comprised of carbohydrates, protein, vitamins, amino acids, minerals, lipids, etc. (Brodschneider and Crailsheim 2010; Basualdo et al. 2014; Zheng et al. 2014; Hoffman and Chen 2015; Glavinic et al. 2017; Slater et al. 2020). The immunity to fight pests and diseases was probably considered in opting for the abovementioned components.

3.1.7 Microbe-based nutrition

Microbes are also an excellent source of nutrition, especially single-cell protein providing vitamins (particularly the B-complex), several bioavailable minerals *viz*., chromium (Cr), copper (Cu), iron (Fe), magnesium (Mg), manganese (Mn), selenium (Se), zinc (Zn) etc., and dietary fiber (Pacheco et al. 1997; Jach and Serefko 2018). From 1967 to date, three microbes were used as nutritional supplements. Out of these, yeast was the more commonly utilized microbe. Over ten types of yeast nutrition based on various culturing techniques, *viz*., Brewer's, Bacto, Difco, dry, and extracts, have been utilized in diet preparation for feeding of honey bees (Vandenberg and Shimanuki 1987; Kumar et al. 2021). Powdered Brewer's yeast and Commercial Yeast have dominantly been used in the artificial feeding of honey bees (Figure 4). Generally, the yeast was supplemented with other food components as additional nutrition. Commercial baking yeast has been used by most of the authors in this field (Table 5).

3.2 Natural food components

3.2.1 Cereal grains

Cereals are a well-known source of many essential nutrients, *viz*., Gluten protein, fiber, vitamin B-complex and E, omega-3-fatty acid, folate, phosphorous, magnesium, zinc, and anti-oxidants in minor quantities (Charalampopoulos et al. 2002; Garg et al. 2021). The details of the six major cereal grains which have been commonly used in feeding bee colonies across the world are given in table 6 (Neupane and Thapa 2005; Li et al. 2012; Mahmood et al. 2013; Shehata 2016; Aly et al. 2019; Islam et al. 2020). Wheat and maize are the dominant ones among these (Figure 5).

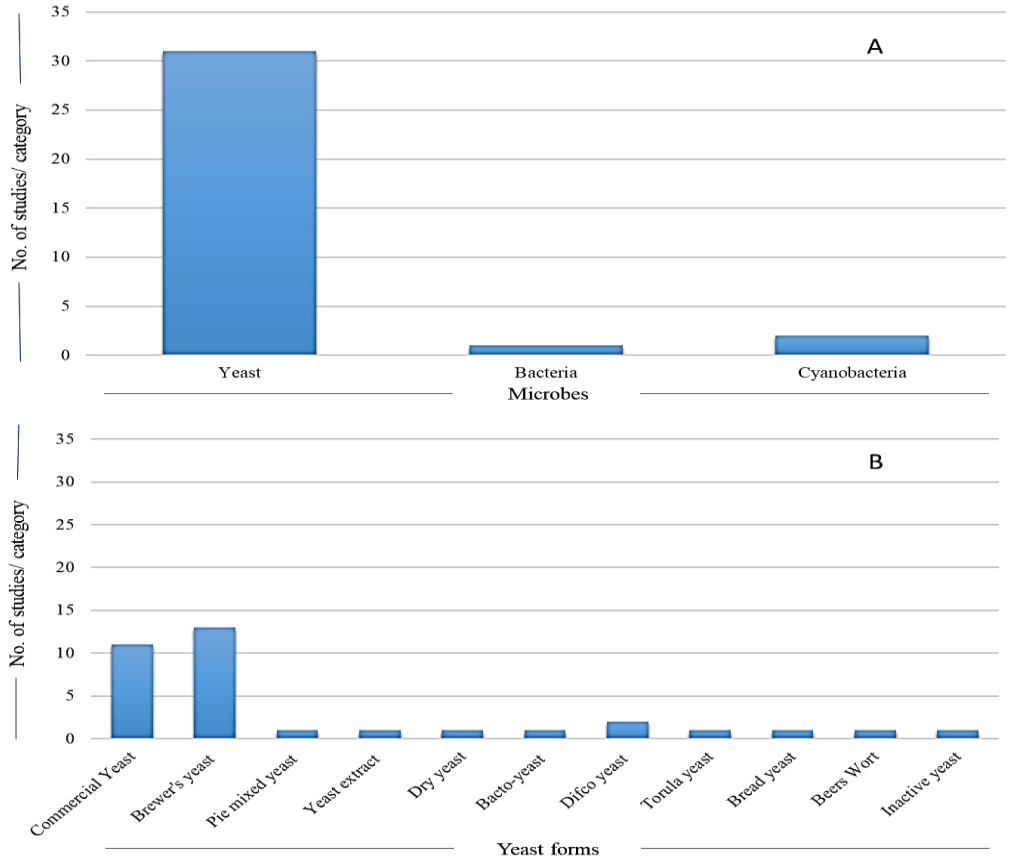

Figure 4 Comparative use of- A- microbes & B- various forms of yeast in artificial feeding of honeybees

Table 5 Utilization of microbes-based nutrition in artificial feeding honey bees

S.N.		Name of yeast	References
1.	Yeast	Commercial yeast	Kumar et al. (2021), Aqueel et al. (2017), Haleem et al. (2015), Kaftanoglu et al. (2011), Al-Ghamdi et al. (2011), Al-Sarhi (2008), Dodologlu and Emsen (2007), Shehata and Nafea (2006), Abd El-Wahab and Gomaa (2005)
		Brewer's yeast	Islam et al. (2020), Kumari and Kumar (2020), Younis (2019), Puškadija et al. (2017), Taha (2015), Pande and Karnatak (2014), Ghazala and Nowar (2013), Mirjanic et al. (2013), Morais et al. (2013), Mahmood et al. (2013)
		Pie mixed yeast	Al-Sarhi (2008)
		Yeast extract	Sihag and Gupta (2013)
		Dry yeast	Zaghloul et al. (2017)
		Bacto-yeast	Rembold and Lackner (1981)
		Difco yeast	Peng et al. (1992), Rembold and Lackner (1981)
		Torula yeast	Hanser (1983)
		Bread yeast	Irandoust and Ebadi (2013)
		Beerswort	Mirjanic et al. (2013)
		Inactive yeast	Mohamed et al. (2023)
2.	Bacteria (EM®Probiotic's live micro-organisms)	-	Tlak-Gajger et al. (2020)
3.	Cyanobacteria (Spirulina, *A. platensis*)	-	Kumar et al. (2013a, b)

Table 6 Cereal grains used in artificial feeding of honeybees

S.N.	Grain	Family	Form	References
1.	Wheat (*T. aestivum*)	Poaceae	Germinated, Gluten	Ghramh and Khan (2023), Aly et al. (2019), Younis (2019), Usha et al. (2014), Irandoust and Ebadi (2013), Omar (2006)
2.	Maize (*Zea mays* L.)	Poaceae	Flour	Ghramh and Khan (2023), Islam et al. (2020), Younis (2019), Amro et al. (2016), Usha et al. (2014), Mahmood et al. (2013), Li et al. (2012), Al-Maktary (2009), Shehata and Nafea (2006), Neupane and Thapa (2005)
			Gluten	Al-Ghamdi et al. (2011), Al-Sarhi (2008)
3.	Rice (*Oryza sativa*)	Poaceae	Grains	Aly et al. (2014)
			Bran	Neupane and Thapa (2005), Morais et al. (2013)
4.	Sorghum (*Sorghum bicolor*)	Poaceae	Flour	Ghramh and Khan (2023)
5.	Oats (*Avena sativa*)	Poaceae	Flour	Aly et al. (2014)
6.	Phalaris (*Phalaris arundinacea*)	Poaceae	Flour	Shehata (2016)

