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Data Analyses and Chemometric Modeling for Rapid Quality Assessment of Enriched Honey

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Abstract

The quality and authenticity of honey are of crucial importance for food safety and consumer confidence. Given the increasing interest in enriched honey and potential fraud, rapid and non-destructive analytical methods for quality assessment, such as Near-Infrared Spectroscopy (NIRS), are needed. Therefore, the aim of this work was to investigate the applicability of NIR spectroscopy coupled with chemometric methods to assess the quality change in honey from three different countries, after addition of five different aromatic plants (lavender, rosemary, oregano, sage, and white pine oil) in three different concentrations (0.5%, 0.8% and 1%). Measurements of basic physicochemical properties, color, antioxidant activity, and NIR spectra were performed for all samples (pure honey and honey with added aromatic plants). Chemometric models, such as Principal Component Analysis (PCA) and Partial Least Squares (PLS) regression, were applied to analyze spectral data, correlate spectra with physicochemical properties, color and antioxidant activity measurements, and develop classification and prediction models. Spectral changes in the NIR region, as expected, showed the ability to distinguish samples depending on the type and concentration of added aromatic plants. Chemometric models enabled efficient discrimination between pure and enriched honey samples, as well as assessment of the influence of different additives on antioxidant activity and color. The results highlight the potential of NIRS as a rapid, non-destructive and environmentally friendly method for quality monitoring and detection of specific additives in honey, offering technical support for quality control and food safety regulation.

Keywords: honey; aromatic plants; NIR spectroscopy; chemometrics; modeling

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1. Introduction

Honey, produced by honey bees (*Apis mellifera* L.), from floral nectar, is a widely recognized food and medicinal product. The physicochemical properties of honey serve as important indicators of its authenticity and freshness [1]. It is a sweet product originating from both floral nectar and the exudates of insects that extract sap from plant tissues, or from secretions of living plant parts. These substances are combined with the bees' secretions, stored in honeycombs, evaporated, and left to mature. The European Union categorizes honey into various types, including nectar and honeydew honey, as well as filtered, pressed, extracted, drained, comb, and chunk or cut comb honey [2,3].

Natural bee honey is a complex substance containing a wide range of compounds across multiple chemical categories, such as glucose, fructose, sucrose, water, organic acids, minerals, and amino acids. It also contains polyphenolic compounds, pigments, vitamins, essential oils, and other bioactive substances. The significance of honey has been well-documented in the scientific literature, with substantial evidence supporting its antioxidant, antibacterial, cough-preventive, fertility-enhancing, and wound-healing properties [4,5]. Over the decades, natural bee honey has been extensively studied; however, its nutritional diversity, prophylactic benefits, and biological activities continue to intrigue scientists. Consequently, methods for assessing honey's quality are constantly being refined and improved to reduce analysis time, eliminate costly and hazardous reagents, minimize labor, and enhance precision [6,7]. Given honey's high economic value and its relative scarcity, it is particularly vulnerable to adulteration, particularly in regions with inadequate regulatory oversight, such as Kosovo. With the increasing demand for trustworthy, high-quality honey, it is crucial to understand the physicochemical characteristics of this valuable product in order to ensure its authenticity and quality [1,8].

The quality and composition of honey are influenced by various ecological factors, including its geographical and floral origin, the season, environmental conditions, and beekeepers' practices [9]. Although it is challenging to obtain honey from a single plant species, referred to as mono-floral honey, beekeepers identify the primary nectar sources in their regions and strategically plan their harvests to keep the highest-quality varieties separate. As a result, the market offers various types of honey, such as chestnut honey, acacia honey, mountain honey, and meadow honey. Economically, beekeeping holds considerable value. In addition to honey, it provides protein-rich drone broods and pollen, as well as pollination services that enhance crop yields. A study by Sillman et al. [10] tested the hypothesis that beekeeping could yield net-positive impacts if pollination services and protein-rich by-products are effectively utilized. Although honey is considered as food and medicine, honey preparations enriched with medicinal and aromatic herbs are very often prepared in traditional medicine. The reason for this is their exceptional functional properties, nutritional richness, and high antioxidant [11]. Enrichment of honey is possible in two ways: (i) adding herbs [12] or (ii) directly feeding bees syrups that are primarily sucrose enriched with fruit juices or plant extracts [13]. Consumer demand for natural alternatives is growing, and therefore it is absolutely necessary to study the synergy of adding herbs in honey [12–14], while the preference of the consumer would be a form as natural possible, such as honey enriched with coumarin from *Melilotus* flowers [14]. However, to confirm or refute the nutritional and/or functional indicators of the samples, it is necessary to carry out analyses that can be expensive and less environmentally acceptable as near-infrared spectroscopy cupelled with chemometrics [15,16].

In food analysis, near-infrared (NIR) spectroscopy has proven to be highly acceptable because it is an analytical technique that offers significant advantages over traditional food analysis methods [17,18]. In the range of 780–2500 nm, NIR radiation interacts with molecular vibrations, especially those involving hydrogen bonds (O-H, C-H, and N-H). These bonds are fundamental components of the main ingredients found in food, including water, fats/oils, carbohydrates, and proteins [19]. In this way, by analyzing absorption spectra at certain wavelengths, precise information about the composition of the observed sample can be obtained. The key advantages of NIR spectroscopy are its non-destructive nature [17], speed [16,18–20], the possibility of on-site analysis using portable devices [16,17,21], and its cost-effectiveness and cost-effectiveness compared to standard chemical methods [17–21]. Non-destructive means that the sample is minimally or not at all prepared for analysis. Therefore, due to the aforementioned advantages NIR spectroscopy was used in this work.

To our knowledge, this is the first study to analyze honeys from three countries of southern Europe (Kosovo, Albania, and North Macedonia) to which five aromatic plants have been added. The aim of this work is to examine the change in color, basic physicochemical parameters, and the antioxidant activity of honey when the previously mentioned additives (aromatic plants) are added to it. The changes were also monitored by NIR spectroscopy, and it was crucial to use chemometric tools that would provide insight into similarities/differences and potential changes.

2. Materials and Methods

2.1. Materials

Honey samples from three different producers in Kosovo were jarred and collected in the period between October and December 2023. Five aromatic plants (Rosemary (*Rosmarinus officinalis*), Lavender (*Lavandula angustifolia*), Oregano (*Origanum vulgare*), Sage (*Salvia officinalis*), and White pine (*Pinus sylvestris*) were added to honey samples at three different concentrations 0.5%, 0.8%, and 1%. Additionally, the same concentrations were added to three honey samples from North Macedonia and to three honey samples from Albania. The first four aromatic plants were added in the form of powder (*Harissa spice store*, online shop), while white pine (*Terra Organica*, online shop) was in the form of an oil. Plants are added in the form of powder or oil in order to simulate as natural a supplement as possible, which would be of interest to the consumer [12–14]. Samples were homogenized by stirring at a temperature of 35 °C. Prepared honey samples were stored in glass jars in dark at room temperature before analysis. The total number of analyzed honey samples was 144 (Table 1).

Table 1. Coding of honey samples with corresponding abbreviations.

Country	Honey Samples	Added Aromatic Plant	Concentration (%)	Sample Numbers *
Kosovo	3 (H1–H3)	Rosemary (R) Lavender (L) Oregano (O) Sage (S) White Pine oil (W)	0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1	1–48
North Macedonia	3 (H4–H6)	Rosemary (R) Lavender (L) Oregano (O) Sage (S) White Pine oil (W)	0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1	49–96
Albania	3 (H7–H9)	Rosemary (R) Lavender (L) Oregano (O) Sage (S) White Pine oil (W)	0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1 0; 0.5; 0.8; 1	97–144

* per each Country: 3 controls (pure honey samples) + 45 samples with added aromatic plants.

2.2. Physicochemical Analysis

The moisture content of honey samples was determined using ABBE refractometer (220 V BOE 32,400 Model RMT). The sample's refractive index was measured at 20 °C. A refractive index-based table was utilized to ascertain the water content (%) in milliliters per millimeter, according AOAC 969.38–1969 [22].

Brix levels of the samples were measured using ABBE refractometer according to BRIX Method at 20 ± 2 °C. The International Honey Harmonized Methodologies Commis-

sion was used to analyze the physicochemical parameters such as electrical conductivity (EC), free acidity (FA), moisture, ash, and °Brix [23]. Digital pH meter (HI 8314, Hanna Instruments, Woonsocket, RI, USA) was used to determine pH.

Conductivity was measured using standard AOAC methods [24]. Expected conductivity should not be over 0.8 µS/cm, unless it is honey made from honeydew [25].

Free acidity was estimated using titration. In this process, 0.1 N sodium hydroxide was used to titrate the honey sample (10 g diluted with 75 mL of distilled water) while phenolphthalein was used as an indicator.

Ash was determined by burning the sample at a temperature of 600 °C in a porcelain cup previously dried and cooled to room temperature (desiccator). Honey sample was weighed on an analytical scale (m_1) in an empty cup (m_0). Then 10 mL of pre-distilled heated almost to the boiling point water was added to the sample cup and placed in a furnace at a low temperature of 100–300 °C, which gradually raised to 600 °C. At this temperature, the sample remains until it has turned into a gray to white material. The hot sample was placed in a desiccator and weighed after cooling (m_2). The calculation follows in Equation (1), and its amount is expressed in %:

$$Ash(\%) = \frac{m_1 - m_2}{m_1 - m_0} \cdot 100 \quad (1)$$

where

m_0 = weight of empty cup (g)
m_1 = weight of sample with the cup (g)
m_2 = weight of the cup after burning and cooling (g)

2.3. Color Measurement of the Honey Samples

To measure the color of honey samples, PCE-CSM3 colorimeter (PCE Instruments, Berlin, Germany) was used. For the determination of color change (ΔE) between pure honey samples and samples containing different concentrations of aromatic plant extracts, Hunter's parameters (L^*, a^*, b^*) were measured, with pure honeys as reference samples. The total color change (ΔE) was calculated according to following equation:

$$\Delta E = \sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b - b_0)^2} \quad (2)$$

where L_0, a_0 and b_0 values were measured for pure honey samples and L^*, a^* and b^* values were measured for honey samples containing different concentrations of aromatic plants. Three parallel measurements were performed for each sample and the results are presented as mean value ± standard deviation (SD).

2.4. Antioxidant Activity Measurement

The antioxidant activity of honey samples was measured by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) method according to Bertoncelj et al. [26], with slight modifications. A volume of 200 µL of the 30% aqueous honey solutions was mixed with 2 mL of DPPH (0.06 M) dissolved in methanol. The mixture was shaken vigorously on a Vortex mixer for 1 min. Prepared samples were stored in the dark for 1 h after which the absorbance was measured at 515 nm against the blank, using the UV-vis spectrophotometer (Biochrom, Cambridge, UK). The blank was the honey sugar analog, which was prepared according to Beratta et al. [27] as an aqueous sugar solution whose composition is as follows: 20% water,

10% maltose, 30% glucose, and 40% fructose. The percentage of DPPH radical inhibition (radical scavenging activity, I (%)) was calculated using the following formula [27]:

$$I\ (\%) = \frac{(A_s - A_B)}{A_C} \cdot 100 \quad (3)$$

where I (%) represents the percentage of DPPH radical inhibition, A_B is the absorbance of the control (blank) sample at t = 0 while A_S and A_C are the absorbance of the sample (S) and control (C) after the reaction time (t = 1 h). DPPH measurements were performed in duplicates and the results were expressed as the average value ± standard deviation (SD).

2.5. Near-Infrared Spectroscopy

Near-infrared (NIR) spectra of honey samples (a total of 144 samples) were recorded using the bench top NIR spectrophotometer; NIR-128-1.7-USB/6.25/50 µm (Control Development, South Bend, IN, USA), with the installed SPEC32 software version 1.6 (Control Development, South Bend, IN, USA) and a halogen light source (HL-2000), operating within the wavelength range of 904 nm to 1699 nm. Three NIR spectra for every honey sample were recorded across the entire spectral range and the average spectrum was used for further analyses [28–30].

2.6. Chemometrics

In order to achieve valid calibration and validation, preprocessing of NIR spectra is necessary. The actual implementation of processing and modeling is shown in the flowchart (Figure 1), showing steps followed to construct the chemometric models.

