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Evaluation of honeys of different botanical origins stored under average day and night temperatures

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Abstract: The objective of this study was to evaluate the properties of different honey samples (assa-peixe, bracatinga, coffee, cipó-uva, eucalyptus, gurucaia, laranjeira, and silvestre) during storage, over 180 days, at the average annual day (29.8°C) and night (19.3°C) temperatures. Several properties were quantified before and after storage, including fructose and glucose content, moisture, and fructose/glucose and glucose/ moisture ratios. Additionally, water activity, absorbance, electrical conductivity, color, and microscopic analyses were performed at the initial (T0), intermediate (T90), and final (T180) times of the experiment. Rheological behavior at the initial (T0), intermediate (T60), and final (T120). Therefore, the analysis time for this parameter was shorter, since it was based on pre-testing and previous work by the authors. In general, assa-peixe and cipó-uva honeys had greater changes during storage, especially at night temperatures. These two varieties showed intense and more pronounced crystallization based on the absorbance, color, and microscopy analyses. The changes observed at night temperature were more significant compared to those at daytime temperature. Varying storage conditions are important to preserve the quality of honeys from different sources. Therefore, studying the crystallization rate during storage is essential for the industry, since each honey crystallizes differently, altering its physical–chemical and rheological properties.

Keywords: stability; crystallization; botanical origin.

Practical Application: This study offers guidance on optimal storage and quality control of honey in the industry.

1 INTRODUCTION

Honey is a natural food produced from bee pollination. During the collection of nectar from flowers, bees mix plant compounds with secretions from their salivary glands and deposit this mixture in the honeycomb for maturation (Zheng et al., 2019). After maturation, honey is removed from the comb and can be characterized as a supersaturated solution composed of glucose, fructose, other carbohydrates, moisture, ash, protein, trace amounts of vitamins, enzymes, and other nutrients (Baloš et al., 2023; Schiassi et al., 2021). Its composition is influenced by geographic region, type of bee, botanical origin, and storage conditions, including temperature, packaging, and exposure to light and moisture (Schiassi et al., 2022).

Temperature, sugar composition, and water content are the three main factors that cause honey crystallization (Ji et al., 2023). Among them, the storage temperature is the one that can be controlled after processing and, therefore, must be optimized. Honey crystallization involves the separation of the liquid phase by breaking the bonds between glucose and water. Initially, a glucose molecule is linked to five water molecules. As crystallization occurs, this glucose molecule becomes monohydrate and releases four water molecules (Baloš et al., 2023; Gleiter et al., 2006).

The release of these water molecules can cause irreversible changes to the honey and favor the growth of microorganisms, such as osmophilic yeasts (Schiassi et al., 2022). Moreover, other chemical (absorbance, electrical conductivity) and physicochemical (color, viscosity, and microscopy) changes may occur after honey crystallization.

The content of the two most abundant sugars in honey (fructose and glucose) can also influence crystallization, as glucose has lower solubility and begins to crystallize first. The fructose/glucose (F/G) and glucose/moisture (G/M) ratios are two key indicators of the honey crystallization rate (Baloš et al., 2023).

Some authors have studied the effect of the temperature difference between day and night on various foods (Pniewski et al., 2023; Song et al., 2023), but none have evaluated this effect on honey. Therefore, it is necessary to identify these temperature variations to find the best storage conditions for honey, aiming to avoid changes and maintain its original quality.

With this in mind, the aim of this study was to assess the physicochemical, rheological, and microscopic changes in honey samples stored for 180 days at the average day (29.8°C) and night (19.3°C) temperatures.

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1.1 Relevance of the work

The relevance of this work lies in its contribution to a better understanding of the physical, chemical, and rheological behavior of different types of honey during storage under real-world temperature conditions. The results allow for the optimization of storage practices, ensuring product stability and preserving its sensory and nutritional characteristics. This is essential for the beekeeping industry, which seeks to maintain the quality and competitiveness of honey in the market.

