Original Paper

Quality and Composition of Rapeseed and Sunflower Honey Originating from the Territory of the Slovak Republic

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The aim of the study was to compare the chemical composition of two types of floral honey (rapeseed and sunflower) obtained from sites in Dohňany and Tekovský Hrádok with honey from other locations. Rapeseed and sunflower honey are the most common honey types associated with agricultural production. Among the physicochemical properties, the honey samples were analyzed and evaluated for parameters such as glucose and fructose content, sucrose, percentage of water mass, content of water insoluble substances, free acid and heavy metal content. By comparing the obtained results with the analyses of honey from other Slovak and international locations, we found that our honey samples met the criteria set by Decree No. 41/2012 on honey in all monitored indicators. Based on this, it can be concluded that the impact of intensive agricultural production in these sites did not result in a deterioration in the quality of either rapeseed or sunflower honey.

Keywords: composition of honey, honey, rapeseed honey, quality, sunflower honey

1 Introduction

Currently, there is significant interest in screening biologically active compounds in plant-based food products (Jiang et al., 2020; Sytar & Hajihashemi, 2024). Honey is considered a plant-based food product because it is primarily derived from the nectar collected by bees from flowers. Although the production of honey involves an animal process, wherein bees transform nectar into honey, it remains fundamentally plant-based due to its primary source-flowering plants. The composition of honey includes sugars, amino acids, vitamins, minerals, and antioxidants, many of which are directly sourced from the plants visited by the bees (Majtan et al., 2021). Natural bee honey is a sweet product made by the species of bees *Apis mellifera* L. Secretions of living plant parts combine with specific secretions of bees, stored, concentrated, and left in the combs to mature. Honey can be divided into floral from nectar or honeydew honey (forest). According to the method of collection and processing, it is classified as extracted honey, comb, dripped, chunk or cut comb in honey, pressed and filtered honey. In terms of use, it is divided into table honey, industrial honey, or baker's honey (Alvarez-Suarez et al., 2014). Honey, due to its unique properties, can be considered one of the most important bees product. Honey intended for human consumption should be of optimal quality. Honey contains various bioactive compounds such as vitamins E, A, K, B1, B2, B6, C, phenols, flavonoids, amino acids and fatty acids. The above substances contribute to pharmacological properties, such as wound healing, antimicrobial activity, anti-inflammatory, antidiabetic, antioxidant, antibacterial and antitumor effects (Bouhlali et al., 2019). Honey can be considered a functional food because it is a complex mixture of sugars, such as monosaccharides, glucose and fructose, and other important components (proteins, minerals, vitamins, organic acids and enzymes) (Mokhtar et al., 2021). Indicator of the quality and origin of honey are its physicochemical properties, which depend not only on the type of flowers, but also on geographical conditions, beekeeping practices, and environmental climate changes. The main indicators of honey quality

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include moisture, sucrose and reducing sugar content, pH value, electrical conductivity, ash content, free acidity, diastase activity and hydroxymethylfurfural content (HMF) (Ajibola, 2015; Jovanović, 2015), which is a product of fructose and is formed naturally in honey during its storage (Del Campo et al., 2016). The objective of this study is to conduct a comparative analysis of the phytochemical constituents present in monofloral honeys, specifically *Brassica napus* (rapeseed) and *Helianthus annuus* (sunflower) varieties, harvested from apiaries within the Slovak Republic.

2 Material and Methods

2.1 Sample Analysis

The physicochemical analysis was conducted on samples of two types of floral honeys (rapeseed and sunflower honey). The rapeseed honey was harvested on May 15, 2023, originating from the locality of Dohňany. Its yield was 13 kg. The sunflower honey was harvested on August 5, 2023, from the locality of Tekovský Hrádok, with a yield of 23 kg. The analysis of selected honey types was carried out at the Vetlab Testing Laboratory in Dolné Kočkovce. The physicochemical indicators analysed were focused on the determination of glucose and fructose content, sucrose content, percentage of water mass, water-insoluble substances, free acids, and heavy metals (lead, cadmium, nickel, zinc, and copper). The obtained results for individual quality of honey indicators were compared with the standards set by Decree No. 41/2012 of the Ministry of Agriculture and Rural Development of the Slovak Republic.

