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Research Article

Impact of Different Feeding Methods on Honey Composition and Bee Health in Northern Iraq

Mohammed Sadeeq Ramadhan[1], Ali Ölçücü[2], Ercan Aydoğmuş[3*], Maruf Hurşit Demirel[4],
Mehmet Mürşit Temüz[5], and Mustafa Hamdi Karagöz[6]

[1]Department of Chemistry, Faculty of Science, Fırat University, Elazığ, Türkiye
[2]Department of Chemistry, Faculty of Science, Fırat University, Elazığ, Türkiye
[3]Department of Chemical Engineering, Faculty of Engineering, Fırat University, Elazığ, Türkiye
[4]Department of Basic Pharmaceutical Sciences, Faculty of Pharmacy, Fırat University, Elazığ, Türkiye
[5]Department of Chemistry, Faculty of Science, Fırat University, Elazığ, Türkiye
[6]Department of Chemistry, Faculty of Science, Van Yüzüncü Yıl University, Van, Türkiye

**(ercanaydogmus@firat.edu.tr) Email of the corresponding author*

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Abstract – Honeybee nutrition is essential for maintaining colony health, enhancing honey quality, and ensuring ecological stability. This study explores the effects of different feeding methods, including natural floral sources, fruit-based nutrition, and artificial sugar syrups, on the physicochemical composition of honey in the northern region of Iraq. The research compares 'fruit honey' produced by bees fed 1 kg of watermelon, sugar syrup, and candy, as well as naturally sourced honey. Physicochemical analyses, including Fourier transform infrared spectroscopy (FTIR), refractive index, viscosity, microscopic imaging, pH, and density measurements, were conducted to assess honey quality. The results indicate that feeding practices significantly influence honey composition, affecting sugar content, viscosity, acidity, and bioactive compound levels. Unlike bees solely reliant on sugar solutions often exhibiting reduced lifespans, weakened immunity, and increased inflammation those supplementing their diets with fruit juices demonstrate improved colony health and honey quality. This study highlights the importance of natural and fruit-based nutrition as a sustainable and cost-effective alternative to artificial feeding. Promoting these practices can enhance bee health, support colony growth, and ensure the economic viability of beekeeping while maintaining ecosystem stability by preventing hive abandonment and pollination disruptions.

Keywords – Honeybee nutrition, Honey composition, Fruit-based feeding, Colony health, Physicochemical properties

I. INTRODUCTION

Honey is the natural sweet product produced by Apis mellifera bees from nectar of plants (nectar honey), from secretions of livings parts of plants or excretions of plant-sucking insects of the living part of plants (honeydew honey) [1]. Honey crystallization is a natural process that occurs due to the saturation of sugars in the solution. The key factors influencing crystallization include sugar composition, temperature, storage conditions, and the presence of seed crystals. Honeys with a high glucose-to-fructose ratio (e.g., clover honey) crystallize faster, while honeys rich in fructose (e.g., acacia honey) stay liquid longer [2-4].

Honey cannot be considered a complete food by human nutritional standards, but it offers potential as a dietary supplement. Honey mainly contains simple sugars or monosaccharides of which fructose and glucose are the main components (65 %), and approximately 18 % water. Proteins flavour and aroma, phenolic compounds (phenolic acids and flavonoids), free amino acids, organics acids, vitamins and minerals constitute minor components of honeys [5].

The sources included in the literature scanned for the planning of this study provide us with preliminary information about the feasibility of this study. The natural diet of the adult honey bee is pollen and honey. Sometimes, however, when nectar is not available, bees collect sweet-tasting juices from overripe fruit and plant [6]. Bananas are healthy, nutrient-rich fruits, that can be introduced into a healthy balanced diet to indirectly boost your iron levels and maintain healthy immunity, and brain and muscle function [7]. It could be recommended to move the honey bee colonies to banana plantations during the dearth period to economize the cost of feeding, maintain the strength of colonies, and obtain good honey yield [8].

Banana syrup feeding was found superior to (Sugar syrup, Rice bran syrup, Maize syrup, Pumpkin syrup), and therefore, its supplementation can reduce the cost of sugar feeding by more than 50% and increase brood production during off-season [9]. Honey's aroma is shaped by its floral source, volatile organic compounds, and geographical origin. Processing and storage can weaken its scent by breaking down key compounds. High moisture content may cause fermentation, leading to sour or alcoholic odors [10, 11].