2 MATERIAL AND METHODS

2.1 Honey samples

Assa-peixe (*Vernonia polysphaera*), bracatinga (*Mimosa scabrella* Benth.), coffee (*Coffea* spp.), cipó-uva (*Serjania lethalis*), eucalyptus (*Eucalyptus* spp.), gurucaia (*Parapiptadenia rigida*), laranjeira (*Citrus sinensis*), and silvestre honeys were acquired from an apiary located in São Lourenço, Minas Gerais, Brazil. According to the apiary owner, all the honeys were obtained in the 2023 harvest. After collection, they were centrifuged, filtered, packaged in 300 g transparent polyethylene tubes, and stored at room temperature. The botanical origin of the honeys can be attested, as they have been inspected and registered in accordance with current regulations (Brasil, 2000). All samples evaluated in the study have the Federal Inspection Seal (SIF) from the Ministry of Agriculture and Livestock (MAPA), which gives credibility to beekeepers and gives us support to ensure the floral origin of the honeys.

2.2 Sample preparation

To remove any crystals, the honey samples were heated in a 3-L digital water bath (WARMS1, Araucária, Brazil) at 40°C for 60 min (Schiassi et al., 2022). Subsequently, the honeys were removed from the water bath and left for 30 min under ambient conditions. To confirm the absence of crystals in the honeys, microscopic analysis was conducted using an optical microscope (ML2000, Meiji Techno Co., Ltd., Tokyo, Japan).

The samples were subsequently added to 200 mL transparent glass jars with lids. Each sample consisted of 150 mL of honey transferred to six separate jars, one for each time point (T90 and T180 days). Honeys for the initial time point (T0) were not stored in jars, as their analyses were conducted immediately after sample preparation.

The glass jars containing the honey samples were stored in a biological oxygen demand (BOD) refrigerated incubator (SL 200/300, SOLAB, Piracicaba, Brazil) at two distinct temperatures: the average day (29.8°C) and night (19.3°C) temperatures. These temperatures were obtained from the survey conducted by Dados Mundiais (2024).

2.3 Characterization of honey samples

The fructose and glucose content of honey samples was quantified by high-performance liquid chromatography (HPLC) with the Prominence HPLC System (Shimadzu Scientific Instruments, Tampa, United States), following the methodology proposed by Bogdanov (2009). Briefly, 1 g of honey was dissolved in 9 mL of ultrapure water, then centrifuged at 10,000 × g for 10 min at 30°C. The resulting supernatant was filtered with a 0.45 μm syringe filter (Filtrilo, Colombo, Brazil). The filtrate was injected into the HPLC system, which was equipped with a refractive index detector (RID-10A, Shimadzu, Barueri, Brazil). The analysis was conducted using the SUPELCOGEL™ 8H column (Shimadzu, Barueri, Brazil) with the following conditions: mobile phase, 5 mM sulfuric acid (LC-20AT pump, Shimadzu, Barueri, Brazil); flow rate, 0.5 mL/min; injected volume, 20 μL with a SIL-20A injector (Shimadzu, Barueri, Brazil); and column temperature, 30°C. The evaluated sugars were identified based on their retention times compared to sugar standards, and their concentrations were calculated using their respective calibration curves.

The moisture content was measured using a portable refractometer (RT-280, Instrutherm Measuring Instruments, São Paulo, Brazil) following the methodology by Association of Official Analytical Chemists (AOAC, 2012). The refractive index of each honey sample was determined, and the result was converted into moisture content using a reference table (Chataway) and expressed as a percentage. The honey crystallization rate was evaluated by calculating the fructose/glucose (F/G) and glucose/moisture (G/M) ratios.

2.4 Evaluation of honey samples during storage

2.4.1 Physicochemical analysis

The water activity (aw) of the honey samples was measured using a water activity meter (Aqualab CX2 T, Decagon Devices Inc., Pullman, USA) at 25 ± 0.3°C. The absorbance analysis was carried out according to the methodology proposed by Lupano (1997): the samples were placed in a 10 mm square optical glass cuvette with a volume of 3.5 mL, and the absorbance was measured at 660 nm in a spectrophotometer (VIS 325–1000 nm, model Biospectro SP-22, São Paulo, Brazil).