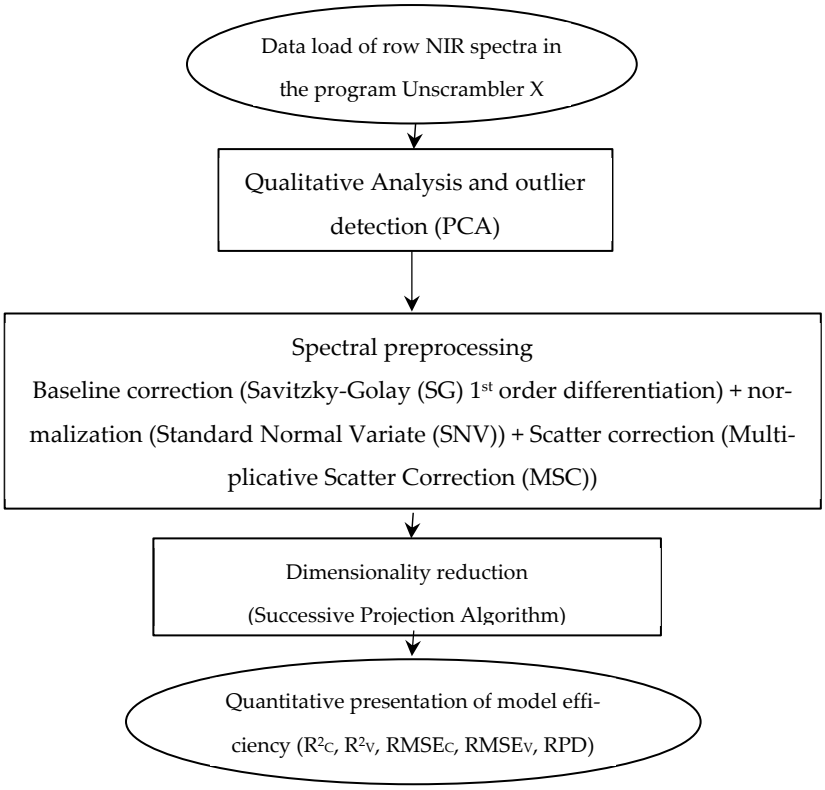


Figure 1. Flowchart presenting implementation of chemometric models for predicting color parameters and physicochemical parameters from NIR spectra of enriched honey enriched.

Principal component analysis allows for qualitative visualization of patterns (Biplot) in four quadrants of the coordinate system (based on similarity or dissimilarity in the observed

data matrix). PCA also allows for the identification of outliers due to measurement errors and their removal [31].

As can be seen in Figure 1, there is noise and scatter in the spectral data that must be corrected, and (i) baseline correction (first-order Savitzky–Golay differentiation), (ii) Multiplicative Scatter Correction (MSC), and (iii) normalization (Standard Normal Variete, SNV) were applied. Scatter correction is required to compensate for any variations in measurements due to differences in particle sizes (as is the case with added aromatic plants), while MSC and SNV are required to reduce the effect of non-uniform light scattering (due to particle size, refractive index, and light distance) [32,33].

Multivariate analysis was conducted by using standard chemometric tools as Principal Component Analysis (PCA) and Partial Least Square (PLS) regression. The first tool enables qualitative observation of the sample similarities/differences while the PLS regression was used as a quantitative chemometric tool [29,30,34]. To perform calibration, validation, and model verification, the data matrix was divided into 94 samples for calibration (~65%), 36 for validation (25%), and 10% (14 samples) for model checking. The samples were randomly assigned to clusters. In the PLS regression models were NIR spectra the input variables while the dependent variables were color, physicochemical properties, concentration of aromatic herbs and the antioxidant activity. To assess the adequacy of the PLS regression models, the following parameters were used: coefficient of determination (R^2), root mean square error of validation (RMSEP), and the ratio of standard error of performance to standard deviation (RPD) [35]. XLStat (Addinsoft, New York, NY, USA) was used for the data analysis, and the Unscrambler X 10.5.1 (CAMO, Oslo, Norway) for the chemometric modeling.

3. Results

The following results present a comprehensive physicochemical and colorimetric analysis of nine honey samples (H1–H9) with the addition of five aromatic plants in three different concentrations, originating from Kosovo, North Macedonia, and Albania. These samples were further evaluated for antioxidant activity using the DPPH method, both in pure form and after the addition of various aromatic plant extracts. The data allow for comparison among the samples based on origin and treatment, revealing important differences in composition and quality.

3.1. Physicochemical Properties, Color, and Antioxidant Activity of Honey Samples

The results for the physicochemical properties of honey samples (H1–H9) are shown in Table 2, while the average values of the rest of the 135 samples (with the originated honey) are presented in the Appendix in Tables A1–A8.

The pH of honey is an important indicator of its acidity, which affects shelf life and microbial stability [23,36]. Kosovo's honey samples ranged from 3.85 to 4.18. North Macedonian samples showed slightly higher values, especially H4 with 4.72, indicating a more neutral character. Albanian samples had a pH range of 3.7 to 4.1, with H9 being the most acidic. Overall, the samples exhibited typical honey acidity, beneficial for preventing microbial growth [37].

Brix values, representing the sugar concentration in honey, are critical for assessing its maturity and quality. All samples showed high Brix values (82.9–84.5%), confirming high sugar content consistent with mature, unadulterated honey, and those values are slightly higher than the reference concentration levels for commercial honeys [38]. Kosovo's H2 and H3 had the highest Brix values (84.4% and 84.5%), suggesting a higher sugar concentration compared to other regions, although the adulterated honey samples with corn syrup show also higher Brix values [39].

Table 2. Average values of physicochemical parameters of observed honey samples, with corresponding standard deviations.

Country	Honey	pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)
Kosovo	H1	4.18 ± 0.02^{ab}	83.2 ± 0.1^{a}	0.51 ± 0.03^{b}	25 ± 0.1^{b}	14.8 ± 0.1^{a}	0.28 ± 0.04^{b}
	H2	3.89 ± 0.01^{a}	84.5 ± 0.8^{b}	0.20 ± 0.03^{a}	8 ± 0.1^{a}	13.4 ± 0.8^{a}	0.01 ± 0.01^{a}
	H3	3.85 ± 0.01^{a}	84.4 ± 0.3^{b}	0.44 ± 0.01^{b}	31 ± 0.1^{b}	13.4 ± 0.3^{a}	0.27 ± 0.03^{b}
North Macedonia	H4	4.72 ± 0.01^{b}	82.9 ± 0.1^{a}	0.25 ± 0.01^{a}	8 ± 0.1^{a}	14.2 ± 0.1^{b}	0.10 ± 0.01^{ab}
	H5	4.1 ± 0.01^{ab}	84.2 ± 0.1^{ab}	0.18 ± 0.1^{a}	7 ± 0.1^{a}	14.0 ± 0.1^{a}	0.03 ± 0.01^{a}
	H6	4.18 ± 0.01^{ab}	84.2 ± 0.3^{ab}	0.20 ± 0.01^{a}	5 ± 0.1^{a}	14.1 ± 0.3^{a}	0.02 ± 0.01^{a}
Albania	H7	3.77 ± 0.01^{a}	83.5 ± 0.1^{a}	0.16 ± 0.01^{a}	12 ± 0.1^{a}	14.6 ± 0.1^{a}	0.02 ± 0.00^{a}
	H8	4.1 ± 0.08^{ab}	83.5 ± 0.3^{a}	0.21 ± 0.02^{a}	6 ± 0.1^{a}	14.6 ± 0.3^{a}	0.02 ± 0.01^{a}
	H9	3.7 ± 0.07^{a}	84.0 ± 0.1^{ab}	0.16 ± 0.01^{a}	11 ± 0.1^{a}	14.6 ± 0.1^{a}	0.19 ± 0.01^{b}

Different small letters, in the same column, indicate statistically significant differences ($p < 0.05$).

Conductivity reflects the presence of minerals and other conductive substances [36,39]. H1 from Kosovo had the highest conductivity (0.51 mS/cm), indicating richer mineral content. In contrast, Albanian honeys had the lowest values (0.16–0.21 mS/cm), pointing to possible floral origin differences or lower mineral content.

Free acidity as following quality marker showed for Kosovo's H3 the highest acidity (31 meq/kg), which could suggest fermentation or floral source variability. North Macedonia's honeys were less acidic (as low as 5 meq/kg), and Albanian samples showed moderate levels (6–12 meq/kg). All measurements are in the expected range of <50 milli-equivalents acid/1000 g [25,36,40].

Moisture (%) or the water content in honey affects its viscosity and shelf life. The samples displayed a moisture range between 13.4% and 18.2%, all within acceptable limits. H4 from North Macedonia had the highest moisture content (18.2%), which could risk fermentation if not properly stored. Lower moisture in Kosovo's H2 and H3 (13.4%) points to better preservation characteristics. Quality deterioration include high moisture content because it decreases the honey stability [41].

The ash content is linked to mineral content and botanical origin. Kosovo's H1 and H3 had relatively high ash contents (0.28% and 0.27%, respectively), while North Macedonian and Albanian samples were lower, especially H2 (0.01%), H6 (0.02%), and H8 (0.02%), indicating differing mineral profiles across regions [38].

Color in honey is a key quality and marketing attribute, influenced by botanical source and processing. It was quantified using L^* (lightness), a^* (red-green axis), b^* (yellow-blue axis), Chroma (C), and Hue angle (h) and presented in Table 3 for the control samples (H1–H9).

Table 3. Average values of measured color parameters for observed honey samples, with corresponding standard deviations.

Country	Honey	L^*	a^*	b^*	C	h
Kosovo	H1	37.43 ± 0.13^{b}	1.03 ± 0.02^{a}	2.03 ± 0.03^{b}	$2.28 \pm 0.04^{a,b}$	$63.21 \pm 0.09^{b,c}$
	H2	$35.35 \pm 0.02^{a,b}$	1.43 ± 0.01^{b}	0.78 ± 0.03^{a}	1.63 ± 0.01^{a}	28.65 ± 0.81^{a}
	H3	$35.59 \pm 0.02^{a,b}$	1.31 ± 0.01^{ab}	1.08 ± 0.01^{a}	1.69 ± 0.01^{a}	$39.50 \pm 0.29^{a,b}$
North Macedonia	H4	37.54 ± 0.01^{b}	1.08 ± 0.01^{a}	3.19 ± 0.01^{c}	3.36 ± 0.01^{c}	71.43 ± 0.06^{c}
	H5	$35.24 \pm 0.01^{a,b}$	1.38 ± 0.01^{b}	0.79 ± 0.01^{a}	1.59 ± 0.01^{a}	29.78 ± 0.04^{a}
	H6	$35.13 \pm 0.01^{a,b}$	1.39 ± 0.01^{b}	0.77 ± 0.01^{a}	1.58 ± 0.01^{a}	28.83 ± 0.26^{a}
Albania	H7	$35.89 \pm 0.05^{a,b}$	1.51 ± 0.01^{c}	$1.92 \pm 0.01^{a,b}$	$2.44 \pm 0.01^{a,b}$	51.86 ± 0.09^{b}
	H8	$36.08 \pm 0.03^{a,b}$	1.55 ± 0.02^{c}	2.16 ± 0.02^{b}	2.66 ± 0.01^{c}	54.28 ± 0.30^{b}
	H9	34.95 ± 0.04^{a}	1.24 ± 0.07^{a}	1.16 ± 0.01^{a}	1.73 ± 0.01^{a}	41.75 ± 0.04^{b}

Different small letters, in the same column, indicate statistically significant differences ($p < 0.05$).

Most samples had L^* values of around 35–37, indicating medium color intensity. The lightest was H4 from North Macedonia (L^* = 37.54), while H9 from Albania was the darkest (L^* = 34.95). The a^* values (red-green) ranged from 1.03 (H1) to 1.55 (H8), showing slight reddish tones. b^* values (yellow-blue) varied more, with H4 showing the strongest yellow tone (3.19), suggesting a bright golden hue. This aligns with the typical color variation in honeys of different floral sources [27]. Also, data were collected of the Chroma (C, color intensity) and Hue Angle (h, color type). Chroma was highest in H4 (3.36), confirming vivid color saturation while the hue angle ranged from 28.65° (H2) to 71.43° (H4), showing a progression from reddish to more yellowish hues. Samples from North Macedonia generally showed brighter and more saturated colors, indicating potential botanical and geographical influences.

To present the grouping of samples with added aromatic plants around their control honey, the 3-D chart of all samples is presented (Figure 2A,B) as well as the non-visibility in color change by adding aromatic plants in the honeys (Figure 2C).