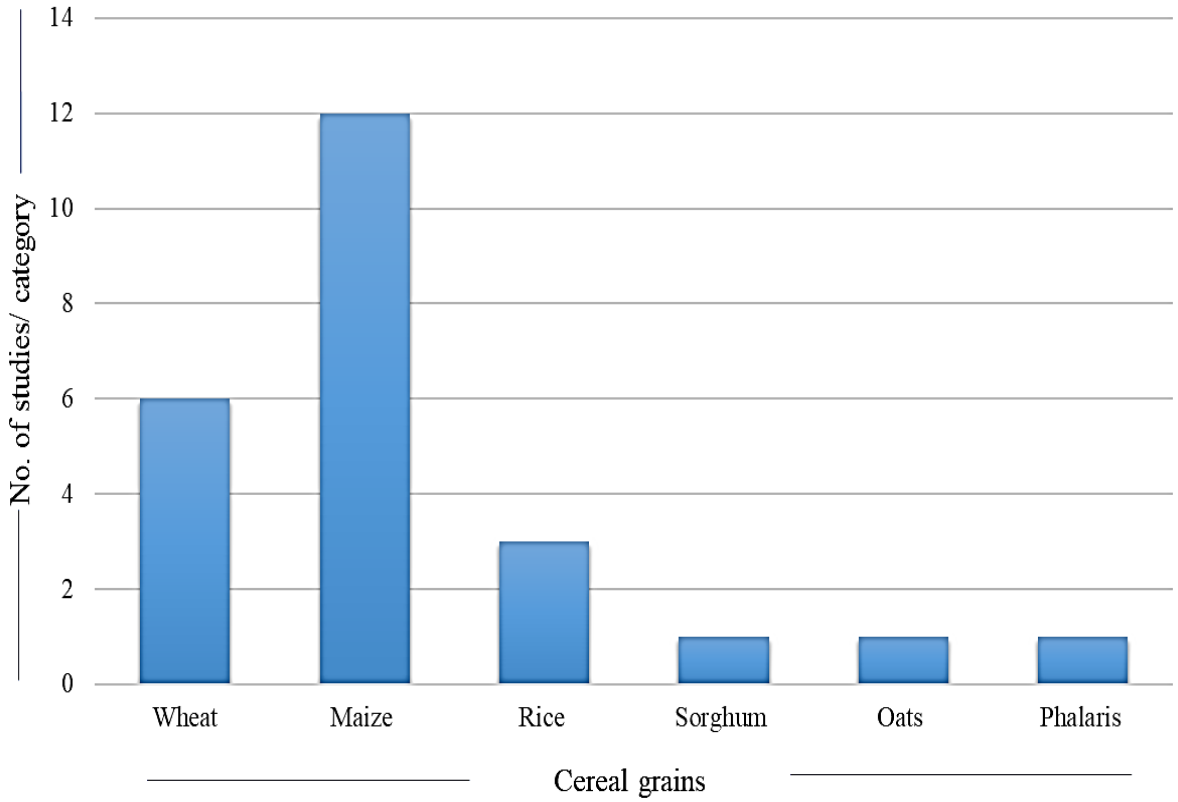

Figure 5 Comparative use of various types of cereals in artificial feeding of honeybees

3.2.2 Pulses and beans

Pulses are a novel source of protein for every living being, including bees. In addition, carbohydrates, fat, vitamins, minerals, and a broad range of essential amino acids can also be obtained from many pulses (Peas, chickpeas, lentils) and beans (Mukherjee et al. 2017; Boye and Maltais 2011). In the artificial feeding of bees, at least 14 pulses and beans in grounded form have been used in feeding honey bees to date (Puškadijaet al. 2017; Kumari and Kumar 2020; Islam et al. 2020; Ullah et al. 2021) (Table 7). Soybeans have been dominantly used as plants in two forms, *i.e.*, normal and defatted flour (Figure 6).

Table 7 Pulses and beans used in feeding of honey bees

S.N.	Grain	Family	Form	References
1.	Soybean (*Glycine max*)	Fabaceae	Flour	Ullah et al. (2021), Ahmad et al. (2021), Kumari and Kumar (2020), Islam et al. (2020), Aly et al. (2019), Younis (2019), Manning (2018), Puškadija et al. (2017), Al-Shammary and Al-Gerrawy (2017), Zaghloul et al. (2017), Abd El-Wahab et al. (2016), Shehata (2016), Mahfouz (2016), Amro et al. (2016), Rezaei et al. (2015), Taha (2015), Usha et al. (2014), Irandoust and Ebadi (2013), Kumar et al. (2013a, b), Sihag and Gupta (2013, 2011), Li et al. (2012), Al-Eitby (2009), Avni et al. (2009), Zahra and Talal (2008), Dastouri et al. (2007), Dodologlu and Emsen (2007)
			Defatted flour	Kumar and Agrawal (2014)
2.	Chickpea (*Cicer arietinum*)	Fabaceae	Powder	Ghramh and Khan (2023), Tesfaye (2019), Younis (2019), Zaghloul et al. (2017), Aly et al. (2014), Pande and Karnatak (2014), Usha et al. (2014), Mahmood et al. (2013), Sihag and Gupta (2011)
			Parched gram powder	Kumari and Kumar (2020), Singh (2003)
			Dehusked parched powder	Puškadija et al. (2017), Chhuneja et al. (1992)
3.	Pea (*Pisum sativum*)	Fabaceae	Harvested pea flour	Aly et al. (2014), Gemeda (2014), Dastouri et al. (2007)
			Germinated pea flour	Pande and Karnatak (2014)
4.	Kidney bean (*Phaseolus vulgaris*)	Fabaceae	Powder	Aly et al. (2014)
5.	Green gram (*Vigna radiata*)	Fabaceae	Powder	Tesfaye (2019), Pande and Karnatak (2014), Sihag and Gupta (2011)
6.	Hoarse gram (*Macrotyloma uniflorum*)	Fabaceae	Powder	Pande and Karnatak (2014)
7.	Mesquite pods (*Prosopis juliflora*)	Fabaceae	Powder	Amro et al. (2016)
8.	Red gram (*Cajanus cajan*)	Fabaceae	Powder	Manning (2018), Kishan and Srinivasan (2016), Sihag and Gupta (2011)
			Parched powder	Kishan and Srinivasan (2016)
9.	Winged bean (*Psophocarpus tetragonolobus*)	Fabaceae	Roasted seeds	Wijayati et al. (2019)
10.	Groundnut (*Arachis hypogea*)	Fabaceae	Powder	Ullah et al. (2021)
11.	Liquorice (*Glycrrhiza glabra*)	Fabaceae	Root extract	Al-Shammary and Al-Gerrawy (2017)
12.	Lentil (*Lens culinaris*)	Fabaceae	Powder	Irandoust and Ebadi (2013)
13.	Black gram (*Vigna mungo*)	Fabaceae	Powder	Kumar et al. (2021), Ullah et al. (2021)

3.2.3 Fruits and vegetables

The fruits and vegetables from over 12 families have been used in one or more forms for supplementary feeding of honey bees (Nowar 2011; Pande et al. 2015; Shehata 2016; Omar et al. 2017; El-Nagar et al. 2019). Among these, the Rutaceae family was most utilized in many forms, *viz*., fruit and shell juice of citrus, mandarin, and orange fruit (Table 8). Interestingly, the use of fruits dominated vegetables and other plants. In this literature, sugarcane has been kept under the fruit and vegetable category despite being a Poaceae family member.

3.2.4 Medicinal plants/Spices/Condiments

The authors probably utilised medicinal plants in bee feeding to keep the bees' immunity against various pests and diseases. Results presented in table 9 revealed that a total of 14 plants under the category of medicinal/spices/condiments have also been utilized

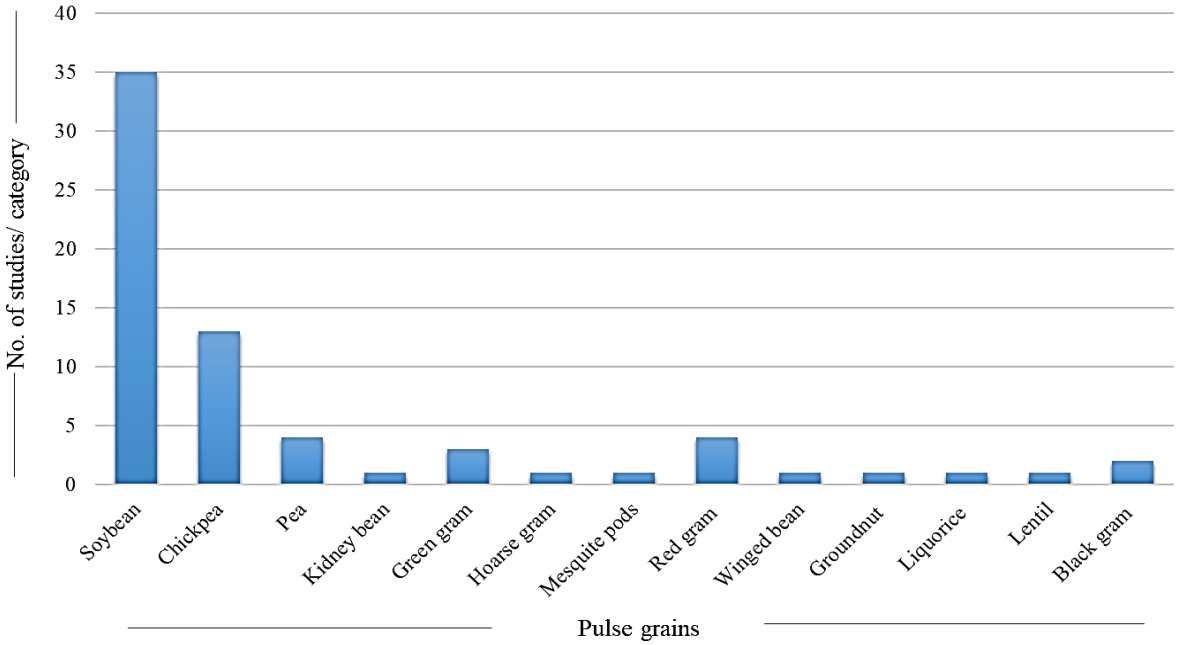

Figure 6 Comparative use of various types of pulse grains in artificial feeding of honeybees