The pH of honey is acidic from (3.2 - 4.5), due to the presence of gluconic acid, acetic acid, and citric acid. These acids are primarily produced by the enzymatic action of glucose oxidase, which converts glucose into gluconic acid and hydrogen peroxide. The acidity of honey helps inhibit microbial growth [12-14]. Analyzing honey's physicochemical properties using instruments like pH meters, refractometers, viscometers, FTIR spectroscopy, density measurements, and microscopic imaging is essential for assessing its quality, authenticity, and origin [15, 16].

This study aims to provide a comprehensive understanding of how different feeding methods impact honey composition and overall colony health. By comparing honey produced from natural floral sources, fruit-based nutrition, and artificial sugar syrups, we seek to highlight the benefits of sustainable feeding strategies for beekeeping. The findings of this research will contribute to the development of cost-effective and ecologically viable practices that enhance honey quality, improve bee health, and support long-term colony survival. Encouraging the use of natural and fruit-based nutrition can not only optimize honey production but also strengthen pollination services, ultimately ensuring environmental stability and economic sustainability in apiculture.

II. MATERIAL AND METHOD

Collection of samples honey

Four liquid honey samples were collected from *Apis mellifera* or *Apis florea* bees' colonies during July and August. After harvesting the honey or removing it from the hive boxes, the bees were fed fruit like Watermelons (*Citrullus lanatus*), Sugar syrup, and Candy bees for about one month to replicate the (unnatural honey) production process, sourced from beehives in Akre, while (natural honey) from Erbil located in the Northern Region of Iraq. Mix 1 kg powdered sugar with 200 mL raw honey, 5 g sea salt, 100 g thyme, 10 g pollen, and 10 g Brewer's yeast for protein to prepare bee candy. Gradually mix until a dough forms. Shape into patties, let dry, and place in the hive [17-23].

Local beekeepers prepared the honey samples using traditional methods and stored them in clean, sealed plastic bags in a dark environment at 20 °C until analysis [24]. Following this period, physicochemical analyses were performed on the honey. The study also involves collecting honey from bee boxes, as depicted in Figure1 and Figure 2.

Figure 1. Providing watermelon to bees as an alternative food source and collecting honey samples for analysis

Figure 2. Collection of honey samples to assess where bee colonies receive protein-rich sugar and its effect on composition

Physicochemical properties of honey

The physicochemical properties of honey samples were analyzed using various techniques, including FTIR spectroscopy, refractometer, viscometer, microscopic imaging, electrical conductivity, pH, and density measurements.

FTIR analysis

Fourier transform infrared spectroscopy (FTIR) was performed using the Shimadzu IR Spirit QATR-S instrument to analyze the molecular composition of honey samples. A small aliquot of honey was placed directly onto the Attenuated Total Reflectance (ATR) crystal, and spectra were recorded in the 4000–400 cm^{-1} range with a resolution of 4 cm^{-1}, and 32 scans were averaged per sample to ensure accurate results. The instrument was calibrated using a background scan before each measurement to eliminate interference from the atmosphere. Each analysis was conducted in triplicate for reproducibility. The spectra were analyzed using Shimadzu Lab Solutions IR software to identify functional groups and detect potential adulterants. This method is highly effective in characterizing honey's sugars, organic acids, and phenolic compounds [25].

Refractive index (%Brix)

The refractive index of samples honey was measured using a handheld refractometer (Atago PAL-1, Japan) to determine the moisture content and sugar concentration. A drop of honey was placed on the prism, and the Brix value was recorded at (20 °C), and humidity (36 %). The refractometer was calibrated with distilled water prior to use. This method provides a rapid and non-destructive assessment of honey quality, as the refractive index is directly correlated with the total soluble solids content [26].

