PHYSICOCHEMICAL AND SENSORY CHARACTERIZATION OF HONEY AND ITS ADULTERANTS

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ABSTRACT

The honey market in Bosnia and Herzegovina faces significant challenges regarding product authenticity and quality control. The lack of a well-regulated inspection system, combined with limited consumer awareness, creates favorable conditions for the distribution of adulterated products. In this study, 25 honey samples were examined: 10 honey samples within their declared shelf life, 7 samples older than three years, 3 commercially available samples suspected of adulteration, and 5 laboratory-prepared adulterants consisting of inverted sugar syrups with varying proportions of honey and tartaric acid. Physicochemical analysis included determination of sugar content, ash content, water content, total acidity, hydroxymethylfurfural (HMF) concentration, and electrical conductivity, conducted in accordance with applicable regulations. Sensory evaluation was performed using descriptive testing methods by trained assessors. Only four of the ten samples within shelf life were in accordance with all chemical parameters, while the remaining six exhibited elevated HMF values, excessive moisture, or increased acidity. All samples older than three years showed markedly elevated HMF content (174–1478 mg/kg). Two of the three suspected commercial samples were confirmed as adulterated by chemical analysis, and none passed sensory evaluation. All laboratory adulterants failed chemical testing, while sensory evaluation identified them as adulterated in only 55% of cases. Overall, two-thirds of declared honey samples were sensorily accepted, while fewer than half were chemically correct. The findings demonstrate that current prescribed analytical methods are insufficient to guarantee honey authenticity, and the introduction of additional detection methods along with stricter market surveillance is strongly recommended.

Keywords: honey, adulteration, quality control, physicochemical analysis, sensory evaluation.

INTRODUCTION

Honey has been a foodstuff of particular importance to human nutrition since antiquity, with its use dating back at least 10,000 years, as evidenced by a cave painting depicting honey gathering discovered in the Cueva de la Araña, Valencia, Spain. Throughout history, honey has been used not only as a food but also for medicinal purposes in the treatment of wounds and various ailments, in the mummification process in ancient Egypt, and even as a means of tax payment in the Roman Empire, while China is regarded as the cradle of organised beekeeping [1].

Honey consists essentially of different sugars (up to 80%), predominantly fructose and glucose, and water (approximately 17%), together with minor constituents such as organic acids, minerals, vitamins, enzymes, pigments, volatile oils, and aromatic substances. Carbohydrates are primarily responsible for determining key physicochemical properties such as viscosity, granulation, and hygroscopicity. Organic acids are present in the smallest quantities (approximately 0.5%) and include lactic, citric, butyric, propionic, formic, acetic, tartaric, succinic, oxalic, gluconic, and malic acids. In addition, honey mineral content ranges from 0.04% to 0.2%, consisting of macro- and microelements [2]. Honey has a low water activity and an acidic pH, and creates an inhospitable environment for microorganisms [3].

Its consistency may range from fluid to viscous, or from partly to entirely crystallised. Owing to its botanical origin, taste and aroma vary considerably, and color ranges from almost colorless to dark brown [4]. Honey is readily digestible, rapidly and almost completely metabolized, and represents a natural source of energy (approximately 1270–1320 kJ per 100 g), owing primarily to its high content of readily absorbable monosaccharides, glucose and fructose [5].

Honey quality is traditionally assessed based on a range of physicochemical parameters (Table 1), as defined by the applicable national regulation on honey and other bee products [6]. These parameters serve not only to assess overall quality but also as indicators of botanical and geographical origin, storage conditions, thermal treatment, and potential adulteration [7].

Table 1. Quality requirements for honey according to the current national regulation

Quality parameter	Honey type	Regulatory limit
Reducing sugars (glucose + fructose)	Blossom honey	≥ 60 g/100 g
	Honeydew honey and blends	≥ 45 g/100 g
Sucrose content	General requirement	≤ 5 g/100 g
	Honeydew, acacia, and lavender honey	≤ 10 g/100 g
Moisture content	All honey types	≤ 20 g/100 g
Electrical conductivity	Blossom honey (except those listed below) and blends Exceptions include linden, heather, and honeydew honey.	≤ 0.8 mS/cm
	Honeydew honey, chestnut honey, and their blends	> 0.8 mS/cm
Free acidity	All honey types	≤ 50 meq/kg
Hydroxymethylfurfural (HMF)	All honey types	≤ 40 mg/kg

Sensory analysis encompasses the evaluation of color, viscosity, crystallisation, odor, aroma, and taste, and is used to confirm botanical origin, verify the absence of sensory defects, and understand consumer preferences. Sensory evaluation can reveal defects such as fermentation, foreign odors (e.g., smoke), metallic taste, or inconsistency with the declared botanical origin, defects that standard physicochemical analyses cannot always detect [8].