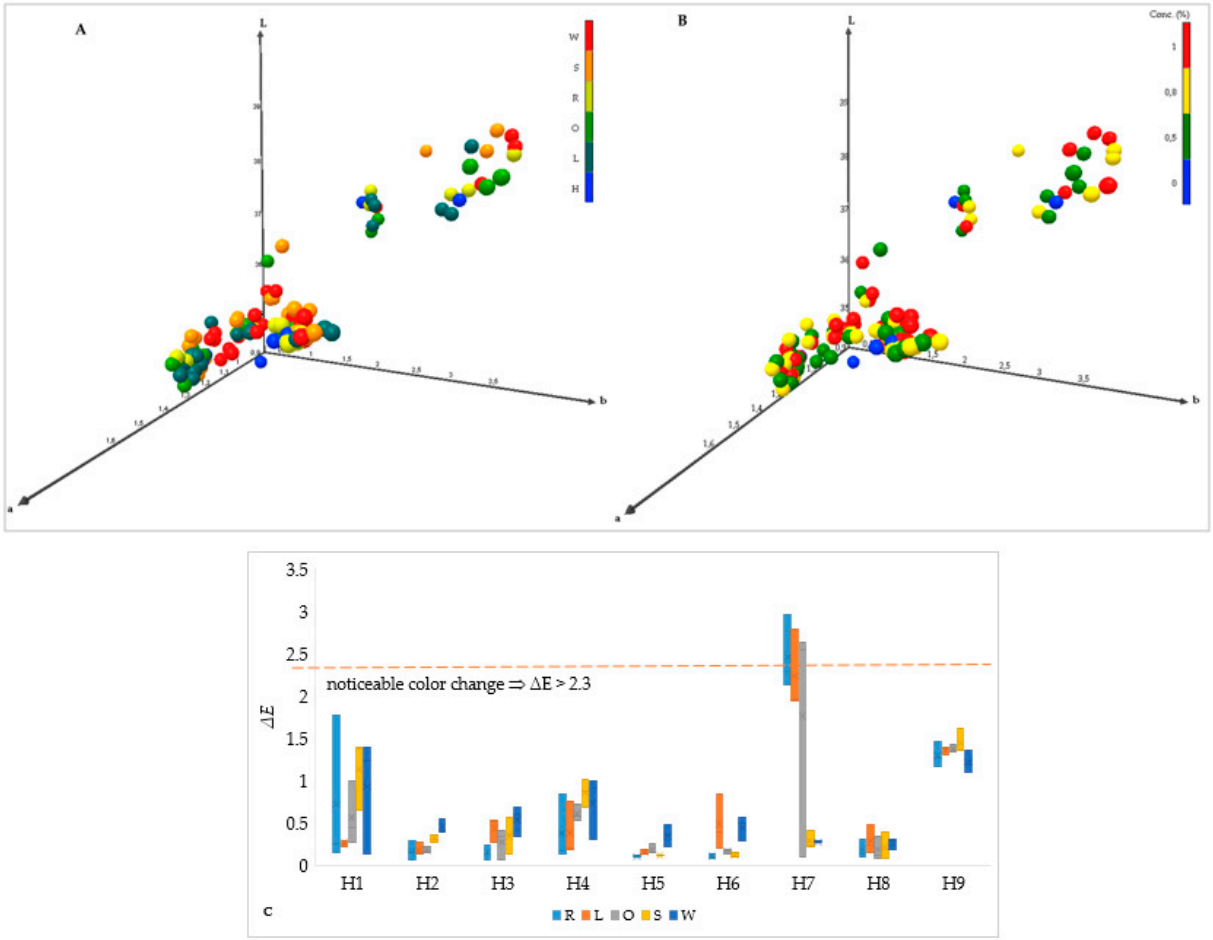


Figure 2. Three-dimensional representation of the results of measured honeys: (**A**) added aromatic plant extracts (different colors of the samples present different added aromatic plant: rosemary (R), lavender (L), oregano (O), sage (S), and white pine oil (W)) and (**B**) concentration of added plant extracts (different colors present different concentrations of added aromatic plants: 0-pure honey; 0.5, 0.8, and 1 are percentages of added aromatic plants). Color change in all honey samples is presented with ΔE (**C**).

Figure 1 illustrates how the addition of aromatic plants (rosemary, lavender, oregano, sage, and white pine oil) and their concentrations (0%, 0.5%, 0.8%, and 1%) altered honey properties. Figure 2C shows the ΔE values, representing the color difference, which quantifies perceptible changes. Even at low concentrations, the addition of these extracts

visibly changed the color profile of the honeys, confirming their influence on visual appeal and possibly antioxidant capacity; however, only one sample can see this with the naked eye (H7, where only added Sage and White pine oil have not significantly changed the color from the original honey sample).

The DPPH assay results (Figure 3) evaluate the antioxidant potential of the honey samples, both in pure form (A) and with plant extracts (B) added in the concentration 0.5%, 0.8%, and 1%, regardless which aromatic plant extract was added. Without additives, honey samples showed moderate inhibition effects, with variations reflecting their antioxidant potential related to added aromatic plants [11]. The antioxidative activity increases proportionally with the increase in the added concentration of the aromatic plant. This trend demonstrates the effectiveness of rosemary, lavender, oregano, sage, and white pine oil in enhancing honey's bioactivity. The increased DPPH inhibition at 1% concentration suggests potential for formulating functional honey products with health-promoting benefits [42].



Figure 3. DPPH radical inhibition for honeys (H1–H9) without added aromatic plants (**A**) and with added aromatic plants in concentrations of 0.5, 0.8 and 1% (**B**).

3.2. Physicochemical Color Parameters and Antioxidant Activity of Enriched Honey Samples

Data presented in Tables A1–A8 provide the physicochemical properties and antioxidant inhibition of honey samples enriched with various aromatic plants, as well as the color parameters. The tables present row honeys (H1–H9), with and without additives like rosemary, lavender, oregano, sage, and wild pine oil, each tested at three concentrations (0.5%, 0.8%, and 1%).

The pH values ranged from 3.63 (H6 + added 1% lavender) to 5.4 (H8 + 1% rosemary and 0.7% of sage). The °Brix values tends to vary with both plant type and concentration. Oregano shows a slight concentration-dependent increase in °Brix, potentially due to evaporation or sugar content interactions, and the highest value is detected in H4 with 0.8% oregano (85.6%) while the lowest value is in H6 with 1% lavender (80.8%).

The conductivity values ranged from 0.14 mS/cm (H9 + 1% lavender) to 0.51 mS/cm in H1 control, and are highest in unmodified honeys and decrease with plant additions, especially lavender and sage. Rosemary significantly increases acidity, especially at higher concentrations (highest in H3 with 0.8% rosemary, 38 meq/kg, while wild pine oil drastically lowers acidity across samples (lowest value: H8 with 1% wild pine oil: 3 meq/kg). Moisture increases notably with added rosemary (H3 with 0.8 and 1% rosemary: 18.6%) and lavender ($\geq$16% for the majority of samples) at higher concentrations—likely due to hygroscopic behavior or water retention properties. Rosemary and lavender at 0.8–1% concentrations consistently led to increased ash content and slightly reduced moisture. In honey H1, the ash content increases notably with the addition of lavender from 0.24% to 0.31% as concentration rises from 0.5% to 1%. This coincides with stable acidity and reduced moisture, both promoting better preservation and possibly greater antioxidant retention [36].

Antioxidant inhibition, often associated with the polyphenolic content and radical scavenging ability of honey [31,32], and in general, the addition of aromatic plants improved the antioxidant capacity of honey in several samples. While some samples such as H5 at 1% oregano show a high inhibition (36.23%), others, such as H2 at 0.8%, show significantly low values (1.96%), and the concentration of added plant displays inconsistent behavior. These discrepancies may be attributed to interactions between honey matrix components and oregano-derived compounds, which could have antagonistic effects under certain conditions [32]. Oregano consistently impacted the antioxidant potential in a dual fashion. While at low concentrations (0.5%), it led to very low antioxidant inhibition values (e.g., H1 shows 10.45%), this was even lower at 0.8% (4.93%), and only slightly recovered at 1% (10.06%). This may suggest a non-linear interaction between oregano constituents and honey's native antioxidants. Sage and wild pine oil displayed significant antioxidant effects at higher concentrations. For instance, in H4, wild pine oil at 0.5% yielded the highest inhibition (40.13%), while 1% oregano also resulted in high inhibition (35.37%), implying that the efficacy of plant additives is highly sample-dependent. Conversely, the inhibition was remarkably low or even negative in some cases, such as lavender at 0.5% in H3 (−3.68%) and rosemary at 1% (−0.76%), highlighting potential degradation or antagonistic effects of specific compound interactions.

These results emphasize that both the type and concentration of the additive profoundly affect antioxidant behavior.

Color parameters also offer insights into antioxidant properties. Samples with higher chroma ('C') and specific hue angles ('h') often correlate with enhanced bioactivity. For example, in H4 and H7, increased concentrations of sage and oregano led to higher chroma values and moderate hue angles.

3.3. Near-Infrared Spectra of Honey Samples

From the previously presented results, it is clear how complex the samples are and how the samples overlap, potentially grouping based on their physicochemical composition, color and antioxidant inhibition that is similar or different (in the observed data set). Since the excitation of molecules in the near-infrared region can be monitored by NIR spectroscopy [17], these measurements were also performed and presented in Figure 4.

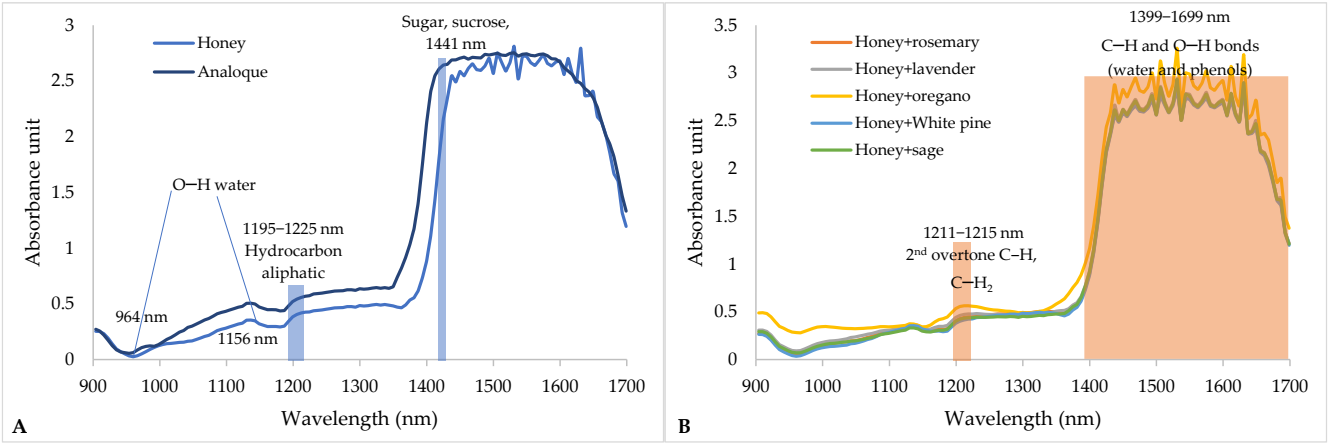


Figure 4. Row NIR spectra (absorbance) for pure honey and honey analog (**A**) and enriched honeys (**B**). Highlighted are specific wavelength for water and sugar [43] (blue) and wavelength related with phenolics [33,44] and physicochemical indicators form added plants.

NIR spectra of pure honey and analogs show a specific shape, but also noise that indicates the necessity of preprocessing the spectra before additional processing. Williams et al. [43] and Beć et al. [33] list NIR spectral wavelengths that are associated with sugars, water, total phenols and specific changes in O−H and C−H bonds. In the work of Gajdoš Kljusurić et al. [44], the wavelength range of 1399–1699 nm was applied in the analysis of the phenolic profile of berry extracts. From all of the above, it is clear that it is necessary to apply chemometric tools that would enable a better understanding of the changes in the observed samples.

3.4. Chemometric Modeling

In order to extract meaningful information from complex chemical data, mathematical, statistical and computational methods, i.e., chemometrics, are applied. Since Botanical and Geographical Origins can also be determined for honey [45], we wanted to check this possibility on our samples. Since our goal is a qualitative analysis in which, for example, we could distinguish between the type of honey and the added aromatic herbs, we applied principal component analysis (Figure 4). Furthermore, in order to quantitatively relate the NIR spectrum and the collected data on physicochemical composition, color, and antioxidant activity, the Partial Least Square Regression method was applied.