Viscosity measurements

Measurements were made on Lamy RM 100 Plus rotary viscometer, which has the highest speed and torque range with a torque range of 0.005 – 30 mN·m and a range of 0.3-1500 rpm. The measurement was conducted using the spindle at a rotational speed (shear rate) of 20 rpm, following the manufacturer’s guidelines for viscosity determination [27]. The instrument was calibrated before each measurement using a standard viscosity reference fluid. Viscosity readings were recorded in centipoise (mPa·s), and each measurement was performed in triplicate to ensure accuracy and reproducibility. The viscometer, viscosity is the measured resistance to flow encountered by a spring when a spindle rotates in liquid. The most common application of this type of measurement is the quantification of a fluid's viscosity when compared to either a target performance or when compared against another fluid. For example, the instrumentation was used in developing target viscosities for the standardization of nectar-thick and honey-thick barium products that are used during videofluoroscopic evaluations of swallowing [28].

Microscopic images

Microscopic images were conducted to identify pollen grains, crystals, and other particulate matter in honey samples. A small amount of honey was diluted with distilled water, and a drop of the mixture was placed on a glass slide. Images of honey samples were examined with a Dcorn HDMI LCD Digital Microscope (7 Inc IPS Screen – 16 MP). The morphology of pollen grains was analyzed to determine the botanical origin of the honey, while the presence of foreign particles indicated potential adulteration [29].

pH test

The pH, conductivity, and total dissolved solids (TDS) of honey samples were measured using an AZ 86505 multi parameter meter. These parameters are critical for assessing the stability and quality of honey. This method provides critical information about the acidity, mineral content, and stability of honey. For instance, pH influences microbial growth, while conductivity reflects the mineral content [30]. The pH and electrical properties of the honey sample were measured using a digital pH meter (model 86505) at a controlled temperature of 25 °C and a relative humidity of 36 %. A volume of 10 mL of honey was carefully placed into a clean beaker, and the pH probe was immersed in the sample, ensuring full electrode contact. The instrument was calibrated using standard buffer solutions (pH 4.0, 7.0, and 10.0) before measurement. Additionally, millivolt (mV), electrical conductivity (µS/cm), and total dissolved solids (ppm) readings were recorded. Each measurement was performed in triplicate to ensure accuracy and reproducibility.

Determination of density

The density of the honey sample was determined using a gravimetric method. A fixed volume of 1 mL of honey was carefully transferred into a pre-weighed tube. The total mass of the tube with honey was recorded using an analytical balance (accuracy: ±0.0001 g). All measurements were conducted at a controlled temperature of 25 °C. To ensure accuracy and reproducibility, each measurement was performed in triplicate. This method provides accurate measurements of honey density, which is influenced by the concentration of sugars and other solutes [31]. The mass of the empty tube was subtracted to obtain the net mass of the honey sample. The mass of the empty tube was subtracted to obtain the net mass of the honey sample. The density was then calculated using the Eq. 1:

$$\text{Density (g/mL)} = \frac{\text{Mass of honey (g)}}{\text{Volume of honey (mL)}} \qquad \text{(Eq. 1)}$$

The pycnometry method was used to determine the density of the honey sample using the expression.

III. RESULTS AND DISCUSSIONS

Some physical and chemical properties of the honey samples in the study and the results obtained are expressed in this section.

FTIR spectra of different honey types are shown in Figure 3, Figure 4, Figure 5, and Figure 6. FTIR spectroscopy revealed significant differences in honey samples based on feeding methods. Watermelon-fed honey exhibited strong hydroxyl (-OH) and carbonyl (C=O) stretching, indicating high sugar content. Candy and sugar syrup-fed honey showed weaker spectral intensities, suggesting reduced natural compounds such as phenolic acids and flavonoids.

The FTIR analysis of different honey samples, including watermelon honey, candy honey, sugar honey, and natural Erbil honey, reveals key molecular components based on their functional groups and vibration intensities. The hydroxyl (O–H) stretching vibration, observed between 3274–3284 cm^{-1}, is strong and broad across all samples, confirming the presence of hydroxyl groups from water and sugars (glucose and fructose). This result aligns with previous studies, emphasizing honey's high moisture and sugar content [33].

The C–H stretching vibrations, representing aliphatic bonds in carbohydrates, appear at varying intensities, with watermelon honey (2949 cm^{-1}) and Sugar Honey (2967 cm^{-1}) showing strong peaks, whereas Candy Honey and Natural Erbil Honey exhibit weaker intensities around 2930 cm^{-1} [34]. These differences indicate slight variations in sugar composition across honey types.