Honey, as a high-value food product, is highly susceptible to adulteration through the addition of inexpensive commercial sugar syrups such as high-fructose corn syrup, glucose syrup, invert sugar syrup, cane sugar syrup, and rice or wheat syrups, or indirect feeding of bees with syrups during the production period, premature extraction of immature honey, mislabelling of geographical origin, or thermal treatment aimed at removing natural crystallisation. Such adulteration alters the chemical composition of honey, reduces its bioactive compounds, and consequently diminishes its nutritional quality, authenticity, and commercial value [9], [10]. Although advanced analytical techniques (spectroscopic, chromatographic, isotopic) provide high specificity and reliability in confirming adulteration, basic physicochemical parameters (moisture,

pH, electrical conductivity, HMF) remain a valuable and accessible tool for preliminary screening of honey authenticity [11].

The present study was motivated by the widespread occurrence of adulterated products marketed and labelled as honey. Considering the above, this study aimed to compare the physicochemical composition with the sensory properties of both honey and its adulterants to define reliable indicators for the detection of adulteration.

MATERIALS AND METHODS

A total of 25 samples were examined, divided into four groups: 10 honey samples within their declared shelf life, 7 samples older than three years, 3 commercially available samples suspected of adulteration, and 5 laboratory-prepared adulterants consisting of inverted sugar syrups with varying proportions of honey and tartaric acid (Table 2).

Table 2. Honey samples

Sample	Notes	Sample
N1	Declared honey, within shelf life	Acacia honey
N2		Meadow honey
N3		Meadow honey
N4		Oak honeydew
N5		Fructose honey
N6		Sage honey
N7		Heather honey
N8		Buckwheat honey
N9		Chestnut honey
N10		Oak honeydew
O1	Honey >3 years old	Acacia honey
O2		Meadow honey
O3		Meadow honey
O4		Honeydew
O5		Linden honey
O6		Honey with fruit
O7		Acacia honey, with honeycomb
SA1	No label; purchased at open market	suspected of adulteration
SA2		suspected of adulteration
SA3		suspected of adulteration
LA1	Lab-prepared adulterant	Inverted sucrose, 1 g tartaric acid
LA2		Inverted sucrose + 1 g tartaric acid + 7.5% acacia honey
LA3		Inverted sucrose + 1 g tartaric acid + 20% acacia honey
LA4		Inverted sucrose+1g tartaric acid+40% acacia honey; incubated 15 days at 35°C
LA5		Inverted sucrose + 2 g tartaric acid

Physicochemical analysis included determination of sugar content (total sugar content, TSC; reducing sugar content, RSC; and sucrose content, SC), ash content, moisture, total acidity (TA), hydroxymethylfurfural (HMF) concentration, and electrical conductivity (EC), conducted in

accordance with the applicable regulation on methods for the control of honey and other bee products [12]. Results are expressed as mean values ± standard deviation (SD) of three replicates.

Sensory evaluation was performed using descriptive testing methods by trained assessors. The evaluation was based on the color, consistency, odor, aroma, and taste of honey to distinguish genuine from adulterated honey.

Statistical analysis was performed using one-way ANOVA followed by Tukey's HSD post-hoc test, using IBM SPSS Statistics 22.0, with statistical significance set at $p < 0.05$.

RESULTS AND DISCUSSION

The results of the physicochemical analysis of the analyzed honey samples are presented in Table 3. Statistically significant differences were observed between samples ($p < 0.05$).

The total sugar content (TSC) ranged widely, from 58.5% (O4) to 77.9% (N6 and LA1), with the majority of genuine honey samples clustering above 65%. Reducing sugar content ranged from 22.5% to 74.2%. All commercial and suspicious market samples contained more than 60 g/100 g reducing sugars, complying with the regulatory requirements for blossom honey. In contrast, laboratory-prepared adulterated samples LA2 (22.5%) and LA3 (39.2%) were well below the minimum permitted value, clearly indicating the addition of sucrose-based sweeteners. Sucrose content showed the greatest variability, ranging from 0.1% (O5) to 49.7% (LA2).