Table 8 Utilization of different fruits & vegetables in feeding honey bees

S.N.	Name of fruit/vegetable	Plant Family	Form	References
1.	Date (*Phoenix dactylifera*)	Arecaceae	Pulp	Shehata (2016), Shehata and Nafea (2006)
2.	Papaya syrup (*Carica papaya*)	Caricaceae	Paste	Ulla et al. (2021) Amro et al. (2016)
			Pulp	Pande et al. (2015)
3.	Sweet potato (*Ipomea batatas*)	Convolvulaceae	Shell juice	Nowar (2011)
4.	Melon (*Cucumis melo*)	Cucurbitaceae		Shehata (2016), Shehata and Nafea (2006)
5.	Pumpkin (*Cucurbita pepo*)	Fagaceae	Syrup	Neupane and Thapa (2005)
6.	Chestnut (*Castanea sativa*)		Nut powder	Omar et al. (2017)
7.	Neem (*Azadirachta indica*)	Meliaceae	Fruits pulp	Singh and Singh (2012)
8.	Banana (*Musa Paradisiaca*)	Musaceae	Shell juice	Shehata and Nafea (2006)
9.	Banana (*Musa acuminate*)	Poaceae	Syrup	Pande et al. (2015), Neupane and Thapa (2005)
10.	Sugarcane (*Saccharum officinarum*)		Juice	Carrillo et al. (2015)
11.	Lemon (*Citrus limon*)	Rutaceae	Juice jelly	Ullah et al. (2021), Abou-Shaara (2017)
			Juice	El-Nagar et al. (2019)
12.	Mandarin (*Citrus reticulata*)	Sapotaceae	Shell juice	Shehata and Nafea (2006)
13.	Orange (*Citrus aurantium*)		Fruit juice	Islam et al. (2020), El-Nagar et al. (2019), Shehata (2016), Abd El-Wahab et al. (2016)
14.	Mahua (*Bassia latifolia*)		Shell juice	Shehata (2016)
			Pulp	Singh and Upadhyay (2008)
15.	Potato (*Solanum tuberosum*)	Solanaceae	Flour	Hussein (1981), Chalmers (1980)
16.	Grape (*Vitis vinifera*)	Vitaceae	Syrup	Bailey (1966)

Table 9 Use of medicinal/spices/condiments in artificial feeding of bees

S.N.	Medicinal plants/ Spices/ Condiments	Plant Family	References
1.	Coriander (*Coriandrum sativum*) seeds	Apiaceae	Aly et al. (2014)
2.	Caraway (*Carum carvi*) seeds		Mohamed et al. (2023), Aly et al. (2014)
3.	Fennel (*Foeniculum vulgare*) seeds		Aly et al. (2014)
4.	Anise (*Pimpinella anisum*) seeds		Mohamed et al. (2023), Aly et al. (2014)
5.	Chamomile (*Matricaria chamomilla*)	Asteraceae	Mohamed et al. (2023), Al-Ghamdi et al. (2021)
6.	Fenugreek (*Trigonella foenum-graecum*) Seeds	Fabaceae	Aly et al. (2014)
7.	Fenugreek (*Trigonella foenum-graecum*) seeds		Islam et al. (2020)
8.	Mint (*Mentha piperita*) oil	Lamiaceae	Al-Ghamdi et al. (2021), Abd El-Wahab et al. (2016)
9.	Thyme (*Thymus vulgaris*)		El-Nagar et al. (2019)
10.	Cinnamon (*Cinnamomum verum*)	Lauraceae	Ghramh and Khan (2023), Al-Ghamdi et al. (2021), Zaghloul et al. (2017), Shehata (2016)
11.	Laura paper (*Cinnamomumtamela*)		Mohamed et al. (2023)
12.	Turmeric (*Curcuma longa*)	Zingiberaceae	Ghramh and Khan (2023), Islam et al. (2020)
13.	Ginger (*Zingiber officinale*)		Mohamed et al. (2023)
14.	Garlic (*Allium sativum*)	Amaryllidaceae	El-Nagar et al. (2019)

from over seven plant families for supplementary feeding of honey bees (Aly et al. 2014; Zaghloul et al. 2017; Islam et al. 2020; Al-Ghamdi et al. 2021).

3.2.5 Non-traditional/miscellaneous stuff

Apart from traditionally known food materials, some nontraditional commodities were tested to explore better food options (Table 10). These include dried drone's pupa powder, fish meal, candy made with drone brood + glucose + sugar + honey, magnetized water, hexane extracts of larvae containing brood pheromone, star (Egyptian product/commercial liquid), royal jelly, milk powder, yoghurt, salt (NaCl), camphor oil, meat scrap, dried egg yolk, onion waste, calcium hydrogen phosphate (used as filler/binder in food products), eucalyptus (*Eucalyptus globule*) extract, etc. (El-Sherif 2002; Madras-Majewska et al. 2005; Dastouri et al. 2007; Irandoust and Ebadi 2013; Abd El-Wahab and Ghania 2016; Manjy and Shaher 2019; Ullah et al. 2021). However, logical reasons were insufficient to support selecting such materials in bee food.

4 Diet combinations used in the artificial feeding of honey bee

When combinations of different food components were searched in the available literature, thirteen different types of diets (combinations) were found; the detail of these combinations was given in this article's subsequent section.

4.1 Diets containing pollen substitutes alone

At least 33 types of diets based on either pollen or pollen substitutes alone or in combination with each other were noted (Table 11). In these types of combinations, the natural pollens from various plant sources alone or in combination were dominantly used in the artificial feeding of bees (Sabir et al. 2000; Puškadija et al. 2017; Ricigliano et al. 2017, 2022; Amro et al. 2020). Apart from natural pollen grains, different types of grains, *viz.*, cereals and pulses, fruits and vegetables, milk powders, meat craps, fish meals, etc., were also used as pollen substitutes for honey bees (Irandoust and Ebadi 2013; Tesfaye 2019; Ullah et al. 2021).

4.2 Diets containing pollen substitutes in combination with yeasts

Under this diet, nine combinations of pollen substitutes alone or with other similar foods were fed to honey bees with either yeast, drugs or both (Table 12). The soybean, in combination with similar supplements, was used dominantly (Alexandru et al. 1977; Mishra et al. 1979).

4.3 Diets containing pollen substitutes with vitamins/proteins/ minerals/amino acids

In this diet, at least eight pollen substitutes were combined with various vitamins, proteins, minerals, and amino acids in the artificial feeding of honeybees (Table 13). The soybean (*G. max*) and maize (*Z. mays*), as pollen supplements, were used in combination with different vitamins and other essential biochemicals (Sabir et al. 2000; Zahra and Talal 2008). Besides, the milk powder and natural pollen were also tried in a combination of vitamins and other essential biochemicals (Pirk et al. 2010).

Table 10 Non-traditional commodities utilized in feeding honey bees

S.N.	Name of component	References
1.	Dried drone's pupa powder	Beota et al. (2005)
2.	Skimmed milk powder	Ullah et al. (2021), Kumar et al. (2021), Kishan and Srinivasan (2016), Amro et al. (2016), Taha (2015), Pande and Karnatak (2014), Kumar et al. (2013a, b), Irandoust and Ebadi (2013)
3.	Fish meal	Irandoust and Ebadi (2013), Winston et al. (1983)
4.	Candy made with drone brood, glucose, sugar & honey	Madras-Majewska et al. (2005)
5.	Magnetized water	Manjy and Shaher (2019)
6.	Hexane extracts of larvae containing brood pheromone	Pankiw et al. (1998)
7.	Star (commercial liquid-Egyptian product)	Abd El-Wahab and Ghania (2016)
8.	Royal Jelly	Aqueel et al. (2017)
9.	Milk powder	Dastouri et al. (2007)
10.	Yoghurt	Nowar (2011)
11.	Salt (NaCl)	Srivastava (1996)
12.	Camphor oil	El-Sherif (2002)
13.	Meat scrap	Standifer et al. (1973)
14.	Dried egg yolk	Haydak (1945)
15.	Onion waste	Cho et al. (2021)
16.	Calcium hydrogen phosphate (used as filler/binder in food products)	Li et al. (2012)
17.	Eucalyptus (*Eucalyptus globule*) extract	Al-Maktary (2009)
18.	Parnove (*Plucheadioscoridis*)	El-Nagar et al. (2019)
19.	Pulicaria (*Pulicaria arabica*)	Al-Maktary (2009)
20.	Medicinal mushroom (*Agaricus brasiliensis*)	Stevanovic et al. (2018)
21.	White clover (*Trifolium repens*)	Omar et al. (2017)
22.	Palm oil (*Elaeisguineensis*)	Sereia et al. (2013)
23.	Cotton (*G. hirsutum*) seed	Herbert and Shimanuki (1979a), Haydak (1939)
26.	Linseed (*L. usitatissimum*)	van der Steen (2007)
27.	Crushed Panicum grass (*Panicum* sp.)	Shehata (2016)