The presence of C=O stretching vibrations (amide groups) between 1649–1673 cm^{-1} suggests protein-related carbonyls, likely derived from enzymes and minor proteins [35]. Watermelon Honey (1649 cm^{-1}) and Sugar Honey (1649 cm^{-1}) show medium and weak intensities, respectively, while Candy Honey exhibits a stronger peak at 1673 cm^{-1}. This variation indicates differences in enzymatic activity and protein content among honey types. The C=C stretching vibration, indicative of aromatic ring compounds from phenolic compounds and flavonoids, is observed in watermelon honey (1534 cm^{-1}) and candy honey (1516 cm^{-1}) but is not detected in sugar honey and natural Erbil honey [36]. This absence suggests that sugar and natural Erbil honey may contain fewer antioxidant compounds compared to the other samples.

Hydroxyl bending vibrations (O–H bending) appear in the range of 1374–1461 cm^{-1}, with varying intensities across honey types. Watermelon Honey has a medium-intensity peak at 1461 cm^{-1}, while Sugar Honey (1374 cm^{-1}) and Candy Honey (1411 cm^{-1}) exhibit weaker intensities [37]. This indicates slight differences in sugar interactions and hydrogen bonding. The presence of C–O stretching vibrations, indicative of carbohydrates, is confirmed in all samples between 1245–1254 cm^{-1} [33]. The peaks are weak, suggesting that polysaccharides contribute minimally compared to simple sugars like glucose and fructose. The C-O stretching vibrations between 1016–1039 cm^{-1}, associated with primary alcohols in sugars, are strong and sharp in all honey samples, further confirming their carbohydrate-rich nature [38].

FTIR analysis highlights key molecular differences among honey types. Watermelon and sugar honey exhibit stronger aliphatic C-H stretching peaks, suggesting higher sugar content, whereas candy and natural Erbil honey show weaker intensities. The presence of phenolic compounds in watermelon and candy honey suggests greater antioxidant potential compared to the other samples. Protein-related carbonyl groups vary in intensity, indicating different levels of enzymatic activity. These findings, supported by references, demonstrate that FTIR spectroscopy effectively differentiates honey varieties based on their chemical composition, contributing to quality assessment and authentication [33–38].