Table 3. Physicochemical characteristics of the analyzed honey samples

	TSC (%)	RSC (%)	SC (%)	EC (mS/cm)	Ash (%)	moisture (%)	TA (mmol/kg)	HMF (mg/kg)
N1	74.4^{jk}±0.7	72.0^{l}±0.7	2.3^{cde}±0.2	0.14^{a}±0.03	0.10^{a}±0.01	15.8^{a}	11.1^{b}±0.3	6.9^{abc}±0.7
N2	70.6^{gh}±0.7	70.0^{j}±0.4	0.6^{ab}±0.1	0.34^{a}±0.05	0.20^{a}±0.07	21.0^{a}	48.5^{q}±05	11.2^{bcd}±0.4
N3	72.4^{i}±0.6	69.7^{j}±0.5	2.5^{cdef}±0.1	0.27^{a}±0.04	0.09^{a}±0.04	19.0^{a}	32.3^{l}±0.4	18.0^{d}±0.3
N4	65.8^{d}±0.5	63.4^{g}±0.4	2.2^{cde}±0.1	0.26^{a}±0.03	0.15^{a}±0.06	23.0^{a}	37.7^{n}±0.4	4.5^{abc}±0.3
N5	68.3^{ef}±0.5	60.7^{e}±0.3	7.3^{i}±0.2	O.04^{a}±0.00	0.01^{a}±0.00	19.6^{a}	3.7^{a}±0.1	247.2^{j}±3.6
N6	77.9^{m}±0.7	70.4^{jk}±0.9	7.1^{i}±0.4	0.49^{a}±0.16	0.34^{a}±0.16	18.4^{a}	40.6^{p}±0.2	2.6^{ab}±0.2
N7	69.8^{fg}±0.3	67.3^{i}±0.8	2.4^{cde}±0.1	0.53^{a}±0.13	0.38^{a}±0.13	17.4^{a}	17.0^{fg}±0.1	2.5^{ab}±0.2
N8	70.4^{g}±0.5	67.9^{i}±0.3	2.4^{cde}±0.1	0.40^{a}±0.14	0.28^{a}±0.14	18.2^{a}	56.1^{r}±0.2	56.0^{e}±0.5
N9	73.0^{ij}±0.4	70.1^{j}±0.5	2.8^{defg}±0.1	0.73^{a}±0.16	0.43^{a}±0.16	17.0^{a}	26.7^{k}±0.1	1.9^{a}±0.1
N10	63.1^{c}±0.5	61.3^{ef}±0.3	1.7^{bcd}±0.2	15.98^{b}±1.54	13.55^{b}±0.85	17.4^{b}	99.9^{s}±0.6	17.5^{d}±0.2
O1	67.6^{e}±1.1	67.1^{i}±0.8	0.5^{ab}±0.1	0.14^{a}±0.02	0.03^{a}±0.01	18.0^{a}	16.1^{ef}±0.7	455.7^{l}±8.0
O2	70.4^{g}±1.0	67.1^{i}±0.7	3.1^{efg}±0.3	0.22^{a}±0.04	0.06^{a}±0.01	17.2^{a}	35.7^{m}±1.0	1405.9^{o}±9.7
O3	69.5^{fg}±0.9	65.5^{h}±0.7	3.8^{fgh}±0.2	0.26^{a}±0.05	0.07^{a}±0.02	18.2^{a}	38.7^{no}±0.8	1478.3^{p}±6.4
O4	58.5^{a}±0.6	55.2^{d}±0.5	3.1^{efg}±0.1	0.74^{a}±0.13	0.57^{a}±0.18	16.4^{a}	39.2^{o}±0.6	174.9^{g}±4.5
O5	74.3^{jk}±0.5	74.2^{m}±0.4	0.1^{a}±0.0	0.49^{a}±0.10	0.35^{a}±0.15	18.8^{a}	14.8^{d}±0.3	0^{a}
O6	60.7^{b}±0.5	31.3^{b}±0.3	27.9^{k}±0.6	0.12^{a}±0.02	0.07^{a}±0.02	17.8^{a}	23.1^{i}±0.9	263.9^{k}±5.8
O7	73.3^{ij}±0.6	68.2^{i}±0.4	4.9^{b}±0.2	0.12^{a}±0.02	0.02^{a}±0.00	18.4^{a}	15.7^{de}±0.5	188.1^{h}±4.1
SA1	72.2^{i}±0.7	70.7^{jk}±0.5	1.5^{bc}±0.6	0.18^{a}±0.05	0.07^{a}±0.01	18.6^{a}	21.7^{h}±0.3	51.4^{e}±1.4
SA2	72.5^{i}±0.7	70.8^{jkl}±0.4	1.6^{bcd}±0.2	0.10^{a}±0.04	0.1^{a}±0.03	19.6^{a}	12.1^{bc}±0.1	13.4^{cd}±0.6
SA3	73.6^{ij}±0.5	69.8^{j}±0.4	3.8^{fgh}±0.2	0.14^{a}±0.04	0^{a}	17.2^{a}	27.2^{k}±0.5	1083.2^{n}±7.6
LA1	77.9^{m}±0.8	61.8^{ef}±0.6	15.4^{j}±0.3	0.11^{a}±0.03	0^{a}	17.8^{a}	12.1^{bc}±0.3	110.2^{f}±1.9
LA2	72.1^{hi}±0.9	22.5^{a}±0.5	49.7^{m}±0.3	0.07^{a}±0.01	0^{a}	18.4^{a}	12.4^{c}±0.2	0^{a}
LA3	75.8^{kl}±1.1	39.2^{c}±0.7	36.5^{l}±0.4	0.10^{a}±0.01	0^{a}	17.0^{a}	16.9^{fg}±0.2	4.5^{abc}±0.1
LA4	70.6^{gh}±0.7	62.3^{fg}±0.5	8.4^{i}±0.2	0.11^{a}±0.02	0^{a}	17.2^{a}	17.6^{g}±0.1	202.1^{i}±4.5
LA5	76.1^{l}±0.8	71.5^{kl}±0.4	4.6^{b}±0.4	0.19^{a}±0.03	0^{a}	19.2^{a}	25.1^{j}±0.5	523.1^{m}±5.8