The determination of glucose and fructose content was performed using the Total Sugar Test (glucose and fructose) device from Merck company. The results were read on a refractometer in mg·1 l^{-1} of honey, converted to grams, and expressed as percentages.

The determination of sucrose content was done using titration, and the content of reducing sugars in % of invert sugar was calculated using the following formula:

$$x = 500/c \cdot \gamma \ (\%)$$

where: γ – the volume of diluted honey solution used up during the determination (ml); c – the concentration of the diluted honey solution in g of honey

Using the reducing sugar content in % of invert sugar, the sucrose content in % was calculated. The value of x was determined by the following formula:

$$x = (a - b) \cdot 0.95 \qquad (\%)$$

where: a – the content of invert sugar after inversion (%); b – the content of invert sugar before inversion (%)

To determine the percentage of water mass, a handheld RMM refractometer was used, with a scale calibrated to measure the water content in honey as %.

The determination of water-insoluble substances was performed using filtration according to the methodology of Bogdanov et al. (1997), and their content was calculated using the following formula:

$$x = n/m \cdot 100 \ (\%)$$

where: n – the weight of solid substances insoluble in water (g); m – the weight of the honey sample used for analysis (g)

The free acid content in the honey samples was determined by titration with 0.1 mol·l^{-1} sodium hydroxide solution up to the equivalence point (pH = 8.3). The acidity was expressed as milliequivalents of acid·100 g^{-1} of honey. The calculation of acidity (x) in mekv·kg^{-1} of honey:

$$x = V \cdot 10 \ (\text{mekv}\cdot\text{kg}^{-1})$$

where: x – acidity of honey (mS·cm^{-1}); V – volume of 0.1 mol·l^{-1} NaOH (ml)

The determination of heavy metal content was carried out using flame atomic absorption spectrometry.

3 Results and Discussion

The obtained results for individual quality of honey indicators were compared with the standards set by Decree No. 41/2012 of the Ministry of Agriculture and Rural Development of the Slovak Republic.

The analysis results showed that rapeseed honey contained 81.1 g·100 g^{-1}, and sunflower honey contained 82 g·100 g^{-1} of glucose and fructose (Table 1). As the decree specifies a minimum content of these sugars at 60 g·100 g^{-1}, it can be concluded that both samples comply with the limits set by the decree.

Glucose and fructose are the most important components of honey in terms of content. An average concentration of carbohydrates in honey is 60–78%. The sum of glucose and fructose content is one of the most reliable indicators of the quality and authenticity of monofloral honeys (Kukurová et al., 2004).

Rapeseed honey is characterized by its higher glucose content, which causes rapid crystallization. The texture of the crystals resembles creamed honey, making it easy to use in this form while also achieving a stable consistency (Kružík et al., 2019). In contrast, sunflower honey typically contains a higher proportion of fructose (Živkov Baloš et al., 2023).

There were no significant differences in the glucose and fructose content found in our honey samples compared to honey from other Slovak beekeepers. Research shows that honey sourced directly from Slovak beekeepers has higher glucose and fructose levels (rapeseed: 76.8 g·100 g^{-1}; sunflower: 75.28 g·100 g^{-1}) compared to honey from retail stores claiming Slovak origin, where sample of sunflower honey contained 72.97 g·100 g^{-1} and rapeseed honey 72.96 g·100 g^{-1} of glucose and fructose (Kukurová et al., 2008). Comparison of Slovak and Polish rapeseed honeys, focusing on the impact of geographic origin on composition. Tomczyk et al. (2019) found only minor differences in glucose and fructose content, which was confirmed by the rapeseed honey sample analysed in this study. The authors argue that more significant role than geographic origin in determining honey composition are the biochemical profile of the plant nectar is from, genetics and physiology of the source plant, its climatic conditions, and even properties the soil the plant get its nutrient from. These conclusions are supported by studies on Bulgarian and Serbian sunflower honeys, which examined a larger number of samples and found broader variability between individual values (Manolova & Balkanska, 2021; Živkov Baloš et al., 2023). Some samples of Bulgarian and Serbian sunflower honeys matched the values found in sunflower honey from Slovakia. Significantly higher glucose and fructose levels (89–91 g·100 g^{-1}) were reported in Ukrainian honeys from various regions (Kołacz et al., 2023). Turkish sunflower honey displayed similar glucose and fructose contents to European samples (on average of 74.3 g·100 g^{-1}) (Durmuş & Aziz, 2016).