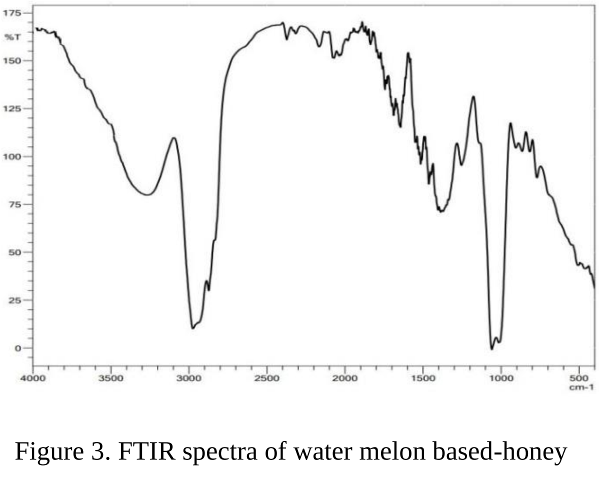

Figure 3. FTIR spectra of water melon based-honey

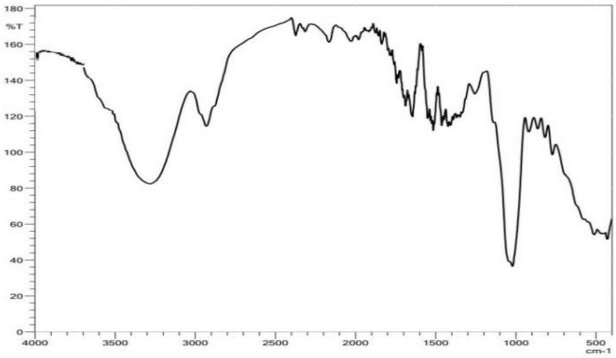

Figure 4. FTIR spectra of candy sample honey

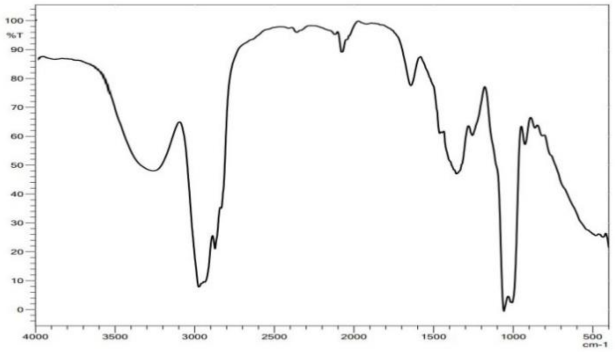

Figure 5. FTIR spectra of sugar sample honey

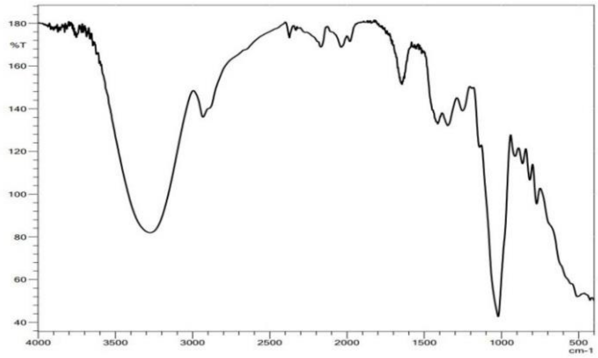

Figure 6. FTIR spectra of Erbil natural honey

Table 1 shows the refractometer (Brix) measurement results of honey samples. Honey samples displayed varying Brix values, with candy honey having the highest (83 °Bx) and sugar honey the lowest (79 °Bx).

Table 1. Refractometer (Brix) of samples honey

Type of Honey	Brix3 (^{o}Bx)
Water Melon Honey	82
Candy Honey	83
Sugar Honey	79
Natural Erbil Honey	82

Table 2 shows the viscosity results of honey samples at room temperature (25 °C) and 20 rpm shear rate. Viscosity measurements indicated that candy honey had the highest viscosity (34792), implying higher sugar density and complex structural properties compared to sugar-fed honey.

Table 2. Viscosity results of honey samples

Type of Honey	Viscosity (mPa·s)
Water Melon Honey	16650
Candy Honey	34792
Sugar Honey	5775
Erbil Natural Honey	22700

Figure 7, Figure 8, Figure 9, and Figure 10 show microscope images of different honey samples. Microscopic examination revealed differences in pollen grains and crystal structures. Natural honey exhibited diverse pollen types, while sugar-fed honey contained fewer pollen particles.