Both Bi-plots (Figure 5) show clustering; however, the coverage of all variations in the observed data set is significantly higher when using only NIR spectra (Figure 5A) of measured samples (F1 + F2 = 91.18%), than when using physicochemical data and color parameters (Figure 5B) where only 64.35% (F1 + F2 = 64.35%) of all variations in the observed data set are explained. The biplot includes the score plot and loading plot in one, and the axes (F1 and F2) represent the amount of variance in the observed data set. Therefore, if their sum is higher, a higher percentage of the variability is described by the observed data set. Thus, Figure 5 confirms that the association of NIR spectra with data on color, antioxidant activity and physicochemical properties of the samples significantly

increased the coverage of variability. All color parameters, except for the parameter "a", have a significantly higher weight in F1, while the physicochemical parameters, which are significant (not reduced in the PCA), conductivity, ash and acidity are the variables that contribute to the second principal component (F2). Figure 5A shows a lot of overlap between honey samples (if the country of origin of the honey is considered), and the association of NIR data provides a clearer, but not clean, division by country. However, this was not the primary goal, but it showed that there is potential in NIR spectra for their association with other data. The advantage of using of PCA is the data reduction. Based on the PCA results, for the physicochemical parameters as moisture, DPPH, and Brix values, the Factor loading in the first two principal components was less than 0.5, and therefore they were not included in the Bi-plot itself, indicating no significant influence in the observed data matrix. On the other hand, for the NIR spectra, which have 796 absorbance data (for each wavelength in the range from 904 to 1699 nm), the reduction is more than welcome. According to the literature, the rule that VIP > 1 was used [30], thus reducing the number of wavelengths by 50%, including the part of the spectrum associated with (i) the third overtone region for C–H bonds, Ar–OH, R–OH, and H_2O in the wavelength range of 904–1027 nm, as well as the (ii) second overtone of previously mentioned bonds (1373–1629 nm) and (iii) first overtone for C–H and Ar–CH bonds, in the (1631–1699 nm) [33,43–46].

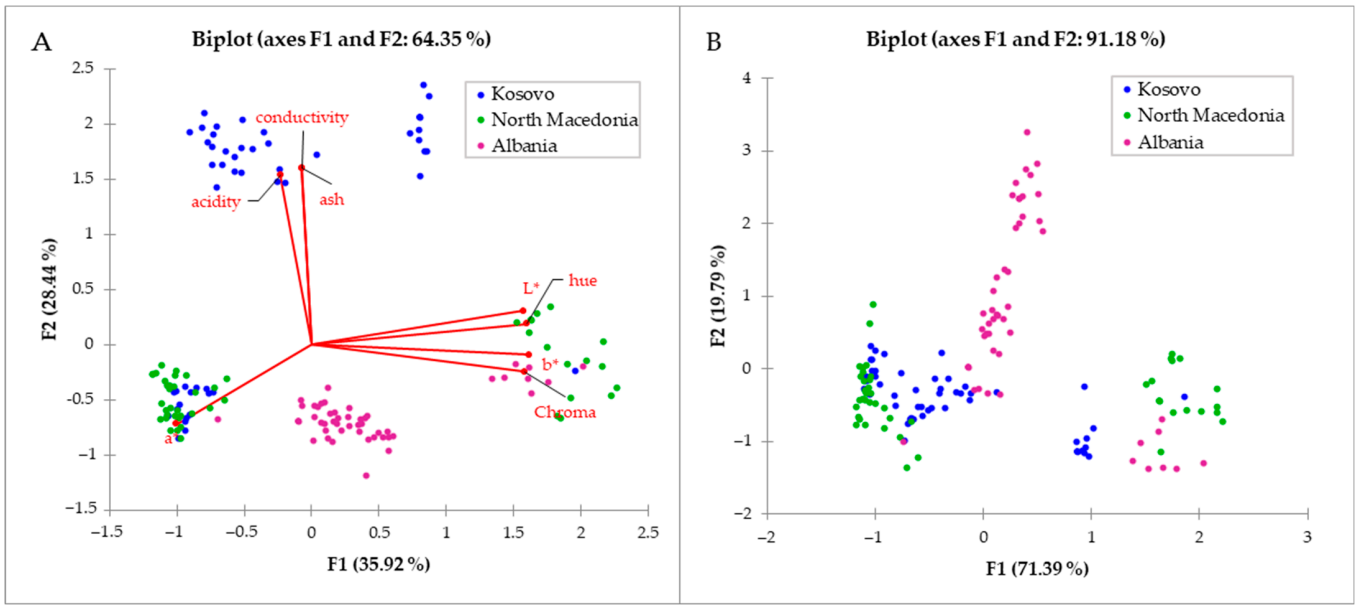


Figure 5. Principal component analysis including honey sample physicochemical and color properties (**A**) and including NIR spectra (**B**). F1 and F2 are the first two principal components of the PCA.

After qualitative analysis of honey samples, the next chemometric tool, standardly used for processing spectroscopic data with associated physicochemical parameters and measured color parameters, is the least squares regression method.

The results of the modeling are presented in Table 4.

Table 4. Model efficiency of calibration and validation of physicochemical and color properties based on NIR absorbance as input data.

Observed Parameter	LVs	R^2_C	$RMSE_C$	R^2_V	$RMSE_V$	RPD
Geographical region #	7	0.987	0.174	0.860	0.291	3.59
Concentration (%) *	9	0.985	0.541	0.849	0.777	1.159
pH	6	0.997	0.098	0.834	0.178	1.00
°Brix	5	0.984	0.221	0.737	0.325	1.03
Conductivity (mS/cm)	5	0.996	0.044	0.817	0.073	1.82
Acidity (meq/kg)	6	0.994	0.973	0.987	1.142	3.19
Moisture (%)	4	0.982	1.578	0.972	2.131	2.65
Ash (%)	4	0.996	0.022	0.855	0.042	1.04
I (%)	5	0.996	3.221	0.796	3.904	3.04
L	6	0.989	0.547	0.872	0.669	1.87
a	7	0.989	0.044	0.782	0.071	0.58
b	5	0.996	0.347	0.885	0.546	1.12
C	4	0.995	0.326	0.843	0.449	1.05
h	4	0997	1.003	0.986	1.112	3.28

Country of honey origin; * added aromatic plant (0%; 0.5%; 0.8%, and 1%); LVs—latent variables; R^2—coefficient of determination for calibration (R^2_C) and validation (R^2_V); $RMSE_C$—root mean square error of calibration; $RMSE_V$—root mean standard error of validation; RPD—ratio of standard error of performance to standard deviation.

For the results summarized in Table 4, the models were built with a maximum of seven latent variables (LVs) with less than 5% of outliers were removed as in the study of Rambo [47]. An R-squared value closer to 1 represents better calibration (Rc) and validation (Rv), while the target value for RMSEs (measures of precision and accuracy of calibration and validation) should be as low as possible. The ratio of the standard error of performance to the standard deviation, i.e., the RPD value with higher values suggests higher accuracy of the model, and with values greater than 5 it can also be used in quantitative predictions [28]. As can be seen from the parameters used in determining the quality of the model, the R^2-validation values range from the lowest value for the color parameter a, i.e., the estimate of red (+*a*) to green (−*a*) honey color, and the °Brix value (0.737), from the set of observed physicochemical properties. Since the aim of this work was to qualitatively determine the physicochemical and color properties of honey, their similarities and/or differences—the application of NIR spectroscopy showed a very good potential. In addition to the parameters listed for assessing the efficiency of the model (RMSE and R2 after calibration; RMSE and R2 RPD after validation), a test was performed for 10% of the honey samples (n = 14) and the expected values were calculated for each observed parameter (first column in Table 4) using the PLS regression model. Then, paired t-Student data analysis was used between the data obtained in the laboratory and the data predicted by the chemometric models and a *p*-value of less than 0.05 indicates statistically significant differences in the mean values of the parameters determined in the laboratory and those estimated by the models. A graphical representation of the calibration, validation and test values for the observed parameters is given in Figure S1. All models resulted in values that did not significantly differ from the laboratory values (*p*-value for all parameters is greater than 0.05).

4. Discussion

The main focus of this study is investigating the integration of Near-Infrared (NIR) Spectroscopy and chemometric techniques to evaluate honey enriched with aromatic plants, aiming to assess changes in its physicochemical properties, color, and antioxidant activity. This research covers honey samples from Kosovo, Albania, and North Macedonia, examining how botanical and geographical variables influence honey quality.

The data reveal significant variations among honey samples from different regions what is in accordance with recent studies [48–50]. Kosovo honeys showed higher conductivity and ash content, indicative of richer mineral profiles possibly due to local floral sources or environmental conditions. All values of ash content were under 0.6% which is the maximal allowable value for floral honeys [50]. Meanwhile, North Macedonian honeys exhibited slightly higher moisture and pH levels, suggesting a different nectar composition [9]. Albanian samples maintained more consistent sugar content and lighter coloration, aligning with a more uniform coloration of the samples. The impact of aromatic plant addition—namely rosemary, lavender, oregano, sage, and white pine oil—was significant across all tested parameters. Even at low concentrations (0.5%), these extracts altered the honey's visual characteristics, evident through Hunter color values and ΔE measurements [51]. This not only affects marketability but may also signal underlying compositional changes [49,50].

In summary, the data show that aromatic plant additions can markedly boost the antioxidant potential of honey, as measured by DPPH inhibition. However, this effect is highly specific to the plant type, concentration, and honey matrix. Wild pine oil and sage are among the most consistently effective additives, while rosemary, lavender, and oregano demonstrate variable performance. These findings underscore the need for targeted formulation when developing functional honey products with enhanced antioxidant properties.

What was certainly expected was a change in antioxidant capacity with the addition of aromatic herbs [11,36] and the antioxidant activity, as measured by the DPPH method. The antioxidant activity improved notably with the inclusion of aromatic extracts, supporting the hypothesis that plant additives can enhance honey's functional properties. The correlation between concentration and increased antioxidant capacity was especially evident at the 1% addition level. This suggests a potential pathway for developing value-added functional foods, appealing to health-conscious consumers. However, no clear linear trend was found where by increasing the concentration of added herbs, honey has an increasingly stronger antioxidant activity, which is most likely a consequence of the uneven distribution and particle size of the powders of added herbs [52,53].

The employment of chemometrics, particularly Principal Component Analysis (PCA) and Partial Least Squares (PLS) regression, proved critical in making sense of the complex, high-dimensional data set [13,19]. PCA enabled the clustering of samples based on spectral and physicochemical similarities, while PLS regression models demonstrated high predictive power for quality parameters, with R^2 values nearing 1 [25,27,29] for several traits like ash content, antioxidant activity, and acidity. Our study highlights that NIR, when coupled with chemometric tools, offers a non-destructive, rapid, and eco-friendly alternative to traditional analytical techniques as confirmed in other studies as well [13,14,17,19]. This is particularly valuable for real-time quality control in food production environments [19,25,42]. Another notable contribution of this work is its demonstration of geographic traceability. The PLS–DA model successfully distinguished honey origins with over 96% accuracy, especially strong in Albanian samples. This capability is critical in combating food fraud and enhancing consumer confidence [48,50]. By linking spectral data to origin and composition, the system could be expanded into authentication protocols across the honey supply chain.

Although this study provides robust insights, some limitations exist: (i) geographical narrowness (the samples are originally from Kosovo, Albania, and North Macedonia, which potentially limits the generalizability of our conclusions); (ii) limited scope of added herbs (only five aromatic herbs were tested in three different concentrations, and sensory and microbiological analysis was not performed); (iii) form of added samples (powder and oil, with which it was intended to simulate a "home-made" preparation) which can also affect the measurements due to particle size). In the sensory evaluation, we could only evaluate

the extremely pleasant smells of the preparations, but their evaluation or taste evaluation was not performed. This is certainly necessary if the enriched honey preparation is to be offered to consumers. Furthermore, environmental variables like seasonality and storage were not deeply explored, which could influence the reproducibility of results [54,55].

Overall, the integration of NIR and chemometrics represents a significant advancement in honey analysis, combining scientific rigor with practical application potential [45].

5. Conclusions

There are clear plant-specific and concentration-dependent effects on the physicochemical properties of honey: (i) added wild pine oil increases pH and reduces acidity and moisture—potentially desirable traits for stability; (ii) added rosemary tends to increase acidity and moisture, particularly at 0.8%; (iii) the addition of lavender often lowered pH, °Brix, and conductivity, especially at higher concentrations; (iv) the addition of oregano showed modest positive effects on °Brix and antioxidant inhibition, depending on the row honey to which it was added, and (v) adding sage maintains °Brix values close to the control across most honeys while decreases slightly pH and conductivity.

These observations suggest that aromatic plant additions not only impact antioxidant activity but also significantly modulate honey's core quality attributes. Sage, unlike rosemary or oregano, does not induce extreme changes, making it a balanced additive for improving antioxidant activity without compromising honey's physicochemical quality. It may be especially suitable where moderate acidity and stable sugar content are desired. In conclusion, antioxidant inhibition (I) in enriched honey samples is influenced by a complex interplay of plant type, concentration, and the base honey's original properties. While additives like wild pine oil and sage show consistent benefits, others like oregano exhibit variability depending on context. Optimizing additive type and concentration is essential for maximizing honey's functional qualities, including antioxidant activity.