Sucrose content is a critical factor in determining the authenticity of honey, as sucrose in form of beet or cane sugar is one of the most common methods of falsification (Kukurová et al., 2004). According to Decree No. 41/2012 on honey, the maximum allowed sucrose content is 5 g·100 g^{-1} (5%). The rapeseed honey contained 1.11 g·100 g^{-1}, and the sunflower honey contained 0.89 g·100 g^{-1} of sucrose (Table 1). Therefore, both honey samples meet the criteria specified by the decree.

Its content in honey should typically be around 1%, in cases of higher sucrose concentrations up to 5%, tolerances are allowed for higher content. A significant role is due to factors influencing elevated sucrose levels including feeding bees with sugar solutions during nectar shortages or naturally higher sucrose levels in certain plant nectars (Preedy, 2012). Comparing Slovak rapeseed and sunflower honeys analysed in this study, it can be concluded that these samples exhibited lower sucrose content. Kukurová et al. (2004; 2008) state that the average sucrose content in rapeseed honey was around 5%, while sunflower honey averaged 3.39%. Slovak rapeseed honeys had an average sucrose content of 4.6% compared to Polish samples (Tomczyk et al., 2019). Analysis of Bulgarian sunflower honeys displayed similar results as our analysis (from 0.5% to 3.7%) with an average of 1.7% (Manolova & Balkanska, 2021). Rapeseed honeys from Ukraine had lower differences of sucrose levels, but showed significant regional differences, with sucrose content ranging from 1.5% in the Vinnytsia region to 3.21% in the Kyiv region. Sunflower honeys exhibited smaller regional sucrose differences (1.32% and 1.86%) (Kołacz et al., 2023). Turkish sunflower honey had a sucrose content of approximately 1.41% (Durmuş & Aziz, 2016), while Serbian sunflower honey demonstrated significantly lower values (average 0.33%) (Živkov Baloš et al., 2023).

The decree limits the water content in honey to a maximum of 20%, meaning that honey with higher water content does not meet the requirements for market placement (except for heather and baker's honey, with a higher water content allowance). The rapeseed honey sample contained 17.8% water, and the sunflower honey contained 16.1% water (Table 1). Based on this, it can be concluded that both honey samples meet the legislative criteria.

Another crucial indicator of honey quality is the water content. It influences some of honey's properties (viscosity, density, ripeness, taste, and crystallization), and is dependent on factors such as climatic conditions, bee colony characteristics, hive humidity and air

Table 1 Results of the analysis of rapeseed and sunflower honey samples

Indicator	Rapeseed honey	Sunflower honey
Sugar content as glucose and fructose (%)	81.1	82.0
Sucrose content (%)	1.11	0.89
Percentage of water mass content (%)	17.8	16.1
Water insoluble substances content (%)	0.026	0.066
Free acids content (mekv·kg^{-1})	18.0	22.0