Table 11 Diet combinations with given pollen grains and or pollen substitutes

S. N.	Diet composition Pollen/Pollen supplements		References
1.	Natural Pollen of Willow tree (*Acacia salicina*), Mustard (*Brassica tournefortii*), Land- caltrops (*Tribulus terrestris*), Prosopis (*Prosopis juliflora*), Egyptian clover (*Trifolium alexandrinum*), Broad bean (*Vicia faba*), Maize, Canola (*Brassica napus*), Fennel (*Faeniculum vulgare*), Coriander, Caper (*Brassica kaber*)		Amro et al. (2020), Puškadija et al. (2017), Ricigliano et al. (2017), Amro et al. (2015), Rezaei et al. (2015), Zheng et al. (2014), Al-Ghamdi et al. (2011), DeGrandi-Hoffman et al. (2010), Khodairy and Moustafa (2008), Al-Sarhi (2008)
2.	Maize (*Z. mays*)	Gluten	Rezaei et al. (2015), Al-Sarhi (2008)
3.		Flour	Ghramh and Khan (2023), Haydak (1936)
4.	Wheat flour (*T. aestivum*) flour		Ghramh and Khan (2023)
5.	Oat flour (*Avena. sativa*) flour		Haydak (1936)
6.	Sorghum (*S. bicolor*) flour		Ghramh and Khan (2023)
7.	Germinated wheat (*Triticum aestivum*)		Herbert and Shimanuki (1979b), Standifer et al. (1977)
8.	Pea (*Pisum sativum*) flour		Gemeda (2014), Haydak (1936)
9.	Chickpea (*Cicer arietinum*) flour		Ghramh and Khan (2023), Tesfaye (2019)
10.	Mung bean (*Vigna radiata*) flour		Tesfaye (2019)
11.	Bean (*Phaseolus vulgaris*)		Gemeda (2014)
12.	Peanut (*Arachis hypogaea*) cake		Erickson and Herbert (1980)
13.	Broad bean (*Vicia faba*) flour		Herbert and Shimanuki (1979b), Taber (1978), Barker and Lehner (1976), El-Banby and Gorgui (1970)
14.	Oats (*Avena sativa*) roasted seeds		Herbert and Shimanuki (1979a)
15.	Potato (*Solanum tuberosum*) flour		Hussein (1981), Chalmers (1980)
16.	Cotton (*Gossypium hirsutum*) seed meal		Herbert and Shimanuki (1979a)
17.	Date (*P. dactylifera*) paste		Ulla et al. (2021), Amro et al. (2016), Shehata (2016),
18.	Skimmed milk powder		Chalmers (1980)
19.	Dried whole milk		Stroikov (1966)
20.	Meat scrap		Haydak (1936)
21.	Fish meal		Irandoust and Ebadi (2013), Chalmers (1980)
22.	Hexane extracts of larvae containing brood pheromone		Pankiw et al. (1998)
23.	Soybean (*Glycine max*) flour + Pollen		Standifer et al. (1973)
24.	Soybean (*G. max*) flour + Skimmed milk		Abbas et al. (1995), Haydak (1945)
25.	Germinated wheat (*T. aestivum*) + Soybean (*G. max*)		Aly et al. (2019)
26.	Pollen of *Helianthus* sp.+ *Asparagus* sp. + *C. sativa* + *T. repens*		Omar et al. (2017)
27.	Soybean flour (*G. max*) + Wheat (*T. aestivum*)		Standifer et al. (1973)
28.	Cotton (*G. hirsutum*) seed + Skimmed milk powder		Haydak (1939)
29.	Black gram (*V. mungo*) + Skimmed milk		Abbas et al. (1995)
30.	Chestnut (*C. sativa*) + White clover (*T. repens*)		Omar et al. (2017)
31.	Pollen + Wheat (*T. aestivum*) flour		Stanger and Laidlaw (1974)
32.	Corn flour (*Zea mays*) + fish-meal + Pea (*P. sativum*)flour		Haydak (1936)
33.	Soybean (*G. max*) flour + Skimmed milk powder + Meat scrap		Standifer et al. (1973)

Table 12 Diet combinations of pollen substitutes with yeasts/drugs

S. N.	Diet composition		References
	Pollen supplements/ oils	Yeasts	
1.	Soybean (*G. max*) flour + Dried egg yolk	Brewer yeast (*S. cerevisiae*)	Haydak (1945)
2.	Soybean (*G. max*) flour + Dried skimmed milk		Haydak (1959)
3.	Soybean (*G. max*) flour + Skimmed milk powder		Mishra et al. (1979), Alexandru et al. (1977), Standifer et al. (1970), Forster (1968a, b), Hagedom and Moeller (1968)
4.	Fenugreek (*T. foenum-graecum*) + Turmeric powders (*C. longa*)		Amro et al. (2020)
5.	Chickpea (*C. arietinum*) flour + Germinated wheat (*T. aestivum*)		Amro et al. (2020)
6.	Skimmed milk powder		Haydak (1945)
7.	Fish meal		Winston et al. (1983)
8.	Dehusked parched chickpea (*C. arietinum*)+ Skimmed milk powder		Chhuneja et al. (1992)
9.	Skimmed milk powder	Yeast	Forster (1966)
10.	Wheat (*T. aestivum*) flour+ Cinnamone (*C. verum*) powder		Ghramh and Khan (2023)
11.	Wheat (*T. aestivum*) flour+ Turmmeric (*C. longa*) powder		Ghramh and Khan (2023)
12.	Wheat (*T. aestivum*) flour+ Turmeric (*C. verum*) powder + Cinnamone (*C. longa*) powder		Ghramh and Khan (2023)
13.	Maize (*Z. mays*) flour+ Cinnamone (*C. verum*) powder		Ghramh and Khan (2023)
14.	Maize (*Z. mays*) flour+ Turmmeric (*C. longa*) powder		Ghramh and Khan (2023)
15.	Maize (*Z. mays*) flour+ Turmeric (*C. verum*) powder + Cinnamone (*C. longa*) powder		Ghramh and Khan (2023)
16.	Chickpea (*C. arietinum*) flour+ Cinnamone (*C. verum*) powder		Ghramh and Khan (2023)
17.	Chickpea (*C. arietinum*) flour+ Turmmeric (*C. longa*) powder		Ghramh and Khan (2023)
18.	Chickpea (*C. arietinum*) flour+ Turmeric (*C. verum*) powder + Cinnamone (*C. longa*) powder		Ghramh and Khan (2023)
19.	Sorghum (*S. bicolor*) flour+ Cinnamone (*C. verum*) powder		Ghramh and Khan (2023)
20.	Sorghum (*S. bicolor*) flour+ Turmmeric (*C. longa*) powder		Ghramh and Khan (2023)
21.	Sorghum (*S. bicolor*) flour+ Turmeric (*C. verum*) powder + Cinnamone (*C. longa*) powder		Ghramh and Khan (2023)

Table 13 Diet combinations comprising of pollen substitutes with vitamins/ proteins/ minerals/ amino acids

S. N.	Diet composition		References
	Pollen supplements	Vitamins/proteins/minerals/amino acids	
1.	Soybean (*G. max*) flour	Vit. C, Multi-vitamins	Zahra and Talal (2008)
2.		Vit. B-Complex, Glycine	Sabir et al. (2000)
3.		Vit. B-complex, Methionine	Sabir et al. (2000)
4.	Soybean (*G. max*)flour + Egg yolk	Vit. B-Complex	Sabir et al. (2000)
5.	Maize (*Z. mays*) flour + Egg yolk		Sabir et al. (2000)
6.	Maize (*Z. mays*) flour	Vit. B-Complex, Glysine	Sabir et al. (2000)
7.	Pollen	Casein	Pirk et al. (2010)
8.	Skimmed milk	Vit. C	Zahra and Talal (2008)

4.4 Diets containing nectar substitutes alone

Around 35 nectar substitutes alone or in combination with each other were used in the artificial feeding of honeybees (Table 14). Sugar syrup has been the most dominant nectar substitute in the artificial feeding of honeybees all over the world (Ghazala and Nowar 2013; Zheng et al. 2014; Gemeda et al. 2018; Dolasevic et al. 2020; Islam et al. 2020). After sugar syrup, natural honey is the second most utilized nectar substitute in different forms, *viz*., normal creamed from cotton and clover, Jelly from cotton and candy (Abd El Hamid and Abou-Shaara 2016; Abou-Shaara 2017). The combination of two or more sugar forms viz., royal jelly + fructose, royal jelly + sugar, royal jelly + honey, honey+ sugar powder + sugar syrup, honey + sugar powder + sugar syrup, etc., was also tried in feeding honey bees (Skubida et al. 2008; Avni et al. 2009; Abd El-Wahab et al. 2016; Aqueel et al. 2017; Manjy and Shaher 2019). Besides pure sugar forms, some fruit pulp and shell juices (grapes, papaya, banana, orange, mandarin, lemon, etc.) and vegetable oils (palm and linseed) were also tried (Shehata and Nafea 2006; Nowar 2011; Pande et al. 2015; Shehata 2016; El-Nagar et al. 2019; Islam et al. 2020).