This research confirms that NIR spectroscopy combined with chemometric analysis is a powerful tool for assessing the quality of honey (physicochemical properties, antioxidant activity, and color) enriched with aromatic plant extracts. The method enables differentiation due to botanical additives and predicts quality parameters with high accuracy. These findings support its adoption for efficient, non-invasive, and environmentally sustainable honey quality monitoring. Moreover, the addition of aromatic herbs enhances the antioxidant properties of honey, opening opportunities for developing premium, functional food products with verified health benefits.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/chemosensors13070246/s1, Figure S1. PLSR, visual presentation of the calibrated, validated and tested samples (n_{total} = 144 ⇒$n_{calibration}$ = 94; $n_{validation}$ = 36; $n_{testing}$ = 14). R^2_C—coefficient of determination of the calibration; R^2_V—coefficient of determination of the validation; *p*-value—paired t-Student data analysis between the data obtained in the laboratory and the data predicted by the chemometric models ($p > 0.05$ indicates no statistically significant differences between the predicted (tested) and measured means).

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Abbreviations

The following abbreviations are used in this manuscript:

AOAC	Association of Analytical Communities
DPPH	2,2-Diphenyl-1-picrylhydrazyl
*L**	Lightness
*a**	Red-green axis
*b**	Blue-yellow axis
C	Chroma—Color intensity or saturation
h	Hue angle (type of color (shade))
I (%)	percentage of DPPH radical inhibition (radical scavenging activity)
NIR	Near-infrared
PCA	Principal Components Analysis
PLS	Partial square regression
RMSE	root mean square error of calibration (C) and validation (V)
RPD	ratio of standard error of performance to standard deviation

Appendix A

Appendix A.1. Average Physicochemical Parameters and Radical Scavening Activity for Honey Samplesenriched with Aromatic Plants

The values of physicochemical parameters and antioxidant activity (I (%)) change depending on the added plant and the concentration of the additive, and the values for all 144 honeys are listed in Tables A1–A4, which consists of four parts.

Table A1. Average physicochemical parameters for honey samples with added aromatic plants—part one.

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
H1	/	0	4.18 ± 0.02	83.2 ± 0.1	0.51 ± 0.03	25 ± 0.1	14.8 ± 0.1	0.28 ± 0.04	33.76 ± 0.08
	Rosemary	0.5	4.36 ± 0.01	80.1 ± 0.1	0.48 ± 0.01	25 ± 0.1	18 ± 0.1	0.11 ± 0.01	33.92 ± 0.52
		0.8	4.31 ± 0.01	80 ± 0.5	0.5 ± 0.01	26 ± 0	18.2 ± 0.5	0.15 ± 0	32.35 ± 0.15
		1	4.09 ± 0	81.2 ± 0.1	0.44 ± 0	26 ± 0	17.2 ± 0.1	0.16 ± 0.01	30.86 ± 1.82
	Levander	0.5	4.08 ± 0	82.1 ± 0.1	0.44 ± 0.01	25 ± 0	16.2 ± 0.1	0.24 ± 0.01	27.75 ± 0.53
		0.8	4.09 ± 0.01	81.2 ± 0.5	0.42 ± 0.01	26 ± 0	17.2 ± 0.5	0.26 ± 0.01	25.98 ± 3.09
		1	4.08 ± 0	80.6 ± 0	0.44 ± 0.01	26 ± 0	17.6 ± 0	0.31 ± 0.01	27.05 ± 0.21
	Oregano	0.5	4.87 ± 0.01	81.4 ± 0.2	0.49 ± 0.07	24 ± 0	16.8 ± 0.2	0 ± 0.01	10.45 ± 0.4
		0.8	4.08 ± 0.01	81.9 ± 0.1	0.44 ± 0.01	23 ± 0	16.8 ± 0.1	0 ± 0.01	4.93 ± 1.78
		1	4.18 ± 0.02	82.3 ± 1.3	0.48 ± 0.04	25 ± 0.1	15.8 ± 1.3	0.28 ± 0.01	10.06 ± 0.37
	Sage	0.5	4.07 ± 0.01	82.3 ± 0.3	0.48 ± 0.01	26 ± 0	15.8 ± 0.3	0 ± 0	24.72 ± 0.01
		0.8	4.08 ± 0.02	80.3 ± 0.8	0.48 ± 0.02	26 ± 0	18 ± 0.8	0 ± 0	24.5 ± 3.85
		1	4.15 ± 0	81.8 ± 0.1	0.42 ± 0	25 ± 0	16.6 ± 0.1	0.63 ± 0	28.61 ± 0.03
	W. pine oil	0.5	4.21 ± 0.01	82.3 ± 0.4	0.48 ± 0.01	26 ± 0	16 ± 0.4	0 ± 0	34.36 ± 3.66
		0.8	4.14 ± 0.01	80.3 ± 0.1	0.48 ± 0.01	26 ± 0	18 ± 0.1	0 ± 0.01	39.13 ± 0.42
		1	4.06 ± 0.01	81.8 ± 0.1	0.42 ± 0.01	25 ± 0	16.6 ± 0.1	0.29 ± 0.01	27.37 ± 0.46

Table A1. *Cont.*

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
H2	/	0	3.89 ± 0.01	84.5 ± 0.8	0.2 ± 0.03	8 ± 0	13.4 ± 0.8	0.01 ± 0.01	28.66 ± 19.56
	Rosemary	0.5	3.99 ± 0.01	84.4 ± 0.1	0.2 ± 0.01	10 ± 0	14 ± 0.1	0 ± 0.01	26.15 ± 7.53
		0.8	3.88 ± 0	84.9 ± 0	0.2 ± 0	10 ± 0	13.4 ± 0	0 ± 0	22.94 ± 5.85
		1	3.88 ± 0.01	83.4 ± 1	0.21 ± 0.03	10 ± 0	14.8 ± 1	0 ± 0	24.01 ± 14.31
	Levander	0.5	3.85 ± 0.01	82.8 ± 0.4	0.2 ± 0.03	7 ± 0	15.4 ± 0.4	0.01 ± 0.02	22.99 ± 1.09
		0.8	3.89 ± 0.01	82.8 ± 0	0.21 ± 0.01	7 ± 0	15.4 ± 0	0 ± 0.01	30.1 ± 2.83
		1	3.97 ± 0.01	84.4 ± 0.7	0.2 ± 0.02	7 ± 0	14 ± 0.7	0.01 ± 0.01	24.32 ± 0.09
	Oregano	0.5	3.99 ± 0.01	84.3 ± 0.5	0.2 ± 0.02	8 ± 0	14 ± 0.5	0 ± 0.01	5.93 ± 1.71
		0.8	3.99 ± 0.01	83.8 ± 0	0.2 ± 0.01	8 ± 0	14.6 ± 0	0 ± 0.01	1.96 ± 1.78
		1	3.81 ± 0.01	82.9 ± 0	0.2 ± 0.01	8 ± 0	15.4 ± 0	0 ± 0.01	6.23 ± 1.15
	Sage	0.8	4.15 ± 0.01	82.8 ± 0.5	0.21 ± 0.02	7 ± 0	15.4 ± 0.5	0 ± 0.01	30.08 ± 0.91
		0.5	3.9 ± 0.01	83.2 ± 0.8	0.21 ± 0.02	8 ± 0	14.8 ± 0.8	0 ± 0.01	24.87 ± 2.23
		1	3.77 ± 0.02	82.6 ± 0.7	0.2 ± 0.01	8 ± 0.1	15.4 ± 0.7	0 ± 0.01	20.5 ± 1.09
	W. pine oil	0.5	3.76 ± 0.01	82.8 ± 0.4	0.2 ± 0.01	9 ± 0.2	15.4 ± 0.4	0 ± 0	18 ± 1.81
		0.8	3.77 ± 0.01	83.5 ± 0.2	0.2 ± 0	10 ± 0	14.6 ± 0.2	0 ± 0	25.08 ± 4.27
		1	4 ± 0.01	83 ± 0.3	0.21 ± 0.02	10 ± 0	15.2 ± 0.3	0 ± 0.02	16.12 ± 2.49
H3	/	0	3.85 ± 0.01	84.4 ± 0.3	0.44 ± 0.01	31 ± 0	13.4 ± 0.3	0.27 ± 0	32.28 ± 0.4
	Rosemary	0.5	3.74 ± 0.01	81.7 ± 0.2	0.46 ± 0	35 ± 0	16.8 ± 0.2	0 ± 0	32.89 ± 2.02
		0.8	3.71 ± 0.01	81.4 ± 0.2	0.46 ± 0.01	38 ± 0	18.6 ± 0.2	0 ± 0.01	34.07 ± 0.36
		1	3.75 ± 0.01	81.5 ± 0.3	0.46 ± 0	38 ± 0	18.6 ± 0.3	0 ± 0.01	−0.76 ± 2.27
	Levander	0.5	3.73 ± 0.01	81.8 ± 1	0.45 ± 0.04	37 ± 0	16.8 ± 1	0 ± 0.03	−3.68 ± 4.26
		0.8	3.81 ± 0	81.7 ± 0.1	0.44 ± 0.01	37 ± 0	16.8 ± 0.1	0 ± 0.01	22.66 ± 5.98
		1	3.71 ± 0	81.4 ± 0.2	0.45 ± 0.01	36 ± 0	18.6 ± 0.2	0 ± 0.01	26.52 ± 2.1
	Oregano	0.5	3.71 ± 0.01	80.5 ± 0.5	0.44 ± 0.01	36 ± 0.1	17.8 ± 0.5	0 ± 0	13.57 ± 0.23
		0.8	3.72 ± 0.01	81.9 ± 0.4	0.45 ± 0.01	36 ± 0	16.4 ± 0.4	0 ± 0	−1.53 ± 4.69
		1	3.71 ± 0.01	81.3 ± 0.3	0.45 ± 0.02	36 ± 0	17 ± 0.3	0 ± 0.02	9.75 ± 0.16
	Sage	0.5	3.7 ± 0.01	81.3 ± 0.7	0.43 ± 0.02	35 ± 0.1	17 ± 0.7	0 ± 0.01	27.61 ± 2.11
		0.8	3.82 ± 0.01	81.2 ± 0.3	0.44 ± 0.01	38 ± 0	17 ± 0.3	0 ± 0.01	30.17 ± 0.4
		1	3.87 ± 0.01	81.3 ± 0	0.44 ± 0.01	34 ± 0	17 ± 0	0 ± 0.02	24.14 ± 9.02

Table A2. Average physicochemical parameters for honey samples with added aromatic plants—part two.