temperature, processing and storing conditions, as well as botanical origin of the honey (do Nascimento et al., 2015). Generally, it has higher water content in spring at the start of the beekeeping season. Lower water content is advantageous for longer storage. High water content causes fermentation and acetic acid formation (Chirsanova et al., 2021). While the decree limits the water content in honey to a maximum of 20%, fermentation risk is completely eliminated at water levels below 18% (Kružík et al., 2019). Slovak rapeseed and sunflower honeys had water contents ranging from 16.44% to 21.4%, with rapeseed honey showing generally higher water levels than sunflower honey (Kukurová et al., 2008). Similar findings were observed in our analyzed samples. Moldovan rapeseed honeys exhibited lower water content, with only a 0.3% difference between rapeseed and sunflower honey (Chirsanova et al., 2021). Polish honeys had slightly lower water levels (17.45%) compared to Slovak honeys (17.86%) (Tomczyk et al., 2019). Kružík et al. (2019) state that the average water content in European rapeseed honeys ranges from 14.9% to 19.9%. Interesting results were found in Ukrainian rapeseed and sunflower honeys from various geographically distant areas. It turned out that in each of the regions the average values with significant differences were found. Rapeseed honeys had water content ranging from 17.73% in the Odesa region to 19.5% in the Kyiv region. For sunflower honey, the range was lower, from 17.91% in Odesa to 18.32% in Vinnytsia (Kołacz et al., 2023). Serbian study of sunflower honeys found a broader range between water contents (16.4% to 18.6%) (Živkov Baloš et al., 2023). Bulgarian sunflower honeys contained 15.6% to 19.3% of water (Manolova & Balkanska, 2021). Turkish sunflower honeys demonstrated a higher average water content (19.97%) (Durmuş & Aziz, 2016).

The decree on honey specifies the allowed amount of water insoluble substances at a maximum of 0.1 $g \cdot 100\ g^{-1}$, which is an international standard that some authors consider high. The rapeseed honey sample reached a value of 0.026 $g \cdot 100\ g^{-1}$, while the sunflower honey contained 0.066 $g \cdot 100\ g^{-1}$ of water-insoluble substances (Table 1). This indicates that both samples comply with the limit set by the decree.

Determination of insoluble substances in honey is crucial for assessing its purity. Various solid particles from surroundings can get into honey as a product. Most common are wax, pollen, micro-particles from combs, or bee body fragments. Honey extraction techniques or hive hygiene can also influence its quality (Gobessa et al., 2012). Although the analysis of insoluble substances in honey is less frequently conducted, available data suggest that most of the analyzed honey samples meet the legislative requirements. In Serbian sunflower honey an average of 0.8 $g \cdot 100\ g^{-1}$ insoluble substances content was found. Some samples even exceeded the limit of 1 $g \cdot 100\ g^{-1}$ (Živkov Baloš et al., 2023).

Decree No. 41/2012 on honey states that the allowed free acids content is a maximum of 50 milliequivalents of acid·1,000 g^{-1} (mekv·kg^{-1}). For baker's honey, the limit is higher (80 mekv·kg^{-1}). The rapeseed honey sample reached a value of 18 mekv·kg^{-1}, and the sunflower honey contained 22 mekv·kg^{-1} of free acids. Therefore, it can be concluded that both samples meet the decree's requirements. The amount of free acids in honey plays a significant role in its shelf life and flavour profile. The most prevalent acid in honey is gluconic acid, with smaller quantities of formic, acetic, citric, lactic, maleic, malic, oxalic, pyroglutamic, and succinic (Gobessa et al., 2012). Rapeseed honey samples from Slovakia contained 19 mekv·kg^{-1} (Kasperová et al., 2012), and sunflower honey had 14.8 mekv·kg^{-1} (Kukurová et al., 2004) free acids, which corresponds with our results. Analysis comparing Slovak honey samples between beekeepers and retail chains found notable differences. Content of free acids from sunflower honey ranged from 14.8 to 32.45 mekv·kg^{-1}. Higher values were found in honey from beekeepers. Rapeseed honey samples ranged from 12.5 to 13.98 mekv·kg^{-1} (Kukurová et al., 2008). Against Slovak rapeseed honey with average values of 13.6 mekv·kg^{-1}, Polish samples had 18.6 mekv·kg^{-1} of free acids, which was not considered as significant difference (Tomczyk et al., 2019). Kružík et al. (2019) state that in European rapeseed honey their average content ranged from 6.2 to 29.9 mekv·kg^{-1}. In Bulgarian study focused on sunflower honey also had no samples exceeding free acid limits, with values varying from 17.7 to 36 mekv·kg^{-1} with an average of 23.73 mekv·kg^{-1} (Manolova & Balkanska, 2021). Similar average value of free acids (22.79 mekv·kg^{-1}) was found in Turkish sunflower honey (Durmuş & Aziz, 2016). Serbian sunflower honey had a slightly higher average (28.07 mekv·kg^{-1}), while values were within the range of 20.4 to 37.2 mekv·kg^{-1} (Živkov Baloš et al., 2023). Content of free acids from Ukrainian rapeseed and sunflower honeys also showed a little variation. Differences were not found across individual regions the honeys were from. Rapeseed honeys in various regions had free acid values ranging from 12.69 to 13.6 mekv·kg^{-1}. In sunflower honeys these values ranged from 13.59 to 15.40 mekv·kg^{-1} (Kołacz et al., 2023).