Table 14 Diet combinations comprising of nectar substitutes only

S. N.	Diet composition Nectar supplements		References
1.	Sugar syrup		Dolasevic et al. (2020), Islam et al. (2020), Gemeda et al. (2018), Gamal Eldin et al. (2018), Rashid et al. (2018), Abou-Shaara (2017), Omar et al. (2017), Mahfouz (2016), Shehata (2016), Carrillo et al. (2015), Haleem et al. (2015), Rezaei et al. (2015), Gemeda (2014), Somerville (2014), Usha et al. (2014), de Assis-Pinto (2014), Johnson (2014), Zheng et al. (2014), Ghazala and Nowar (2013), Mahmood et al. (2013), Sahinler and Kaftanoglu (2013), Sammataro and Weiss (2013), Kamandar (2012), Andelkovic et al. (2011), Fasasi (2011), DeGrandi-Hoffman et al. (2010), Sharaf El-Din (2010), Versluijs (2010), Al-Maktary (2009), Bodla et al. (2009), Al-Sarhi (2008), Skubida et al. (2008), Hammad (2007)
2.	Sugar candy		Abou-Shaara (2017), Abou-Shaara (2017), Aly et al. (2014)
3.	Inverted sugar		Carrillo et al. (2015), Atallah and Naby (1979)
4.	Honey	Creamed from cotton	Abou-Shaara (2017), Abd El Hamid and Abou-Shaara (2016).
5.		Creamed from clover	Abd El Hamid and Abou-Shaara (2016)
6.		Jelly from cotton	Abou-Shaara (2017)
7.		Candy	Abou-Shaara (2017)
8.		Normal	Abou-Shaara (2017), Barker and Lehner (1978)
9.	Royal jelly		Vandenberg and Shimanuki (1987)
10.	Sugarcane juice		Carrillo et al. (2015)
11.	Grape syrup (*Vitis vinifera*)		Barker and Lehner (1978), Bailey (1966)
12.	Papaya (*Carica papaya*) syrup		Pande et al. (2015)
13.	Banana (*M. paradisiaca*)	Fruit syrup	Pande et al. (2015), Shehata and Nafea (2006)
14.		Shell juice	
15.	Flowers extract of Mahua (*Bassia latifolia*)		Singh and Upadhyay (2008)
16.	Lemon (*Citrus limon*) juice		El-Nagar et al. (2019), Nowar (2011)
17.	Mandarin (*C. reticulata*) shell juice		Shehata and Nafea (2006)
18.	Melon shell juice (*Cucumis melo*)		Shehata (2016), Shehata and Nafea (2006)
19.	Orange (*C. aurantium*)	Fruit juice	Islam et al. (2020), El-Nagar et al. (2019), Shehata (2016), Abd El-Wahab et al. (2016)
20.		Shell juice	
21.	Corn (*Z. mays*) high fructose syrup		Sammataro and Weiss (2013), DeGrandi-Hoffman et al. (2010)
22.	Pumpkin (*Cucurbita pepo*) syrup		Neupane and Thapa (2005)

S. N.	Diet composition Nectar supplements	References
23.	Palm (*Elaeis guineensis*) oil	Sereia et al. (2013)
24.	Linseed (*Linum usitatissimum*) oil	Sereia et al. (2013)
25.	Sesame (*Sesamum indicum*) powder	Mohamed et al. (2023
26.	Sugar powder + Honey	Avni et al. (2009), Skubida et al. (2008)
27.	Royal jelly + Fructose	Aqueel et al. (2017)
28.	Royal jelly + Honey	Aqueel et al. (2017)
29.	Royal jelly + Sugar	Aqueel et al. (2017)
30.	Powdered sugar + Sugar syrup	Abd El-Wahab et al. (2016)
31.	Sucrose + magnetized water	Manjy and Shaher (2019)
32.	Honey+ Sugar powder+ Sugar syrup	Abd El-Wahab et al. (2016)
33.	Worker Jelly+ Glucose+ Fructose	Asencot and Lenky (1976)
34.	Linseed oil (*L. usitatissimum*) + Palm oil	Sereia et al. (2013)
35.	Corn Fructose-85+Corn Fructose-55+Glucose Monohydrate+ Sucrose syrup	Guler et al. (2018)

Table 15 Diet combinations comprising of nectar substitutes with yeasts/drugs

S. N.	Diet composition Nectar supplements	Yeasts/drugs	References
1.	Royal jelly, Sugar, Water	Yeast extract	Rembold and Lackner (1981)
2.	Honey, Sugar powder, Water	Dried brewer's yeast (*S. cerevisiae*)	Younis (2019)
3.		*Agaricus brasiliensis* (Fungi) extract	Stevanovic et al. (2018)
4.	Royal jelly, D-glucose, D-fructose	Solution of yeast extract	Aupinel et al. (2005)
5.		Difcobacto-yeast extract or Charcoal-treated extract	Rembold and Lackner (1981)
6.		Yeast extract	Vandenberg and Shimanuki (1987)
7.	Sugar powder	Dried brewer's yeast (*S. cerevisiae*)	Ahmed (2000)
8.	Sucrose	Yeast cake	Abd Al-Fattah et al. (2003)
9.	Sugar syrup	Torula yeast (*C. utilis*)	Peng et al. (1984)
10.		Yeast	Haleem et al. (2015), Dodologlu and Emsen (2007)
11.	Royal jelly		Aqueel et al. (2017)
12.	Sugar powder, Water	Yeast culture	Abd El-Wahab and Gomaa (2005)
13.		Brewer's yeast (*S. cerevisiae*)	
14.	Honey, Sugar syrup		Omar (2006)
15.	Sugar syrup	Fumagillin (antimicrobial)	Akyol et al. (2006)
16.	Honey, Sucrose	Torula yeast (*C. utilis*)	Lehner (1983)
17.	Glucose, Fructose, Royal jelly, Water	Yeast extract	Kaftanoglu et al. (2011)

4.5 Diets containing nectar substitutes with yeasts/drugs

Around 17 combinations were found where nectar substitutes were combined with yeasts/drugs and fed to honey bees in the past (Table 15). The nectar substitutes like royal jelly, sugar, honey, glucose, and fructose alone or mixed were used in combination with different types and forms of yeasts and drugs (Fumagillin- an antimicrobial) to feed the bees (Akyol et al. 2006; Kaftanogluet al. 2011; Stevanovic et al. 2018; Younis 2019).

Table 16 Diets containing nectar substitutes with vitamins/ proteins/ minerals/ Amino acids

S. N.	Diet composition		References
	Nectar supplements	Vitamins/proteins/minerals/amino acids	
1.	Sugar syrup	Multi-vitamin	El-Sherif (2002)
2.			Abd El-Wahab et al. (2016)
3.		Multivitamins, Microelements	Andelković et al. (2011)
4.	Sugar candy		Andelković et al. (2011)
5.	Honey	Casein	Mahfouz (2016)
6.	Honey	Whey protein concentrate	Mahfouz (2016)
7.	Royal jelly	Casein	Pirk et al. (2010)
8.	Sugar powder, Sugar syrup	Corn gluten	Gamal Eldin et al. (2018)
9.	Sugar syrup	Vit. A, E, B1, B2, B12, C, K1, Pantothenic acid, Nicotineamid, Folic acid, Biotin, K_2HPO_4	Gençer et al. (2000)
10.		Vit. A, D3, E, B1, B2, B6, B12, C, K3, Niacin, Ca-d-Pantothenate, Vitamix Formula-TOPKIM)	Akyol et al. (2006)

4.6 Diets containing nectar substitutes with vitamins/proteins/ minerals/amino acids

Nectar substitutes were also tried in a combination of vitamins, proteins, minerals, and amino acids. Among the mentioned 10 combinations in table 16, along with honey and different sugar forms, different types of vitamins (vitamin A, E, B1, B2, B6, B12, C, D3, E, K1, K3, and multivitamins), proteins (Casein, corn gluten, and whey protein concentrates), amino acids (Pantothenic acid, Nicotinamide, Folic acid, Biotin, K_2HPO_4) and minerals were tested as an alternate artificial food for honey bees (Gençer et al. 2000; El-Sherif 2002; Akyol et al. 2006; Mahfouz 2016; Abd El-Wahab et al. 2016; Gamal Eldin et al. 2018).