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
	W. pine oil	0.5	3.72 ± 0.01	81.6 ± 0.4	0.43 ± 0.01	33 ± 0	16.8 ± 0.4	0 ± 0.01	27.63 ± 6.08
		0.8	3.85 ± 0.02	81.5 ± 0.5	0.44 ± 0.01	35 ± 0	16.8 ± 0.5	0 ± 0.01	30.95 ± 0.05
		1	3.69 ± 0.01	81 ± 0.5	0.43 ± 0.01	33 ± 0.1	17.2 ± 0.5	0 ± 0	3.76 ± 1.22
H4	/	0	4.72 ± 0.01	82.9 ± 0.1	0.25 ± 0.01	8 ± 0	14.2 ± 0.1	0.1 ± 0.01	18.27 ± 7.13
	Rosemary	0.5	4.38 ± 0.01	83.8 ± 0.1	0.31 ± 0.01	10 ± 0	14.6 ± 0.1	0.19 ± 0.01	7.71 ± 1.91
		0.8	4.4 ± 0.01	82.5 ± 0.1	0.2 ± 0.01	9 ± 0	14.8 ± 0.1	0 ± 0	16.96 ± 1.35
		1	4.27 ± 0.01	83.3 ± 0.1	0.29 ± 0	10 ± 0	14.8 ± 0.1	0.05 ± 0.01	27.48 ± 5.9
	Levander	0.5	4.38 ± 0	84.5 ± 0	0.29 ± 0.01	9 ± 0	14 ± 0	0.24 ± 0.01	27.47 ± 7.88
		0.8	4.4 ± 0	83.4 ± 0.1	0.28 ± 0.01	10 ± 0	14.6 ± 0.1	0 ± 0	22.22 ± 0.44
		1	4.27 ± 0.02	83 ± 0.3	0.19 ± 0	10 ± 0	15.2 ± 0.3	0 ± 0	19.44 ± 22.35
	Oregano	0.5	4.36 ± 0	85 ± 0	0.19 ± 0.01	9 ± 0	13.2 ± 0	0 ± 0.01	17.15 ± 0.28
		0.8	4.18 ± 0.01	85.6 ± 0.2	0.19 ± 0	9 ± 0	13 ± 0.2	0 ± 0	24.69 ± 3.06
		1	4.12 ± 0	85 ± 0	0.19 ± 0.01	10 ± 0	13.2 ± 0	0 ± 0.01	35.37 ± 3.51
	Sage	0.5	4.35 ± 0.01	84.5 ± 0.2	0.26 ± 0	9 ± 0.1	13.8 ± 0.2	0 ± 0.01	8.26 ± 0.47
		0.8	4.37 ± 0.01	84.5 ± 0.3	0.29 ± 0.02	9 ± 0	13.8 ± 0.3	0 ± 0.01	20.42 ± 1.01
		1	4.38 ± 0.01	84.5 ± 0.1	0.28 ± 0	10 ± 0	13.8 ± 0.1	0 ± 0.01	6.96 ± 4.48
	W. pine oil	0.5	4.34 ± 0.01	84.7 ± 0.3	0.19 ± 0.01	9 ± 0	13.4 ± 0.3	0 ± 0	40.13 ± 2.47
		0.8	4.25 ± 0	84.7 ± 0.1	0.2 ± 0.01	8 ± 0	13.4 ± 0.1	0 ± 0	17.23 ± 1.27
		1	4.26 ± 0.01	84.7 ± 0	0.19 ± 0.01	9 ± 0	13.4 ± 0	0 ± 0.01	17.09 ± 3.26
H5	/	0	4.1 ± 0.01	84.2 ± 0	0.18 ± 0	7 ± 0	14 ± 0	0.03 ± 0.01	7.84 ± 7.2
	Rosemary	0.5	3.94 ± 0.01	85.1 ± 0.2	0.19 ± 0	9 ± 0	13 ± 0.2	0 ± 0	11.97 ± 5.94
		0.8	3.81 ± 0.04	85.1 ± 1.1	0.2 ± 0.01	9 ± 0	13 ± 1.1	0 ± 0.03	26.41 ± 1.5
		1	3.86 ± 0.02	85.1 ± 0.5	0.2 ± 0.01	9 ± 0	13 ± 0.5	0 ± 0.01	14.39 ± 9.29
	Levander	0.5	3.8 ± 0.01	83.2 ± 0.2	0.2 ± 0.01	8 ± 0	15 ± 0.2	0 ± 0	11.77 ± 0.34
		0.8	3.7 ± 0.01	83.2 ± 0.9	0.2 ± 0.04	8 ± 0	15 ± 0.9	0 ± 0.02	6 ± 0.38
		1	3.81 ± 0.01	83.2 ± 0.5	0.2 ± 0.01	9 ± 0	15 ± 0.5	0 ± 0.01	8.74 ± 2.18

Table A2. *Cont.*

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
	Oregano	0.5	3.74 ± 0	83.4 ± 0	0.19 ± 0	11 ± 0	14.8 ± 0	0 ± 0	5.47 ± 2.37
		0.8	3.76 ± 0.02	83.1 ± 0.8	0.2 ± 0.01	11 ± 0	15 ± 0.8	0 ± 0.01	1.55 ± 0.98
		1	3.81 ± 0	83.6 ± 0.6	0.2 ± 0.02	11 ± 0	14.6 ± 0.6	0 ± 0.01	36.23 ± 2.07
	Sage	0.5	3.75 ± 0.01	82.9 ± 0.1	0.18 ± 0.01	9 ± 0	15.2 ± 0.1	0 ± 0	16.88 ± 6.89
		0.8	3.76 ± 0.01	83.5 ± 0.4	0.18 ± 0	12 ± 0	14.6 ± 0.4	0 ± 0.01	15.78 ± 6.66
		1	3.98 ± 0.01	82.9 ± 0.1	0.19 ± 0	9 ± 0	15.2 ± 0.1	0 ± 0.01	12.99 ± 4.72
	W. pine oil	0.5	3.75 ± 0.01	83.5 ± 0.1	0.19 ± 0	10 ± 0	14.6 ± 0.1	0 ± 0.01	4.29 ± 0.92
		0.8	3.67 ± 0.01	83.4 ± 0.2	0.19 ± 0.01	9 ± 0	14.8 ± 0.2	0 ± 0.01	1.65 ± 2
		1	3.8 ± 0.01	83.3 ± 0	0.2 ± 0.01	10 ± 0	14.8 ± 0	0 ± 0.01	5.38 ± 1.38
H6	/	0	4.18 ± 0.01	84.2 ± 0.3	0.2 ± 0.01	5 ± 0	14 ± 0.3	0.01 ± 0	16.13 ± 0.16
	Rosemary	0.5	4.58 ± 0.01	82.5 ± 0.3	0.19 ± 0.01	9 ± 0	14.8 ± 0.3	0 ± 0	12.62 ± 0.43
		0.8	4.43 ± 0.01	81 ± 0.8	0.2 ± 0.02	6 ± 0	17.2 ± 0.8	0 ± 0.01	17.75 ± 4.34
		1	4.01 ± 0.01	81.5 ± 0.1	0.22 ± 0.01	9 ± 0	16.8 ± 0.1	0 ± 0.01	15.57 ± 3.04
	Levander	0.5	3.68 ± 0	81.5 ± 0.7	0.19 ± 0.03	7 ± 0	16.8 ± 0.7	0 ± 0.01	21 ± 5.94
		0.8	3.67 ± 0.04	81.5 ± 1.6	0.19 ± 0.04	9 ± 0.3	16.8 ± 1.6	0 ± 0.01	11.59 ± 5.62
		1	3.63 ± 0.01	80.8 ± 0.3	0.19 ± 0.01	7 ± 0	17.6 ± 0.3	0 ± 0.01	23.39 ± 1.22
	Oregano	0.5	3.8 ± 0.01	82.5 ± 0.4	0.2 ± 0.01	9 ± 0	14.5 ± 0.4	0 ± 0	29.29 ± 2.91
		0.8	3.6 ± 0	81.8 ± 0.2	0.2 ± 0.01	9 ± 0	16.4 ± 0.2	0 ± 0.01	29.41 ± 6.02
		1	3.6 ± 0	82.8 ± 0	0.2 ± 0	9 ± 0	15.2 ± 0	0 ± 0.01	18.75 ± 7.53

Table A3. Average physicochemical parameters for honey samples with added aromatic plants—part three.

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
	Sage	0.5	4.05 ± 0.01	81.7 ± 0.2	0.19 ± 0	9 ± 0	16.6 ± 0.2	0 ± 0.01	23.5 ± 8.25
		0.8	3.7 ± 0.01	81.2 ± 0.4	0.19 ± 0	9 ± 0	17.2 ± 0.4	0 ± 0.01	18.25 ± 14.15
		1	3.7 ± 0.01	81.4 ± 0.2	0.19 ± 0	9 ± 0	17 ± 0.2	0 ± 0.01	16.14 ± 0.38
	W. pine oil	0.5	3.77 ± 0	82.1 ± 0.3	0.2 ± 0.01	7 ± 0	16.2 ± 0.3	0 ± 0	7.58 ± 3.82
		0.8	3.5 ± 0.01	82.2 ± 0.4	0.19 ± 0.01	8 ± 0	16 ± 0.4	0 ± 0	1.63 ± 0.87
		1	3.7 ± 0.01	81.6 ± 0.5	0.19 ± 0.01	7 ± 0	16.8 ± 0.5	0 ± 0.01	1.94 ± 1.3
H7	/	0	3.77 ± 0.01	83.5 ± 0.1	0.16 ± 0	12 ± 0	14.6 ± 0.1	0.01 ± 0	15.22 ± 4.78
	Rosemary	0.5	3.76 ± 0.01	82.3 ± 0.1	0.17 ± 0.01	10 ± 0	15.8 ± 0.1	0 ± 0.01	16.14 ± 0.38
		0.8	3.71 ± 0.01	82.1 ± 0.1	0.16 ± 0.01	10 ± 0	16 ± 0.1	0 ± 0	16.21 ± 0.17
		1	3.76 ± 0.01	82 ± 0.1	0.18 ± 0	10 ± 0	16.2 ± 0.1	0 ± 0.01	2.58 ± 2.45
	Levander	0.5	3.82 ± 0	82.1 ± 0	0.16 ± 0.01	10 ± 0	16 ± 0	0 ± 0.01	11.47 ± 13.66
		0.8	3.7 ± 0	81.4 ± 0.1	0.14 ± 0.01	10 ± 0	16.8 ± 0.1	0 ± 0	8.76 ± 5.93
		1	3.73 ± 0.02	82 ± 0.3	0.14 ± 0	10 ± 0	16.2 ± 0.3	0 ± 0	6.93 ± 1.92
	Oregano	0.5	3.65 ± 0	82.1 ± 0	0.16 ± 0.01	11 ± 0	16 ± 0	0 ± 0.01	16.79 ± 7.22
		0.8	3.65 ± 0.01	82.3 ± 0.2	0.16 ± 0	11 ± 0	15.8 ± 0.2	0 ± 0	6.67 ± 6.44
		1	3.59 ± 0	82.1 ± 0.2	0.16 ± 0.01	11 ± 0	16 ± 0.2	0 ± 0.01	19.36 ± 6.48
	Sage	0.5	3.53 ± 0.01	81.2 ± 0	0.16 ± 0.02	10 ± 0	17 ± 0	0 ± 0.01	7.55 ± 1.47
		0.8	3.65 ± 0.01	82.2 ± 0.5	0.16 ± 0.02	10 ± 0	16 ± 0.5	0 ± 0.01	13.19 ± 3
		1	3.67 ± 0.01	83.2 ± 0.2	0.15 ± 0.01	10 ± 0	15 ± 0.2	0 ± 0.01	12.41 ± 3.43
	W. pine oil	0.5	5.38 ± 0.01	82.3 ± 0.2	0.16 ± 0.01	0 ± 0	15.8 ± 0.2	0 ± 0.01	4.7 ± 5.01
		0.8	4.06 ± 0.01	81.9 ± 0.1	0.16 ± 0.01	0 ± 0	16.4 ± 0.1	0 ± 0.02	11.87 ± 5.3
		1	3.97 ± 0.01	81.5 ± 0.1	0.16 ± 0.08	0 ± 0	16.8 ± 0.1	0 ± 0.01	3.28 ± 0.36
H8	/	0	4.1 ± 0	83.5 ± 0.3	0.21 ± 0.02	6 ± 0	14.6 ± 0.3	0 ± 0.01	26.02 ± 2.28
	Rosemary	0.5	5.3 ± 0.01	82.6 ± 0.4	0.2 ± 0.01	4 ± 0	15.6 ± 0.4	0 ± 0.01	27.51 ± 0.05
		0.8	5.15 ± 0.01	82.2 ± 0.1	0.2 ± 0.02	4 ± 0	16 ± 0.1	0 ± 0.01	28.07 ± 2.59
		1	5.4 ± 0	82.6 ± 0	0.2 ± 0.01	3 ± 0	15.6 ± 0	0 ± 0	23.32 ± 3.1
	Levander	0.5	4.84 ± 0.01	82.9 ± 0.3	0.19 ± 0.01	3 ± 0	15.4 ± 0.3	0 ± 0	28.22 ± 0.83
		0.8	4.8 ± 0.02	82.7 ± 0.4	0.19 ± 0	5 ± 0	15.4 ± 0.4	0 ± 0.01	17.12 ± 4.57
		1	5 ± 0.01	82.3 ± 0	0.19 ± 0.01	3 ± 0	15.8 ± 0	0 ± 0	19.3 ± 6.31
	Oregano	0.5	5.7 ± 0.01	82.6 ± 0.4	0.19 ± 0.01	4 ± 0	12.6 ± 0.4	0 ± 0.01	34.14 ± 0.45
		0.8	5.3 ± 0.01	82.4 ± 0.3	0.2 ± 0.01	7 ± 0	15.8 ± 0.3	0 ± 0	28.16 ± 5.35
		1	4.98 ± 0.01	82.3 ± 0.2	0.2 ± 0.01	6 ± 0	15.8 ± 0.2	0 ± 0.01	24.44 ± 7.96
	Sage	0.5	5.1 ± 0.01	82.9 ± 0.2	0.19 ± 0.01	3 ± 0	15.4 ± 0.2	0 ± 0	18 ± 0.48
		0.8	5.4 ± 0	82.6 ± 0	0.2 ± 0.01	4 ± 0	15.6 ± 0	0 ± 0	25.94 ± 3.71
		1	4.95 ± 0	82.7 ± 0	0.2 ± 0.01	4 ± 0	15.4 ± 0	0 ± 0.01	25.4 ± 1.4
	W. pine oil	0.5	5.38 ± 0.01	82.3 ± 0.3	0.2 ± 0.01	3 ± 0	15.8 ± 0.3	0 ± 0.01	23.65 ± 6.41
		0.8	4.06 ± 0.01	81.9 ± 0.1	0.19 ± 0.01	4 ± 0	16.4 ± 0.1	0 ± 0	27.57 ± 3.36
		1	3.97 ± 0	81.5 ± 0.1	0.15 ± 0	4 ± 0	16.8 ± 0.1	0 ± 0.01	23.19 ± 7.38

Table A4. Average physicochemical parameters for honey samples with added aromatic plants—part four.