$^{a-s}$ Mean values with different letters in the same column differ significantly ($p < 0.05$).

Most authentic commercial samples met the maximum permitted value of 5 g/100 g; however, elevated sucrose concentrations were observed in N5, N6, O6, and all laboratory-prepared adulterated samples, particularly LA2 (49.7%) and LA3 (36.5%). Such values are inconsistent with the composition of mature natural honey and strongly suggest adulteration with commercial sugars. Previous studies have reported that nectar-derived honey is typically characterized by a TSC value above 60%, while increased sucrose levels are considered indicative of premature harvesting or possible adulteration [13], [14].

Electrical conductivity in samples ranged from 0.04 to 0.74 mS/cm (samples N5 and O4, respectively), whereas sample N10 exhibited a markedly elevated value (15.98 mS/cm), which statistically distinguished it from all other samples. A similar pattern was observed for ash content, with samples N1–N9 containing 0.01–0.43% ash, whereas sample N10 exhibited a markedly higher value of 13.55%. Notably, ash was undetectable (0%) in most laboratory adulterants (LA2–LA5, SA3), consistent with the expected dilution of mineral content when sucrose/inverted syrup replaces the natural honey matrix. The electrical conductivity of honey results from the presence of mineral salts and organic acids and is directly related to botanical origin, allowing certain honey types to be distinguished on this basis. Similar results for electrical conductivity were reported by some authors [3]. The absence of ash content in all adulterated samples was consistent with the fact that added sugar syrups alter the mineral and elemental composition of honey [2].

Moisture values were relatively homogeneous across the dataset (15.8–23.0%), without a clear separation between genuine and adulterated groups. Most samples complied with the regulatory limit of 20%, whereas N2 (21.0%) and N4 (23.0%) exceeded the maximum permitted value, indicating an increased risk of fermentation and reduced storage stability. The significant increase in honey moisture content was possibly attributable to intensified metabolic reactions occurring at elevated storage temperatures [15]. Elevated moisture can adversely affect honey quality during storage, as it creates favorable conditions for microbial activity, including fermentation [13].

Free acidity ranged from 3.7 to 99.9 mmol/kg (N5 and N10, respectively). Most samples complied with the regulatory limit of 50 mmol/kg, samples N8 (56.1 mmol/kg) and N10 (99.9 mmol/kg) exceeded the permitted value, indicating possible fermentation or deterioration during storage. Higher acidity reflects a greater concentration of organic acids derived from specific nectar sources as well as enzymatic activity during honey maturation, and is influenced by botanical origin and regional environmental conditions [14].