Decree No. 41/2012 does not specify the permitted content of heavy metals in honey. Nevertheless, it is an important indicator of the quality and safety of honey. In the sample of rapeseed and sunflower honey we analyzed, the following contents of selected heavy metals were found, which are listed in Table 2.

Table 2 Content of selected heavy metals in rapeseed and sunflower honey (mg·kg^{-1})

Indicator	Rapeseed honey	Sunflower honey
Amount of lead Pb	0.009	0.010
Amount of cadmium Cd	<0.001	<0.001
Amount of cadmium Ni	0.030	0.036
Amount of cadmium Zn	0.538	0.687
Amount of cadmium Cu	0.175	0.218

In both honey samples, the highest values were recorded for zinc, which is natural, as honey inherently contains this mineral, just like copper, the second most prevalent metal in honey. The content of the most harmful metals to human health in the samples studied was minimal. The rapeseed and the common sunflower plants, from which the honey samples analyzed originated, were grown using a conventional farming system, with regards to soil friendly practices and crop rotation. One consequence of this approach is the low content of harmful heavy metals in the analyzed rapeseed and sunflower honey samples. Research on the presence of heavy metals in honey remains significantly underdeveloped. Most studies tend to focus on the content of minerals, such as zinc or copper. Additionally, researchers often focus on results for floral and honeydew honeys in general rather than specific monofloral honeys.

Heavy metals include both biologically irreplaceable microelements (e.g., Cu, Zn, Mn, Co, Cr, etc.) as well as non-essential chemical elements (e.g., Cd, Pb, Ni, Cr, etc.). These elements exist in varying concentrations in the environment, while their risks are due to ecotoxicity and accumulation in abiotic and biotic components of the environment. At higher concentrations, they become toxic to organisms. Even biologically essential microelements can exhibit toxicity when their concentration exceeds a certain threshold. Anthropogenic sources of heavy metals can come from other sources than industrial activities, mining, metallurgy, like agricultural practices, such as the use of chemical and organic fertilizers, pesticides, liming, and irrigation (Dadová et al., 2016).

The presence of heavy metals in honey is a significant indicator of its quality and safety. Some elements are naturally present in honey, others enter from external environmental sources. Honey is therefore often regarded as a bioindicator of the environment from which it originates. Honey can naturally contain mineral salts Ca, Na, P, Al, Fe, Si, Mg, and trace elements like Ni, Ag, Vd, Cr. The presence of heavy metals in honey is influenced by factors such as environmental accumulation, locality, and the level of industrial, agricultural, or transportation activity in the area (Ciobanu & Rădulescu, 2016). The most frequently monitored heavy metals in honey are amounts of lead and cadmium, which are considered key toxic heavy metals. Lead, mainly originating from transport, can contaminate nectar and honeydew, but is not transported through the soil. Cadmium can be transported from the soil to plants and can subsequently contaminate nectar or honeydew. It enters the soil by an excessive application of phosphate fertilizers, but it can also come from industrial activities. Nickel is commonly found in the environment in minimal amounts. Most often it gets into the soil when lower-quality fertilizers are applied (Oroian et al., 2016). Any heavy metals present in honey more than the limit values are a threat to human health. Their total amount depends on the geographical origin of the honey (Šerevičienė et al., 2022). Research shows that honeys in industrially polluted areas, but also in areas with intensive agricultural production, reach higher values of heavy metals. Honeydew honeys contain slightly more of them, but flower honeys show higher lead content values (Veselý, 2006).