Honey	Aromatic Plants Added		pH	°Brix	Conductivity (mS/cm)	Acidity (meq/kg)	Moisture (%)	Ash (%)	I (%)
	Type	Conc. (%)							
H9	/	0	3.7 ± 0.07	84 ± 0	0.16 ± 0.01	11 ± 0	14.6 ± 0	0.19 ± 0.01	5.41 ± 5.56
	Rosemary	0.5	4.3 ± 0.01	82.5 ± 0.1	0.16 ± 0.01	6 ± 0	16 ± 0.1	0 ± 0.01	19.98 ± 5.16
		0.8	4.17 ± 0.01	82 ± 0.5	0.16 ± 0.23	8 ± 0.1	16.2 ± 0.5	0 ± 0.01	12.57 ± 3.43
		1	4.67 ± 0.01	82.3 ± 0.4	0.16 ± 0.01	9 ± 0	15.8 ± 0.4	0 ± 0.01	24.65 ± 4.32
	Levander	0.5	4.09 ± 0	81.9 ± 0.4	0.16 ± 0.04	7 ± 0	16.4 ± 0.4	0 ± 0.02	15.66 ± 0.95
		0.8	4.1 ± 0.02	82.6 ± 0.2	0.16 ± 0	7 ± 0	15.6 ± 0.2	0 ± 0.01	16.8 ± 23.2
		1	4.15 ± 0.01	82.2 ± 0.4	0.14 ± 0.01	7 ± 0	15.8 ± 0.4	0 ± 0	9.51 ± 0.68
	Oregano	0.5	4.7 ± 0.02	83 ± 0.7	0.16 ± 0.01	12 ± 0	15.2 ± 0.7	0 ± 0	10.85 ± 3.41
		0.8	4.6 ± 0.01	82.1 ± 0.1	0.16 ± 0	12 ± 0	16 ± 0.1	0 ± 0.01	16.47 ± 4.57
		1	4.52 ± 0.01	81.2 ± 0.1	0.16 ± 0	12 ± 0	17.2 ± 0.1	0 ± 0	12.47 ± 0.87
	Sage	0.5	4.47 ± 0.02	81.5 ± 0.6	0.16 ± 0.01	12 ± 0	16.8 ± 0.6	0 ± 0.13	22.88 ± 22.48
		0.8	4.39 ± 0.01	83 ± 0.3	0.17 ± 0.01	11 ± 0	15.2 ± 0.3	0 ± 0	11.84 ± 1.1
		1	4.3 ± 0.01	82.4 ± 0.2	0.17 ± 0.01	11 ± 0	16 ± 0.2	0 ± 0.01	9.36 ± 1.08
	W. pine oil	0.5	5.41 ± 0.02	82.7 ± 0.4	0.2 ± 0.01	8 ± 0	15.4 ± 0.4	0 ± 0.01	4.81 ± 4.47
		0.8	4.7 ± 0.01	82.5 ± 0.3	0.2 ± 0.01	8 ± 0.1	15.8 ± 0.3	0 ± 0	7.88 ± 1.4
		1	4.6 ± 0.02	82.7 ± 0.4	0.2 ± 0.01	8 ± 0	15.4 ± 0.4	0 ± 0.01	9.59 ± 0.1

Appendix A.2. Average Color Parameters for Honey Samples with Added Aromatic Plants

The color parameters, *L**, *a**, *b**, C, and h are part of the CIELAB color space, change depending on the added plant and the concentration of the additive, and the values for all 144 honeys are listed in Tables A5–A8, which consists of four parts.

Table A5. Average color parameters for honey samples with added aromatic plants—part one.

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
H1	/	0	37.43 ± 0.13	1.03 ± 0.02	2.03 ± 0.03	2.28 ± 0.04	63.21 ± 0.09
	Rosemary	0.5	37.62 ± 0.1	1.04 ± 0.01	2.15 ± 0.01	2.39 ± 0.01	64.24 ± 0.15
		0.8	35.73 ± 0.02	1.36 ± 0.01	1.36 ± 0.01	1.92 ± 0	44.78 ± 0.53
		1	37.41 ± 0.02	1.06 ± 0	2.17 ± 0	2.42 ± 0.01	63.97 ± 0.07
	Levander	0.5	37.5 ± 0.03	1.08 ± 0	2.22 ± 0.01	2.47 ± 0.01	63.96 ± 0.06
		0.8	37.42 ± 0.01	1.1 ± 0.01	2.29 ± 0.01	2.54 ± 0.01	64.23 ± 0.45
		1	37.1 ± 0.02	1.08 ± 0	2.24 ± 0.01	2.49 ± 0.01	64.26 ± 0.01
	Oregano	0.5	36.9 ± 0.01	0.96 ± 0.01	2.05 ± 0.07	2.22 ± 0.01	64.45 ± 0.2
		0.8	37.17 ± 0.01	1.04 ± 0.01	2.24 ± 0.01	2.47 ± 0.01	65.16 ± 0.06
		1	36.62 ± 0.08	1.27 ± 0.02	1.32 ± 0.04	1.83 ± 0.01	46.1 ± 1.26
	Sage	0.5	36.94 ± 0	1.34 ± 0.01	1.66 ± 0.01	2.13 ± 0	50.99 ± 0.35
		0.8	36.11 ± 0.02	1.31 ± 0.02	1.44 ± 0.02	1.94 ± 0	47.74 ± 0.81
		1	36.11 ± 0	1.3 ± 0	1.46 ± 0	1.96 ± 0	48.32 ± 0.09
	W. pine oil	0.5	36.16 ± 0.05	1.27 ± 0.01	1.3 ± 0.01	1.81 ± 0	45.81 ± 0.43
		0.8	37.35 ± 0.05	1.01 ± 0.01	2.18 ± 0.01	2.4 ± 0.01	65.2 ± 0.09
		1	36.25 ± 0.01	1.32 ± 0.01	1.53 ± 0.01	2.02 ± 0.01	49.28 ± 0.08
H2	/	0	35.35 ± 0	1.43 ± 0.01	0.78 ± 0.03	1.63 ± 0.01	28.65 ± 0.81
	Rosemary	0.5	35.55 ± 0.01	1.54 ± 0.01	0.94 ± 0.01	1.81 ± 0.01	31.28 ± 0.06
		0.8	35.41 ± 0.03	1.5 ± 0	0.92 ± 0	1.76 ± 0	31.67 ± 0.02
		1	35.38 ± 0.01	1.46 ± 0.01	0.83 ± 0.03	1.68 ± 0	29.7 ± 0.97
	Levander	0.5	35.32 ± 0.01	1.55 ± 0.01	1 ± 0.03	1.85 ± 0.02	32.81 ± 0.42
		0.8	35.46 ± 0.02	1.48 ± 0.01	0.92 ± 0.01	1.74 ± 0.01	31.72 ± 0.04
		1	35.38 ± 0.02	1.51 ± 0.01	0.91 ± 0.02	1.76 ± 0.01	30.94 ± 0.7
	Oregano	0.5	35.49 ± 0.01	1.46 ± 0.01	0.87 ± 0.02	1.69 ± 0.01	30.71 ± 0.45
		0.8	35.47 ± 0.01	1.56 ± 0.01	0.93 ± 0.01	1.81 ± 0.01	30.81 ± 0.01
		1	35.46 ± 0.01	1.52 ± 0.01	0.88 ± 0.01	1.75 ± 0.01	29.99 ± 0.04

Table A5. *Cont.*

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
	Sage	0.8	35.7 ± 0.03	1.47 ± 0.01	0.89 ± 0.02	1.71 ± 0.01	31.1 ± 0.45
		0.5	35.65 ± 0	1.45 ± 0.01	0.89 ± 0.02	1.7 ± 0.01	31.34 ± 0.85
		1	35.56 ± 0.08	1.47 ± 0.02	0.85 ± 0.01	1.7 ± 0.01	30.18 ± 0.67
	W. pine oil	0.5	35.69 ± 0.21	1.42 ± 0.01	1.03 ± 0.01	1.75 ± 0	36.03 ± 0.44
		0.8	35.66 ± 0	1.45 ± 0.01	1.06 ± 0	1.79 ± 0	36.31 ± 0.19
		1	35.64 ± 0.02	1.44 ± 0.01	1.08 ± 0.02	1.8 ± 0.02	36.79 ± 0.35
H3	/	0	35.59 ± 0.02	1.31 ± 0.01	1.08 ± 0.01	1.69 ± 0	39.5 ± 0.29
	Rosemary	0.5	35.61 ± 0.01	1.34 ± 0.01	1.1 ± 0	1.73 ± 0	39.54 ± 0.19
		0.8	35.64 ± 0.01	1.37 ± 0.01	1.18 ± 0.01	1.8 ± 0.01	40.67 ± 0.16
		1	35.73 ± 0.01	1.36 ± 0.01	1.25 ± 0	1.85 ± 0.01	42.72 ± 0.28
	Levander	0.5	35.83 ± 0.01	1.45 ± 0.01	1.52 ± 0.04	2.1 ± 0.03	46.46 ± 0.99
		0.8	35.85 ± 0.02	1.43 ± 0	1.5 ± 0.01	2.08 ± 0.01	46.31 ± 0.15
		1	35.71 ± 0	1.41 ± 0	1.29 ± 0.01	1.91 ± 0.01	42.39 ± 0.16
	Oregano	0.5	35.61 ± 0.06	1.29 ± 0.01	1.03 ± 0.01	1.65 ± 0	38.51 ± 0.49
		0.8	35.76 ± 0.03	1.39 ± 0.01	1.36 ± 0.01	1.94 ± 0	44.23 ± 0.45
		1	35.85 ± 0.03	1.41 ± 0.01	1.39 ± 0.02	1.98 ± 0.02	44.57 ± 0.25
	Sage	0.5	35.63 ± 0.07	1.37 ± 0.01	1.21 ± 0.02	1.82 ± 0.01	41.44 ± 0.65
		0.8	35.89 ± 0.01	1.38 ± 0.01	1.21 ± 0.01	1.83 ± 0.01	41.2 ± 0.33
		1	36.01 ± 0.01	1.46 ± 0.01	1.41 ± 0.01	2.03 ± 0.02	43.87 ± 0.04

Table A6. Average color parameters for honey samples with added aromatic plants—part two.