4.7 Diets containing pollen and nectar substitutes

Around 64 pollen and nectar diet combinations were traced from the literature (Table 17). Different forms of sugars, honey, and fruit juices were kept under the category of nectar substitutes while pollen grains (from different plants sources), commercial diets, grains of different cereals, pulses, beans, skimmed milk powder, fruit past (apple, banana, pumpkin, date, etc.), spices, condiments, etc., under pollen supplements (Omar 2006; Li et al. 2012; Usha et al. 2014; Abd El-Wahab et al. 2016; Mahfouz 2016; Omer et al. 2017; Gamal Eldin et al. 2018; Dolasevicet al. 2020). These supplements were used either alone or in mixtures of each in combination. Single grains from pulses (soybean, chickpea, pea, and

Table 17 Diet combinations of pollen and nectar substitutes

S. N.	Diet composition		References
	Pollen supplements	Nectar supplements	
1.	Pollen	Honey	de Assis-Pinto (2014), Kumar et al. (2013a, b), Al-Eitby (2009), Dodologlu and Emsen (2007)
2.	Bee-Pro®	Sugar syrup	Saffari et al. (2004)
3.	TLS Bee food®		Sena et al. (2012), Saffari et al. (2010)
4.	Feed Bee®		Dolasevic et al. (2020), Guler et al. (2018), Omar et al. (2017), Amro et al. (2016), Sena et al. (2012), Saffari et al. (2004, 2010)
5.		Honey, Sucrose solution, Water	Amro et al. (2016)
6.		Sugar powder, Water	Omar et al. (2017)
7.	High fructose corn syrup	Distilled water	DeGrandi- Hoffman et al. (2008)
8.	Spirulina (*Arthrospira platensis*)	Honey	Kumar and Agrawal (2014)
9.	Parnove (*Pluchea dioscoridis*) boiling water extract	Orange juice	El-Nagar et al. (2019)
10.	Garlic extract (*A. sativum*)	Lemon juice	

S. N.	Diet composition		References
	Pollen supplements	Nectar supplements	
11.	Apple (*M. domestica*)	Sucrose syrup	Pernal and Currie (2000)
12.	Soybean (*G. max*) extract	Honey	Mahfouz (2016), de Assis-Pinto (2014)
13.	Wheat (*T. aestivum*)	Sugar syrup	Stanger and Laidlaw (1974)
14.	Germinated Wheat	Honey, Sugar powder, Sugar syrup,	Omar (2006)
15.	EM® (commercial probiotic mix)	Sugar syrup	Tlak-Gajger et al. (2020)
16.	Soybean flour	Sugar powder	Nowar (2011)
17.		Sugar powder, Sugar syrup	Abd El-Wahab et al. (2016)
18.		Honey, Sugar syrup	Omar (2006), Usha et al. (2014)
19.			Abd El-Wahab et al. (2016)
20.		Honey, Water	Usha et al. (2014)
21.		Honey, Sucrose	Lehner (1983)
22.		Sucrose, Water	Dodologlu and Emsen (2007)
23.	Defatted soybean flour	Honey, Sugar powder, Water	Younis (2019)
24.	Milk powder	Honey, Sugar powder	Mahbobi et al. (2012)
25.	Rice bran syrup	Honey, Sugar powder	Neupane and Thapa (2005)
26.	Banana (*M. paradisiaca*) syrup	Honey, Sugar powder, Water	Neupane and Thapa (2005)
27.	Pumpkin (*Cucurbita*) syrup		
28.	Maize (*Z. mays*) syrup	Honey, Sugar powder	Neupane and Thapa (2005)
29.	Maize (*Z. mays*) flour	Honey, Water	Usha et al. (2014)
30.		Sugar powder, Eucalyptus extract-based sugar solution	Al-Maktary (2009)
31.		Honey, Sugar powder, Water	Younis (2019)
32.	Roasted winged bean (*P. tetragonolobus*) seeds	Sugar solution	Wijayati et al. (2019)
33.	Boiled winged bean seeds		
34.	Chickpea flour	Honey, Sugar powder, Water	Younis (2019)
35.	Pea flour		
36.	Germinated wheat		
37.	Liquorice (*G. glabra*) root extract	Distilled water	Al-Shammary and Al-Gerrawy (2017)
38.	Bean (*V. cowpea*) flour + Chickpea + flour + Coriander	Honey	Aly et al. (2014)
39.	Beans flour + Fennel seeds flour		
40.	Fennel (*F. vulgare*) flour + Chickpea		
41.	Pea flour + Caraway seeds (*Carum carvi*) flour		
42.	Soybean flour + Skimmed milk powder	Honey	Haydak (1937)
43.	White kidney Bean flour + Caraway seeds flour		Aly et al. (2014)

S. N.	Diet composition		References
	Pollen supplements	Nectar supplements	
44.	Sugar cane (*Saccharum officinarum*) candy + Dried drones pupa powder	Glucose	Beota et al. (2005)
45.	Cotton seed (*G. hirsutum*) + Skimmed milk powder	Honey	Haydak (1936)
46.	Linseed + Skimmed milk powder		Haydak (1937)
47.	Fenugreek flour + Sweet potato	Sugar powder	Nowar (2011)
48.	Peanut + Skimmed milk powder	Honey	Haydak (1937)
49.	Pollen/mixed pollen (*P. tanacetifolia*, *B. campestris*, *M. officinalis*, *H. annuus*; *P. banksiana*, *Asparagus* sp., *S. perfoliatum* etc.)	Honey, Sugar solution, Sugar powder, Sucrose, Fructose, Sugar candy, Water	Dolasevic et al. (2020), Gamal Eldin et al. (2018), Omer et al. (2017), Abd El-Wahab et al. (2016), Usha et al. (2014), Li et al. (2012), Al-Ghamdi et al. (2011), Saffari et al. (2010), Skubida et al. (2008)
50.	Mixed pollen + Yoghurt	Sugar powder	Nowar (2011)
51.	Defatted soybean (*G. max*) flour + Skimmed powder milk	Honey, Date (*P. dactylifera*) molasses	Taha (2015)
52.	Soybean (*G. max*) flour + Date (*P. dactylifera*) pollen grains	Powdered sugar, Sugar syrup	Abd El-Wahab et al. (2016)
53.		Sugar powder, Melon shell juice, Mandarin shell juice	Shehata and Nafea (2006)
54.	Soybean flour+Dried skimmed milk	Sugar syrup, Sucrose syrup	Sahinler and Kaftanoglu (2013)
55.	Roasted soybean flour + Mixed pollen	Honey, Sucrose	Avni et al. (2009)
56.	Pollen + Soybean (*G. max*) flour + Wheat (*T. aestivum*) flour	Sugar syrup	Standifer et al. (1973)
57.	Oats (*A. sativa*) flour + Rice (*O. sativa*) flour + Anise (*P. anisum*) flour	Honey	Aly et al. (2014)
58.	Date (*P. dactylifera*) paste + Defatted soybean flour + Skimmed milk powder		Taha (2015)
59.	White kidney beans (*P. vulgaris*) flour + Pea (*P. sativum*) flour + Coriander flour		Aly et al. (2014)
60.	Fenugreek (*T. foenum-graecum*) flour + Beans (*Vi. cowpea*) flour + Fennel flour		
61.	Chickpea flour + Fenugreek flour + Cumin (*C. cyminum*) flour		Aly et al. (2014)
62.	Rice (*O. sativa*) flour + Pea flour + Fennel flour + Fenugreek flour		Aly et al. (2014)
63.	Soybean (*G. max*) + Date (*P. dactylifera*)	Crushed Panicum grass (*Panicum* sp.) + Melon shell juice,Orange shell juice	Shehata (2016)
64.	Soybean (*G. max*) + Date (*P. dactylifera*)	Panicum grass (*Panicum* sp.) + Orange shell juice, Melon juice, Cinnamon oil	Shehata (2016)

beans) or cereals (rice, maize, and wheat) were dominantly used in combination with different forms of nectar supplements (sugars and honey) (Sahinler and Kaftanoglu 2013; Aly et al. 2014; Taha 2015; Shehata 2016; Younis 2019) (Table 17).