The greatest differences were observed for HMF content, which ranged from non-detectable (samples O5 and LA2) to 1478.3 mg/kg (sample O3). While HMF concentrations in fresh commercial samples were generally below the regulatory limit of 40 mg/kg, aged samples (O1–O7) showed substantially higher values, reaching more than 1400 mg/kg. Similarly, laboratory-prepared adulterated samples and suspicious market samples showed markedly elevated HMF concentrations, especially LA5 (523.1 mg/kg) and SA3 (1083.2 mg/kg). These findings indicate that HMF content was markedly affected by prolonged storage, thermal processing, and sugar syrup adulteration. Freshly harvested honey contains negligible or very low HMF concentrations (≤15 mg/kg), whereas elevated HMF levels are associated with prolonged storage, excessive heating, or adulteration with invert sugar syrups [14-17]. Sugar composition, particularly sucrose and reducing sugar content, is among the most sensitive indicators of honey adulteration [2], [18], [19]. The addition of sugar syrups alters the carbohydrate profile and often increases HMF, while certain adulterants may also affect moisture, pH, and electrical conductivity [17], [19]. Consequently, the combined evaluation of HMF and sugar composition provides a more reliable basis for detecting adulteration than either parameter alone.

Most samples within their shelf life were satisfactory according to the RSC, SC, moisture, and EC requirements. N1, N7, and N9 were fully compliant across all six parameters and can be regarded as reference-quality honey. However, several regulatory breaches were identified: N2 and N4 exceeded the 20 g/100 g moisture limit. N8 exceeded both the acidity and HMF limits, while N10 greatly exceeded the acidity limit (99.9 meq/kg) and showed an EC value and ash content that indicated an atypical, non-blossom origin rather than a simple quality defect.

For honey samples older than three years (O1–O7), HMF was the parameter most frequently and most substantially exceeded., with O1–O3 exceeding the 40 mg/kg limit by more than tenfold (455.7–1478.3 mg/kg) as a direct consequence of prolonged storage, while all other quality parameters (RSC, SC, moisture, EC, acidity) remained within regulatory limits for these three samples. O5 was the only sample in this group fully compliant with all parameters, including non-detectable HMF, representing the best-preserved profile despite its age.

Among samples suspected of adulteration (SA1–SA3), SA2 was fully compliant with all regulated parameters. SA1 showed only a marginal HMF exceedance (51.4 vs. 40 mg/kg), while SA3 grossly exceeded the HMF limit (1083.2 mg/kg), providing strong chemical grounds for rejecting this sample despite other quality parameters all falling within permitted ranges.

Laboratory-prepared adulterants (LA1–LA5) best illustrate the limitations of relying on any single regulatory parameter. LA2 and LA3 had RSC well below the 45–60 g/100 g range and SC far above the 5–10 g/100 g range, yet their HMF values were negligible (0 and 4.5 mg/kg). Samples LA4 and LA5 showed RSC and SC values within or close to the permitted range, but both highly exceeded the HMF limit. LA1 was the only sample showing both sugar-related limits and HMF higher than allowed.

Sensory evaluation of samples within their shelf life classified seven of the ten samples as authentic honey, while three samples were not accepted. Sample N2 exhibited a pronounced sour taste, likely resulting from elevated moisture content that induced fermentation. Sample N3 was suspected of containing added table sugar (sucrose) and exhibited an inadequate, heterogeneous consistency. Sample N4 was rejected owing to an atypical odor and taste, with a white foam layer several millimetres thick observed on its surface, characteristic of fermentation.

Sensory evaluation revealed that samples O1–O6 were not accepted for consumption owing to pronounced changes in odor, taste, and consistency resulting from prolonged storage. In contrast, sample O7 was assessed as authentic honey and was fully accepted by the assessors. Notably, the presence of a piece of comb within the honey likely further influenced the perceived authenticity of the sample, even though physicochemical analysis revealed an elevated HMF content. This sample remained entirely homogeneous and in a liquid state after several years of storage, with no visible crystallisation, which was in agreement with the typical characteristics of acacia honey, including a higher fructose-to-glucose ratio, slower crystallisation, and lower acidity and HMF values [20].

Sensory analysis revealed that the physicochemical results were not always consistent with assessors' perception. For sample SA1, assessors were uncertain whether the sample constituted honey based on taste, odor, and aroma, whereas color and consistency were assessed by all evaluators as characteristic of honey. In contrast, sample SA2 was rated as the sensorially poorest sample, particularly with respect to taste and consistency, despite fully meeting the requirements prescribed by the regulation according to the physicochemical analysis. Sample SA3 was accepted as natural honey.