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
	W. pine oil	0.5	35.55 ± 0.01	1.47 ± 0.01	1.36 ± 0.01	2 ± 0.01	42.85 ± 0.43
		0.8	35.86 ± 0.02	1.45 ± 0.02	1.6 ± 0.01	2.15 ± 0.01	47.78 ± 0.52
		1	36.03 ± 0.07	1.42 ± 0.01	1.51 ± 0.01	2.07 ± 0	46.78 ± 0.51
H4	/	0	37.54 ± 0.01	1.08 ± 0.01	3.19 ± 0.01	3.36 ± 0.01	71.43 ± 0.06
	Rosemary	0.5	37.61 ± 0	1.07 ± 0.01	3.09 ± 0.01	3.27 ± 0.01	70.91 ± 0.13
		0.8	38.19 ± 0.02	1.09 ± 0.01	3.71 ± 0.01	3.86 ± 0	73.63 ± 0.1
		1	37.67 ± 0.01	1.06 ± 0.01	3.26 ± 0	3.43 ± 0.01	72.02 ± 0.13
	Levander	0.5	37.36 ± 0.01	1.13 ± 0	3.16 ± 0.01	3.35 ± 0.01	70.28 ± 0.05
		0.8	37.42 ± 0.01	1.12 ± 0	3.05 ± 0.01	3.24 ± 0	69.79 ± 0.06
		1	38.3 ± 0.01	1.1 ± 0.02	3.29 ± 0	3.47 ± 0	71.6 ± 0.28
	Oregano	0.5	38.05 ± 0.01	1.27 ± 0	3.42 ± 0.01	3.65 ± 0.01	69.54 ± 0.04
		0.8	37.81 ± 0.01	1.3 ± 0.01	3.59 ± 0	3.82 ± 0	70.18 ± 0.16
		1	37.94 ± 0.01	1.33 ± 0	3.73 ± 0.01	3.96 ± 0.01	70.39 ± 0.04
	Sage	0.5	38.23 ± 0.07	1.04 ± 0.01	3.41 ± 0	3.57 ± 0.01	73 ± 0.16
		0.8	38.23 ± 0.01	0.92 ± 0.01	2.65 ± 0.02	2.8 ± 0.01	70.83 ± 0.29
		1	38.52 ± 0.01	1.03 ± 0.01	3.49 ± 0	3.64 ± 0.01	73.63 ± 0.11
	W. pine oil	0.5	37.78 ± 0.04	1.08 ± 0.01	3.41 ± 0.01	3.57 ± 0	72.42 ± 0.26
		0.8	38.29 ± 0	1.08 ± 0	3.71 ± 0.01	3.86 ± 0	73.76 ± 0.06
		1	38.45 ± 0.04	1.03 ± 0.01	3.64 ± 0.01	3.78 ± 0.01	74.27 ± 0.02
H5	/	0	35.24 ± 0	1.38 ± 0.01	0.79 ± 0	1.59 ± 0.01	29.78 ± 0.04
	Rosemary	0.5	35.17 ± 0	1.36 ± 0.01	0.71 ± 0	1.53 ± 0	27.69 ± 0.24
		0.8	35.18 ± 0.04	1.43 ± 0.04	0.87 ± 0.01	1.67 ± 0.03	31.14 ± 1.1
		1	35.24 ± 0.01	1.44 ± 0.02	0.87 ± 0.01	1.68 ± 0.01	31.09 ± 0.54
	Levander	0.5	35.23 ± 0.01	1.44 ± 0.01	0.91 ± 0.01	1.7 ± 0	32.33 ± 0.18
		0.8	35.16 ± 0	1.46 ± 0.01	0.89 ± 0.04	1.71 ± 0.02	31.34 ± 0.86
		1	35.23 ± 0.01	1.48 ± 0.01	0.94 ± 0.01	1.76 ± 0.01	32.4 ± 0.52
	Oregano	0.5	35.31 ± 0.01	1.48 ± 0	0.88 ± 0	1.72 ± 0	30.75 ± 0.02
		0.8	35.09 ± 0.01	1.52 ± 0.02	0.93 ± 0.01	1.78 ± 0.01	31.43 ± 0.76
		1	35.17 ± 0.01	1.48 ± 0	0.9 ± 0.02	1.73 ± 0.01	31.23 ± 0.64
	Sage	0.5	35.16 ± 0.01	1.43 ± 0.01	0.88 ± 0.01	1.67 ± 0	31.61 ± 0.14
		0.8	35.14 ± 0	1.36 ± 0.01	0.74 ± 0	1.55 ± 0.01	28.52 ± 0.4
		1	35.15 ± 0.02	1.45 ± 0.01	0.82 ± 0	1.66 ± 0.01	29.57 ± 0.06

Table A6. *Cont.*

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
	W. pine oil	0.5	35.23 ± 0.01	1.39 ± 0.01	1.01 ± 0	1.72 ± 0.01	36.18 ± 0.1
		0.8	35.46 ± 0	1.31 ± 0.01	1.05 ± 0.01	1.68 ± 0.01	38.55 ± 0.21
		1	35.57 ± 0.01	1.32 ± 0.01	1.13 ± 0.01	1.73 ± 0.01	40.5 ± 0.01
H6	/	0	35.13 ± 0.01	1.39 ± 0.01	0.77 ± 0.01	1.58 ± 0	28.83 ± 0.26
	Rosemary	0.5	35.17 ± 0.01	1.46 ± 0.01	0.82 ± 0.01	1.67 ± 0	29.13 ± 0.31
		0.8	35.16 ± 0.01	1.45 ± 0.01	0.8 ± 0.02	1.65 ± 0.01	28.82 ± 0.76
		1	35.04 ± 0.04	1.45 ± 0.01	0.81 ± 0.01	1.66 ± 0.01	29.2 ± 0.13
	Levander	0.5	35.14 ± 0.04	1.49 ± 0	0.96 ± 0.03	1.77 ± 0.01	32.71 ± 0.71
		0.8	35.76 ± 0.28	1.38 ± 0.04	0.88 ± 0.04	1.63 ± 0.01	32.52 ± 1.6
		1	35.45 ± 0.01	1.48 ± 0.01	0.98 ± 0.01	1.77 ± 0.01	33.39 ± 0.32

Table A7. Average color parameters for honey samples with added aromatic plants—part three.

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
	Oregano	0.5	35.3 ± 0.01	1.41 ± 0.01	0.85 ± 0.01	1.64 ± 0	31.12 ± 0.42
		0.8	35.19 ± 0.05	1.42 ± 0	0.84 ± 0.01	1.65 ± 0.01	30.49 ± 0.19
		1	35.3 ± 0.02	1.4 ± 0	0.84 ± 0	1.64 ± 0.01	30.87 ± 0.03
	Sage	0.5	35.2 ± 0.01	1.44 ± 0.01	0.79 ± 0	1.64 ± 0.01	28.89 ± 0.17
		0.8	35.03 ± 0.04	1.42 ± 0.01	0.82 ± 0	1.64 ± 0.01	29.88 ± 0.35
		1	35.2 ± 0.01	1.36 ± 0.01	0.72 ± 0	1.54 ± 0.01	27.92 ± 0.18
	W. pine oil	0.5	35.32 ± 0.04	1.34 ± 0	1 ± 0.01	1.67 ± 0	36.71 ± 0.26
		0.8	35.46 ± 0.01	1.26 ± 0.01	1.1 ± 0.01	1.66 ± 0	41.15 ± 0.35
		1	35.51 ± 0.01	1.21 ± 0.01	1.11 ± 0.01	1.64 ± 0.01	42.63 ± 0.46
H7	/	0	35.89 ± 0	1.51 ± 0.01	1.92 ± 0	2.44 ± 0	51.86 ± 0.09
	Rosemary	0.5	37.61 ± 0	1.07 ± 0.01	3.09 ± 0.01	3.27 ± 0.01	70.91 ± 0.13
		0.8	38.19 ± 0.02	1.09 ± 0.01	3.71 ± 0.01	3.86 ± 0	73.63 ± 0.1
		1	37.67 ± 0.01	1.06 ± 0.01	3.26 ± 0	3.43 ± 0.01	72.02 ± 0.13
	Levander	0.5	37.36 ± 0.01	1.13 ± 0	3.16 ± 0.01	3.35 ± 0.01	70.28 ± 0.05
		0.8	37.42 ± 0.01	1.12 ± 0	3.05 ± 0.01	3.24 ± 0	69.79 ± 0.06
		1	38.3 ± 0.01	1.1 ± 0.02	3.29 ± 0	3.47 ± 0	71.6 ± 0.28
	Oregano	0.5	38.05 ± 0.01	1.27 ± 0	3.42 ± 0.01	3.65 ± 0.01	69.54 ± 0.04
		0.8	37.81 ± 0.01	1.3 ± 0.01	3.59 ± 0	3.82 ± 0	70.18 ± 0.16
		1	35.96 ± 0.01	1.49 ± 0	2 ± 0.01	2.49 ± 0.01	53.19 ± 0.21
	Sage	0.5	35.99 ± 0.02	1.52 ± 0.01	2.1 ± 0.02	2.58 ± 0.01	54.11 ± 0.02
		0.8	36.04 ± 0	1.45 ± 0.01	2.07 ± 0.02	2.53 ± 0.01	55.03 ± 0.46
		1	36.22 ± 0	1.44 ± 0.01	2.14 ± 0.01	2.58 ± 0.01	56.19 ± 0.2
	W. pine oil	0.5	36.06 ± 0.01	1.48 ± 0.01	2.12 ± 0.01	2.58 ± 0.01	55.05 ± 0.19
		0.8	36.14 ± 0.01	1.45 ± 0.01	2.01 ± 0.01	2.48 ± 0.02	54.18 ± 0.1
		1	36.16 ± 0.07	1.47 ± 0.01	2.16 ± 0.08	2.57 ± 0.01	55.16 ± 0.08
H8	/	0	36.08 ± 0	1.55 ± 0	2.16 ± 0.02	2.66 ± 0.01	54.28 ± 0.3
	Rosemary	0.5	36.16 ± 0.01	1.53 ± 0.01	2.05 ± 0.01	2.56 ± 0.01	53.27 ± 0.35
		0.8	36.07 ± 0.01	1.57 ± 0.01	2.26 ± 0.02	2.74 ± 0.01	55.25 ± 0.15
		1	36.06 ± 0.01	1.57 ± 0	2.29 ± 0.01	2.77 ± 0	55.53 ± 0.01
	Levander	0.5	36.16 ± 0.01	1.6 ± 0.01	2.35 ± 0.01	2.84 ± 0	55.74 ± 0.33
		0.8	36.22 ± 0.01	1.57 ± 0.02	2.59 ± 0	3.04 ± 0.01	58.81 ± 0.35
		1	36.18 ± 0.04	1.53 ± 0.01	2.46 ± 0.01	2.89 ± 0	58.11 ± 0.05
	Oregano	0.5	36.05 ± 0.01	1.59 ± 0.01	2.25 ± 0.01	2.76 ± 0.01	54.74 ± 0.35
		0.8	36.02 ± 0.01	1.57 ± 0.01	2.18 ± 0.01	2.69 ± 0	54.23 ± 0.27
		1	36.16 ± 0.01	1.57 ± 0.01	2.31 ± 0.01	2.79 ± 0.01	55.84 ± 0.23
	Sage	0.5	36.25 ± 0.01	1.6 ± 0.01	2.49 ± 0.01	2.95 ± 0	57.3 ± 0.23
		0.8	36.18 ± 0	1.59 ± 0	2.42 ± 0.01	2.89 ± 0	56.7 ± 0.04
		1	36.11 ± 0.01	1.54 ± 0	2.22 ± 0.01	2.7 ± 0.01	55.13 ± 0.02
	W. pine oil	0.5	36.07 ± 0.02	1.56 ± 0.01	2.32 ± 0.01	2.8 ± 0.01	56.15 ± 0.28
		0.8	36.2 ± 0.01	1.61 ± 0.01	2.4 ± 0.01	2.88 ± 0	56.18 ± 0.15
		1	36.34 ± 0.01	1.55 ± 0	2.31 ± 0	2.79 ± 0.01	56.19 ± 0.06

Table A8. Average color parameters for honey samples with added aromatic plants—part four.

Honey	Aromatic Plants Added		Color Parameters				
	Type	Concentration (%)	*L*	*a*	*b*	*C*	*h*
H9	/	0	34.95 ± 0.04	1.24 ± 0.07	1.16 ± 0.01	1.73 ± 0.01	41.75 ± 0.04
	Rosemary	0.5	35.94 ± 0.01	1.45 ± 0.01	1.96 ± 0.01	2.43 ± 0.01	53.51 ± 0.06
		0.8	36.01 ± 0.06	1.46 ± 0.01	1.83 ± 0.23	2.47 ± 0.01	53.66 ± 0.47
		1	35.98 ± 0.04	1.48 ± 0.01	2.14 ± 0.01	2.61 ± 0.01	55.26 ± 0.38
	Levander	0.5	35.95 ± 0.04	1.49 ± 0	2.07 ± 0.04	2.55 ± 0.02	54.17 ± 0.35
		0.8	36.02 ± 0.01	1.5 ± 0.02	2.02 ± 0	2.52 ± 0.01	53.5 ± 0.25
		1	35.92 ± 0.01	1.49 ± 0.01	1.98 ± 0.01	2.47 ± 0	53 ± 0.41
	Oregano	0.5	36.04 ± 0.01	1.49 ± 0.02	2.07 ± 0.01	2.55 ± 0	54.38 ± 0.71
		0.8	35.93 ± 0.01	1.5 ± 0.01	2.05 ± 0	2.54 ± 0.01	53.92 ± 0.15
		1	36.03 ± 0.05	1.49 ± 0.01	1.98 ± 0	2.47 ± 0	53.14 ± 0.06
	Sage	0.5	36.11 ± 0.01	1.42 ± 0.02	1.88 ± 0.01	2.44 ± 0.13	53 ± 0.59
		0.8	36.01 ± 0.01	1.44 ± 0.01	2.01 ± 0.01	2.47 ± 0	54.43 ± 0.32
		1	36.29 ± 0.03	1.48 ± 0.01	2.07 ± 0.01	2.54 ± 0.01	54.51 ± 0.22
	W. pine oil	0.5	35.94 ± 0	1.46 ± 0.02	2.08 ± 0.01	2.54 ± 0.01	55.02 ± 0.39
		0.8	35.94 ± 0.07	1.34 ± 0.01	1.76 ± 0.01	2.21 ± 0	52.67 ± 0.28
		1	35.87 ± 0.01	1.37 ± 0.02	1.74 ± 0.01	2.21 ± 0.01	51.82 ± 0.41

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