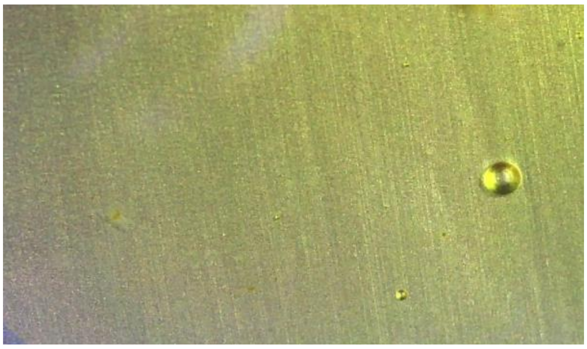

Figure 7. Water melon sample honey under microscope images

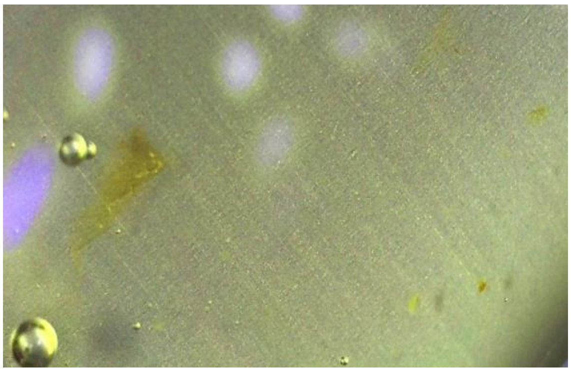

Figure 8. Candy sample honey under microscope images

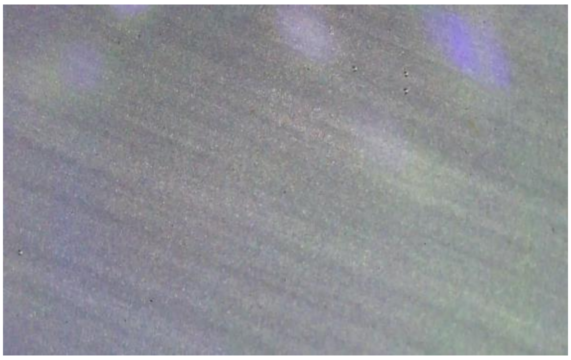

Figure 9. Sugar sample honey under microscope images

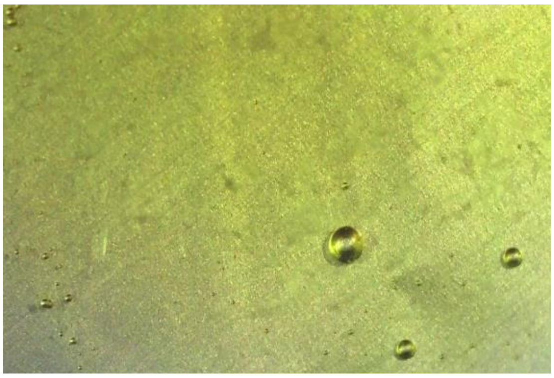

Figure 10. Natural Erbil sample honey under microscope images

Table 3 shows the results of measuring honey samples with a pH meter at room temperature and 36% relative humidity. pH analysis showed acidity variations, with sugar honey having the lowest pH (3.15) and candy honey the highest (3.89), influencing honey's stability and antimicrobial properties.

Table 3. pH results of the honey samples at 25 °C

Type of Honey	pH	mV	µS	ppm
Water melon Honey	3.58	196.9	0.05	0.03
Candy Honey	3.89	183.5	0.06	0.03
Sugar Honey	3.15	220	0.05	0.03
Erbil Natural Honey	3.43	210	0.05	0.03

Table 4 shows the density of honey samples at 25 °C. Density varied across samples, with sugar honey showing the highest density (2.855 g/cm^3), likely due to artificial sugar concentrations, whereas natural Erbil honey exhibited a balanced density (1.507 g/cm^3), suggesting an optimal natural composition.

Table 4. Density of the honey samples at 25 °C

Type of Honey	Density (g/cm^3)
Water Melon Honey	1.552
Candy Honey	1.631
Sugar Honey	2.855
Erbil Natural Honey	1.507

IV. CONCLUSIONS

This study highlights the significant influence of feeding practices on the physicochemical properties of honey and overall honeybee health. The findings indicate that natural floral sources and fruit-based nutrition contribute to superior honey quality by enhancing its nutritional composition, bioactive compounds, and physicochemical properties such as viscosity, acidity, and sugar content. In contrast, artificial feeding methods, such as sugar syrup and candy, result in honey with lower viscosity, altered acidity, and reduced bioactive components, potentially compromising its authenticity and nutritional value. Moreover, bees fed exclusively on artificial sugar solutions exhibited weakened immunity and shorter lifespans, whereas those supplemented with fruit-based nutrition demonstrated improved colony health and resilience. These results emphasize the importance of adopting natural and sustainable feeding strategies to enhance honey quality while maintaining the well-being of honeybee populations.

Implementing sustainable and nutrient-rich feeding practices is crucial for the long-term viability of beekeeping and environmental stability. By promoting the use of natural floral sources and fruit-based nutrition, beekeepers can improve honey quality, support colony growth, and reduce the negative consequences of artificial feeding. Additionally, maintaining healthy bee populations is essential for sustaining pollination services, which are vital for ecological balance and agricultural productivity. Future research should further investigate the long-term effects of different feeding methods on honeybee immunity, honey composition, and colony sustainability. Encouraging natural and fruit-based feeding strategies can serve as a cost-effective and environmentally friendly approach to beekeeping, ensuring both economic benefits for beekeepers and ecological stability for future generations..

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