Sensory evaluation of the laboratory-prepared adulterants showed that sample LA1 had less acceptable color, odor, and aroma, while taste and consistency were rated as relatively acceptable. Samples LA2 and LA3 were satisfactory in terms of color, consistency, and odor, but their taste and aroma were rated as atypical. Sample LA4 was particularly noteworthy, as the assessors expressed no suspicion of adulteration: consistency, color, taste, odor, and aroma were all rated as characteristic of natural honey, despite physicochemical results indicating substantial deviations. Sample LA5 was not accepted by the assessors concerning taste, odor, and aroma. The addition of a small proportion of natural honey to laboratory-prepared adulterated samples may hinder the sensory detection of quality deviations, which was consistent with previous findings showing that low levels of adulteration are more difficult to identify, particularly in acacia honey [9]. This confirms that sensory evaluation alone is insufficient for the reliable detection of honey adulteration and should always be interpreted together with physicochemical indicators, as conventional analytical approaches generally provide only a preliminary assessment of honey authenticity [9], [21], [22]. A similar pattern was reported by Bodor et al. [9], who found that trained assessors were able to distinguish authentic and adulterated acacia honey samples based on

only four sensory attributes, whereas eight sensory attributes differed significantly in linden honey. These findings indicate the limited sensitivity of human sensory perception, particularly at low levels of syrup adulteration. More broadly, honey authentication remains a challenging analytical task because no single method can reliably detect all forms of adulteration [21], [23], [24].

Therefore, recent studies recommend combining routine physicochemical analyses with advanced instrumental techniques and chemometric approaches to improve the reliability of honey authentication [2], [14], [22]. Physicochemical parameters remain essential because they are standardized indicators of honey maturity, stability, and quality; however, they are also influenced by thermal processing, storage conditions, and the addition of sugar syrups [2].

Although sensory analysis is valuable for identifying some adulterated samples, it is more commonly used to differentiate botanical origin and assess overall sensory quality than to provide definitive evidence of adulteration [9], [20]. Consequently, discrepancies between sensory and physicochemical evaluations, as observed in the present study, should be regarded as an expected outcome rather than a contradiction, reflecting the complementary nature and inherent limitations of these two approaches [18], [20].

Electronic nose and electronic tongue technologies have demonstrated high classification accuracy, with misclassifications occurring primarily in samples containing approximately 10% added sugar syrup [9]. Rapid spectroscopic techniques, including portable FT-IR spectroscopy, UV-Vis spectroscopy combined with chemometric analysis, and ion mobility spectrometry (IMS), are increasingly being proposed as practical tools for market surveillance because they enable the rapid discrimination of authentic and adulterated honey samples while requiring less complex analytical procedures [10], [25], [26].

CONCLUSION

The findings of this study demonstrate that the combined application of physicochemical and sensory analyses provides a reliable approach for assessing honey quality and authenticity. Physicochemical analysis revealed significant differences between honey within shelf life, aged honey, suspected of adulteration, and laboratory-prepared adulterated samples. HMF, sucrose, reducing sugar, and moisture content emerged as the most sensitive indicators of deviation. Elevated HMF values were observed in both long-term stored samples and certain laboratory-prepared adulterants, indicating that HMF reflects thermal treatment and honey ageing but, on its own, is not a reliable indicator of adulteration. The laboratory-prepared adulterants confirmed that sugar syrup addition significantly modified the chemical composition of honey, most notably through elevated sucrose levels and reduced reducing sugar content.

Sensory analysis enabled the recognition of most samples with pronounced deviations, but was not sufficient to reliably distinguish all adulterated samples from authentic ones. Certain adulterated samples were sensorially assessed as natural honey, while some samples that met the prescribed physicochemical criteria received poor sensory scores. These results indicate that visual appearance, the presence of honeycomb, or particular consistency characteristics may influence the assessors' subjective evaluations. At the same time, samples with pronounced physicochemical deviations generally exhibited sensory changes that were readily detectable.

It can therefore be concluded that neither physicochemical nor sensory analysis alone is sufficient for the reliable assessment of honey authenticity. Their combined application can substantially increase the reliability of identifying non-authentic and substandard samples, which is of particular importance for consumer protection and for combating honey adulteration.

DECLARATIONS OF INTEREST STATEMENT

The authors affirm that there are no conflicts of interest to declare in relation to the research presented in this paper.

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