It can be stated that by comparing the studied samples of rapeseed and sunflower honey with samples of other Slovak and foreign honeys, significant differences were found between individual indicators. Significant differences were recorded mainly within geographical areas, which probably relates to the fact that all environmental conditions are different for the production and quality of honey. Therefore, there is an importance of influence of the conditions from the specific environments where bees collect nectar. The type of plant from which the nectar honey comes from also determines its composition to a certain extent. Monocultures generally do not provide ideal living conditions for bee colonies due to monotonous food supply and sometimes lack of grazing, as some overbred varieties, especially rapeseed (*Brassica napus* L. var. *napus*), do not provide bees with enough nectar. The impact of pesticides on bee colonies is also significant. Pesticides affect the immune system of bees, which can subsequently be weakened and less resistant to parasitic diseases and viruses. It can also lead to the weakening of entire bee colonies, their deaths and to a reduction in production of honey and other bee products (Zhao et al., 2022). Based on the knowledge gained, it can be stated that agriculture, especially in its conventional form, can often have a rather negative impact on bee colonies and honey production. However, without the cultivation of agricultural crops, bees would be deprived of pasture and some types of honey would not be produced. For the mentioned reason in relation to bees, it is necessary to aim for sustainable agriculture, comply with cropping practices and avoid excessive use of pesticides and artificial fertilizers. Because bees are an essential part of ecosystems and play a key role in preserving biodiversity. Their invaluable contribution lies not only in the production of honey, but also in the pollination of plants, which is a fundamental process for plant production, since most cultivated crops are at least partially dependent on pollination by bees or related insects. Bees are also important for the sustainability of ecosystems and biodiversity, as they contribute to the preservation of plant species and ecological balance. The role of bees in the environment is irreplaceable, and therefore the protection of bees and their habitats should be key to the sustainable development of our planet. The most widely used product produced by bees – honey is also important, which has served humanity as a sweetener since ancient times. It is more than just that, as evidenced by its use not only in the food industry, but also in traditional medicine. Honey should rather be perceived as a multifunctional natural product that is an important source of nutrients. If consumers want a quality product with appropriate sensory and physicochemical properties, it is best to use honey directly from beekeepers, as research shows that such honey is qualitatively more valuable than honey sold in retail chains (Bahgat, 2023).

In conclusion, it can be stated that the composition and quality of honey is variable and depends mainly on the botanical source of nectar from which it is obtained, but also on the geographical location, seasonal and climatic conditions, and the method of processing and storage of honey.

4 Conclusions

The physicochemical properties of honey are important indicators of the quality and origin of honey. Selected indicators such as glucose and fructose content, sucrose, percentage of water mass, content of insoluble substances in water, free acids and heavy metals were evaluated in samples of rapeseed and sunflower honey. The glucose and fructose content in rapeseed honey was 81.1%, sucrose 1.1%, percentage of water mass represented 17.8%, insoluble substances represented 0.026%, free acids 18 mekv·kg^{-1}, Pb 0.009 mg·kg^{-1}, Cd less than 0.001 mg·kg^{-1}, Ni 0.030 mg·kg^{-1}, Zn 0.538 mg·kg^{-1} and the content of Cu was 0.175 mg·kg^{-1}. Sample of the sunflower honey contained 82.0% glucose and fructose, 0.89% sucrose, 16.1% water, 0.066% insoluble matter, 22 mekv·kg^{-1} free acids, 0.010 mg·kg^{-1} Pb, less than 0.001 mg·kg^{-1} Cd, 0.036 mg·kg^{-1} Ni, 0.687 mg·kg^{-1} Zn and 0.218 mg·kg^{-1} Cu. Based on these results, both analysed honey samples met all required indicators set by the Decree on honey No. 41/2012.

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