4.8 Diets containing pollen and nectar substitutes with yeasts/ drugs

In this category, 44 diet combinations were seen where yeasts/drugs were added to pollen and nectar substitutes (Table 18). Under yeasts/drugs, the most common yeast, *viz*., dried brewer's of yeast (*S. cerevisiae*) used in different forms, in combination with antibiotics, spirulina (*A. platensis*), and Creon have been utilized. Another form of sugars and honey, camphor (*C. camphora*) oil, shell juices (*M. paradisiaca*, *C. melo*), enzyme inverted syrup, glucose, date (*P. dactylifera*) syrup, etc., were also treated as nectar supplement. In the case of pollen supplements, pollen grains (from different plant sources), commercial diets, grains of different cereals, pulses, beans, skimmed milk powder, etc., have been used (Shehata and Nafea 2006; Al-Eitby 2009; Nowar 2011;

Table 18 Diet containingpollen substitutes and nectar substitutes with yeasts/drugs

S. N.	Diet composition			References
	Pollen supplements	Yeasts/drugs	Nectar supplements	
1.	Pollen grains	Yeast	Sugar syrup	Dodologlu and Emsen (2007)
2.	Milk powders	Antibiotics	Honey, Citrus juice, Volatile oils	Omar et al. (2016)
3.	Soybean flour	Yeast extract	Honey, NaCl salt	Sihag and Gupta (2013)
4.		Brewer's yeast	Powdered sugar, Sugar syrup	Islam et al. (2020)
5.				
6.			Honey, Sugar syrup, Sugar powder	El-Waseef (2002)
7.				Ghazala and Nowar (2013)
8.			Sugar powder	
9.		Antibiotics	Honey, Citrus juice, Volatile oils	Omar et al. (2016)
10.		Yeast extract	Honey	Sihag and Gupta (2013)
11.		Brewer's yeast	Sugar powder	Mahmood et al. (2013)
12.			Sugar powder, Water	Abd El-Wahab and Gomaa (2005)
13.	Defatted soybean flour		Enzyme inverted syrup	Puškadija et al. (2017)
14.	Defatted soybean flour	Brewer's yeast, Spirulina	Sugar powder, Glucose	Kumar and Agrawal (2014)
15.				Kumar et al. (2013a, b)
16.	Maize flour	Brewer's yeast	Powdered sugar, Sugar syrup	Islam et al. (2020)
17.			Sugar powder	Mahmood et al. (2013)
18.	Chickpea flour			
19.	Skimmed milk powder		Date syrup	Amro et al. (2020)
20.	Germinated horse gram + Skimmed milk powder		Honey	Pande and Karnatak (2014)
21.	Germinated chickpea + Skimmed milk powder			
22.	Pea + Skimmed milk powder			
23.	Germinated Green gram + Skimmed milk powder			
24.	Defatted Soybean flour + Skimmed milk powder		Sugar powder	Kumar et al. (2013a, b)
25.	Soybean + Skimmed milk			Al-Ghamdi et al. (2011)
26.	Chickpea cake + Pollen		Sugar syrup (with Camphor oil)	El-Sherif (2002)
27.	Defatted Soybean flour + Skimmed milk powder		Sugar powder	Kumar and Agrawal (2014)
28.	Defatted Soybean flour + Skimmed milk powder			
29.	Defatted soybean flour + Skimmed milk powder		Honey	Taha (2015)
30.	Soybean flour + Sweet potato	Powdered yeast	Powdered sugar	Nowar (2011)
31.	Mixed pollen +Sedge pollen	Creon	Sugar powder,Water	Al-Eitby (2009)

S. N.	Diet composition			References
	Pollen supplements	Yeasts/drugs	Nectar supplements	
32.	Chickpea parched powder + Skimmed milk powder	Brewer's yeast	Sugar Powder, Sugar syrup, Water	Singh (2003)
33.	Maize +Date paste		Shell juices *(M. paradisiaca, C. melo)*, Sugar powder	Shehata and Nafea (2006)
34.	Egyptian bean + Date paste			
35.	Skimmed milk powder + Soybean flour + Clover extract		Sugar powder	Mansour (2002)
36.	Defatted soybean flour + Parched chickpea flour		Sugar powder, Glucose	Kumar et al. (2013a, b)
37.	Skimmed soybean + Cinnamon	Dry yeast	Honey, Sugar powder	Zaghloul et al. (2017)
38.	Chickpea + Cinnamon			
39.	Yellow corn powder + Cinnamon	Yeast		
40.	Defatted soybean flour + Parched red gram	Dried brewer's yeast	Sugar powder, Glucose	Kumar and Agrawal (2014)
41.	Chickpea cake + Pollen		Sugar syrup, Camphor oil	El-Sherif (2002)
42.	Corn flour + Chickpea flour + Wheat bran		Sugar powder, water	Mansour (2002)
43.	Chamomile + Caraway + Sesame powder	Inactive yest	Powdered sugar	Mohamed et al. (2023)
44.	Anise + Laura paper and ginger		Powdered sugar	Mohamed et al. (2023)

Kumar et al. 2013 a, b; Mahmood et al. 2013; Pande and Karnatak 2014; Kumar and Agrawal 2014; Taha 2015; Omar et al. 2016; Puškadija et al. 2017; Zaghloul et al. 2017; Amro et al. 2020). The combinations were prepared as a single component with single or multiple features. Overall, 42 combinations could be seen under this category of diet combinations (Table 18).

4.9 Diets containing pollen and nectar substitutes with vitamins/proteins/minerals/amino acids

In this category of diet combinations, vitamins/proteins/minerals/ amino acids were added singly or more than one to pollen and nectar substitutes (Table 19). At least nine such diet combinations are known in the available literature. Here, calcium caseinate, whey protein, vitamin B-complex, casein, and several protein were used under the vitamins/proteins/minerals/amino acids section (Sabir et al. 2000; van der Steen 2007; Al-Eitby 2009). Rest, common pollen, and nectar substitutes were used (Table 19).

4.10 Diets containing pollen and nectar substitutes with yeasts/drugs and vitamins/proteins/minerals/amino acids

From the available literature, a minimum of 34 diet combinations have been noted under this category (Table 20). These diet combinations utilized yeasts/drugs, vitamins/proteins/minerals/ amino acids, and pollen and nectar substitutes. Under yeasts/drugs,

Table 19 Diet combination with pollen supplements, nectar supplements and vitamins/ proteins/ minerals/ amino acids

S. N.	Diet composition			References
	Pollen supplements	Vitamins/proteins/minerals/Amino acids	Nectar supplements	
1.	Soybean flour	Calcium caseinate, Whey protein flour (milk protein 80%)	Sucrose solution, Linseed	van der Steen (2007)
2.		Vit. B-complex	Sugar solution	Sabir et al. (2000)
3.	Maize flour			
4.	Bee-Pro	Casein,Gevral protein	Sugar powder, Water	Al-Eitby (2009)
5.	Maize flour + Egg yolk	Vitamin B-Complex	Sugar solution	Sabir et al. (2000)
6.	Mixed pollen + Bee-Pro®	Gevral protein	Sugar powder, Water	Al-Eitby (2009)
7.	Sedge pollen (*Cyperus compressus*) + Soybean (*G. max*) flour			
8.	Soybean flour + Egg yolk	Vit. B-Complex	Sugar solution	Sabir et al. (2000)

Table 20 Diet combination with pollen supplements, nectar supplements, vitamins/ proteins/ minerals/ amino acids, and yeasts/drugs

S. N.	Diet composition				References
	Pollen supplements	Yeasts/drugs/oils	Vitamins/proteins/minerals/ Amino acids	Nectar supplements	
1.	Soybean flour	Dried Brewer's yeast	Protein	Sugar syrup	El-Waseef (2002)
2.			Protein Hydrolysate	Sugar powder, Glucose	Kumar and Agrawal (2014)
3.			Protein Hydrolysate	Sugar powder, Glucose	Kumar et al. (2013a, b)
4.	Soybean flour	Yeast extract	Vitamins, Minerals	Honey	Sihag and Gupta (2013)
5.	Soybean flour		Multivitamin		Lakra (2006)
6.	Soybean				Sihag and Gupta (2011)
7.	Mung bean flour				
8.	Chickpea flour				
9.	Pigeon pea flour				
10.	Pollen + Soybean flour				
11.	Pollen + Mung bean				
12.	Pollen + Chickpea				
13.	Pollen + Pigeon pea				
15.	Mixed- pollen	Fumagillin	Multivitamins	Sugar powder, Sugar syrup	Akyol et al. (2006).
16.	Mixed pollen	Brewer's yeast	Sodium caseinate,casein	Sucrose, water	Malone et al. (2004)
17.		Brewer's yeast	Avidin (protein)	Sucrose, water	Malone et al. (2004).
18.		Brewer's yeast, Aprotinin	Sodium caseinate		
19.		Dried Brewer's yeast			
20.	Palm pollen + Sedge pollen	Creon	Casein	Sugar powder, water	Al-Eitby (2009)
21.	Defatted soybean flour + Pollen	Tetracycline	Vitamin B-complex	Honey, Sugar powder, water	Al-Shammary and Al-Gerrawy (2017)
22.	Defatted soybean flour + Pollen	Brewer's yeast	Protein Hydrolysate	Sugar powder, Glucose	Kumar and Agrawal (2014)
23.	Corn flour + Soybean + Corn gluten	Calcium hydrogen phosphate, Calcium carbonate	Antioxidant Premixes	Sucrose	Li et al. (2012)
24.	Soybean flour + Powder of Fenugreek and Turmeric	Brewer's yeast	Vit. A, D, E	Honey, Sugar syrup, Sugar powder, Orange juice	Islam et al. (2020)
25.	Maize flour + Fenugreek powder + Turmeric				
26.	Soybean flour + Fenugreek Powder + Turmeric				
27.	Maize flour + Fenugreek powder + Turmeric				
28.	Soybean flour + Turmeric + Fenugreek powder	Mint oil			Abd El-Wahab et al. (2016)
29.	Anicotinic acid + Citrus juice	Dried Brewer's yeast, Antibiotics, Volatile oils	Vit. B1, B2	Honey	Omar et al. (2016)

S. N.	Diet composition				References
	Pollen supplements	Yeasts/drugs/oils	Vitamins/proteins/minerals/ Amino acids	Nectar supplements	
30.	Mesquite pods powder + Fresh mixed pollen pellets + Dried skim milk	Brewer's yeast	Multivitamins, minerals (Centrum)	Honey, Sugar powder, water, Coriander oil	Amro et al. (2016)
31.	Date paste + Fresh mixed pollen pellets + Dried skim milk				
32.	Soybean meal + Fresh mixed pollen pellets + Dried skim milk		-	Honey, Sugar powder, water	
33.	Soybean + Liquorice root extract	Tetracycline	Vit. B-complex,	Honey, Sugar powder, water	Al-Shammary and Al-Gerrawy (2017)
34.	Citrus juice	Antibiotics, Volatile oils	-	Honey, Sugar Powder	Omar et al. (2016)

Table 21 Diets either pollen or nectar supplements with yeasts/drugs/oils and vitamins/ proteins/ minerals/ amino acids

S. N.	Diet composition				References
	Pollen supplements	Yeasts/drugs/oils	Vitamins/proteins/minerals/Amino acids	Nectar supplements	
1	Soybean flour	Dried Brewer's yeast	Protein based sugar syrup	-	Ghazala and Nowar (2013)
2	Defatted soybean flour	Brewer's yeast	Soy protein hydrolysate	-	Kumar and Agrawal (2014)
3	-	Yeast	Gluten	Sugar powder	Al-Ghamdi et al. (2011)
4	-	Cholesterol	Casein (Protein)	Sucrose, NaCl Salt	Srivastava (1996)
5	-	Cholesterol, Alphacel (polysaccharide)	Casein, Tocopherol (Vit. E)	Sucrose, Salt mixture	Srivastava (1996)
6	-	Brewer's yeast	Isolated soy protein	-	Sereia et al.(2013)

the most common brewer's yeast (*S. cerevisiae*), along with calcium hydrogen phosphate (CHP), calcium carbonate (CC), tetracycline, aprotinin, Creon, fumagillin, antibiotics, volatile oils, and mint oils were placed. In the case of vitamins/proteins/ minerals/amino acids, different proteins (sodium caseinate, casein, avidin, etc.) and protein hydrolysates, vitamins (A, B, D, E, K, etc.) & multivitamins, minerals, and antioxidant premixes were used. Further, under the nectar category, common sugar, honey, glucose, sucrose, fruit juices (orange), and coriander oil have been part of such diets (Lakra 2006; Akyol et al. 2006; Sihag and Gupta 2011; Li et al. 2012; Kumar and Agrawal 2014; Omar et al. 2016; Amro et al. 2016; Al-Shammary and Al-Gerrawy 2017; Islam et al. 2020). These diet combinations were prepared with single versus single or multiple food components (Table 20).

4.11 Combinations missing pollen or nectar substitutes with yeast/drugs and vitamins/proteins/minerals/amino acids

Further, in the artificial feeding of honey bees, two diet combinations of pollen substitutes, yeasts/drugs and vitamins/proteins/minerals/amino acids, three of yeasts/drugs, vitamins/proteins/minerals/amino acids, and nectar supplements, and another one in a combination of yeasts/drugs in vitamins/proteins/minerals/amino acids (Al-Ghamdi et al. 2011; Ghazala and Nowar 2013; Kumar and Agrawal 2014) (Table 21).

4.12 Combinations missing both pollen and nectar substitutes

In many cases, neither pollen nor nectar substitutes were used, but other contents were fed to honey bees (Table 22). These contents are yeasts, crude proteins, vitamins, multivitamins, and essential and non-essential amino acids (Zahra and Talal 2008; Sereia et al. 2013; Zheng et al. 2014; Haleem et al. 2015; Hendriksma et al. 2019). The yeasts (*Candida utilis*, *S. cerevisiae*, and fodder yeast) have been commonly fed to honey bees in this category (Chalmers 1980; Shimanuki and Herbert 1986).

5 Commercial artificial diets

In commercial bee keeping, ready-to-use diets are also available for feeding bees. These artificial diets are complete nutrition meant to

Table 22 Diets without pollen and nectar substitute

S. N.	Diet composition		References
1.	Yeast	Torula (*Candida utilis*)	Shimanuki and Herbert (1986), Doull (1977)
2.		Brewer's (*S. cerevisiae*)	Chalmers (1980), Free and Williams (1971), Stroikov (1966)
3.		Liquid	Sereia et al. (2013), Al-Sarhi (2008), Hammad (2007)
4.		Baker's (*Saccharomyces cerevisiae*)	Standifer et al. (1977), Standifer et al. (1973), Free and Williams (1971)
5.		Fodder	Free and Williams (1971)
6.	Crude protein		Zheng et al. (2014), Herbert and Shimanuki (1979a)
7.	Casein		Herbert and Shimanuki (1979a)
8.	Commercial casein mixtures		Haydak (1936)
9.	Lactalbumin		Shimanuki and Herbert (1986)
10.	Tankage protein for animal feed		Haydak (1936)
11.	Multivitamins		Haleem et al. (2015), Zahra and Talal (2008)
12.	Thiamine (vit. B)		Haleem et al. (2015)
13.	Vitamin C		Zahra and Talal (2008)
14.	Essential amino acids (EAA)		Hendriksma et al. (2019)
15.	Nonessential amino acids (NAA)		Hendriksma et al. (2019)

Table 23 Common artificial diets being used all over the world

S.N.	Commercial diets	References
1.	Royal king 4 H (German product)	Abd El-Wahab and Ghania (2016)
2.	Royal star (German product)	Abd El-Wahab and Ghania (2016)
3.	Bee-Pro	Saffari et al. (2010), Al-Eitby (2009)
4.	Bee-Pol	Huang (2010)
5.	Feed-bee	Guler et al. (2018), Omar et al. (2017), Saffari et al. (2010), Saffari et al. (2004)
6.	Ultra-bee	Ricigliano et al. (2022)
7.	Global	Ricigliano et al. (2022)
8.	Bulk-Soft	Ricigliano et al. (2022)
9.	Mega-Bee	Ricigliano et al. (2022)
10.	AP23	Ricigliano et al. (2022)
11.	Healthy-Bees	Ricigliano et al. (2022)
12.	Honey-sugar cake with Immunebee solution	Wilde et al. (2014)
13.	Honey-sugar cake with beetonic solution	Wilde et al. (2014)
14.	Honey-sugar cake with Beeodine	Wilde et al. (2014)
15.	Nektapol	Al-Ghamdi et al. (2011)
16.	TLS Bee-food	Sena et al. (2012), Saffari et al. (2010)
17.	Beltsville-bee (BBD)	Jimenez and Gilliam (1989), Herbert and Shimanuki (1983)

maintain the hive's aces and boost bees' immunity. These artificial diets have been developed commercially and are easily available in the market; however, the cost-benefit ratio is of concern. This literature survey has documented over 17 such commercial diets, tested by various authors (Saffari et al. 2010; Al-Ghamdi et al. 2011; Sena et al. 2012; Wilde et al. 2014; Abd El-Wahab and Ghania 2016; Omar et al. 2017; Guler et al. 2018) (Table 23).

Conclusion

The artificial food of honey bees can be categorized in two ways: the first one is the food components, and the second one is their combinations. The food components can further be classified into two categories: natural nutrients and natural food components. The natural nutrients have been proteins, carbohydrates, vitamins, yeasts, antibiotics, amino acids, enzymes, antioxidants, etc. In contrast, the natural food components comprise cereal grains, pulses and beans, fruits and vegetables, medicinal plants, spices, condiments, and some non-traditional/ miscellaneous kinds of stuff. In the artificial feeding of bees, the diet combinations were prepared using the abovementioned nutrients and food components in various forms and proportions. In general, the pollen and nectar, the main food of bees, have been supplemented under various diet combinations. These diet combinations either used pollen and nectar supplements or alone combined with other nutrition, drugs, antibiotics, etc. The present investigation provides an updated overview of the food types and their combinations used in the artificial feeding of bees to date. Apiculturists can use this outcome to develop new effective diet combinations. It will also help researchers explore new food items that have yet to be tested.

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