Electrical conductivity analysis was performed according to Bogdanov (2009). The samples were first diluted in deionized water at 20% (m/v). Then, the electrical conductivity was measured at 20°C using a conductivity meter (NT-CVM, Novatecnica, São Paulo, Brazil), with the results being expressed in μS/cm.

The color of the honey samples was determined with an instrumental colorimeter (CM5, Konica Minolta Business Solutions, São Paulo, Brazil) equipped with the CIELab color system. The parameters L*, C*, and h° were evaluated, where L* is lightness, ranging from 100 for pure white surfaces to 0 for pure black surfaces; C* is saturation; and h° is hue.

2.4.2 Microscopic analysis

An optical microscope (ML2000, Meiji Techno Co., Ltd., Tokyo, Japan) with polarized light was used to evaluate the crystallization process and the morphological state of the samples (Schiassi et al., 2022). An aliquot of each honey was placed on the slide, covered with a glass coverslip, visualized under 10 × magnification, and photographed with a camera (CMOS, EVTSCAN, China).

2.4.3 Rheological behavior

Rheological behavior was determined at 25°C in a concentric-cylinder rotational rheometer (model DV III Ultra, Brookfield Engineering Laboratories, Stoughton, USA) using an SC4-25 spindle. To stabilize the temperature, a Brookfield thermostatic bath (EX 200 model, Brookfield Engineering Laboratories) was coupled to the jacketed cylinder. Each sample was submitted to an increasing shear rate ramp from 0 to 30 s^{-1}. The experimental data were then fitted to Newton's law (Equation 1), Power law (Equation 2), and Herschel-Bulkley (Equation 3) models:

$$\sigma=\mu\dot{\gamma} \tag{1}$$

$$\sigma=k\dot{\gamma}^{n} \tag{2}$$

$$\sigma=\sigma_0+k\dot{\gamma}^{n} \tag{3}$$

where σ is the shear stress (Pa), μ is the Newtonian viscosity (Pa·s), $\dot{\gamma}$ is the shear rate (s^{-1}), k is the consistency index ($Pa{\cdot}s^n$), n is the flow behavior index (dimensionless), and σ_0 is the yield stress (Pa).

2.5 Statistical analysis

The fructose, glucose, and moisture contents, as well as the F/G and G/M ratios, were evaluated at T0 and T180 days since the objective was to characterize the honey samples.

Water activity, absorbance, electrical conductivity, and color (L*, C*, and h° parameters) analyses were evaluated at the initial (T0), intermediate (T90), and final (T180) times of the experiment. The colorimetric analyses were adjusted to a linear regression model to evaluate the effect of storage time on these parameters, using the statistical package Statistical Analysis System software (SAS University Edition, Cary, USA, 2016). Analysis of variance (ANOVA) was used to examine the statistical significance of terms in the regression equations, and residual analysis of the fitted models was performed. The results of the characterization and evaluation of honey samples during storage were submitted to an analysis of variance (ANOVA). And Tukey's average test ($p \geq .05$) with the aid of the software SensoMaker v. 1.91 (UFLA, Lavras, MG, Brazil, 2017), was used for the evaluation of honey samples during storage.

Rheological behavior was evaluated at the initial (T0), intermediate (T60), and final (T120) times of the experiment. Therefore, the analysis time for this parameter was shorter, being based on pre-testing and previous work by the authors (Schiassi et al., 2022), since it was observed that due to the increased crystallization of all samples during storage, it is not possible to perform the rheological analysis on time point T180.

The rheological models were adjusted to the experimental data using the SAS. Furthermore, regression analysis for the viscosities of the honey samples was carried out using the same statistical package. The microscopic analysis was also carried out for 180 days, being evaluated at the initial (T0), intermediate (T90), and final (T180) times of the experiment. Microscopy images at T0 were not presented because the samples did not yet have crystals.

3 RESULTS AND DISCUSSION

3.1 Characterization of samples

The sugar content (fructose and glucose), moisture content, and the F/G (fructose/glucose) and G/M (glucose/moisture) ratios of honeys stored under different temperature conditions (average day and night temperatures) are presented in Table 1.

The main sugars in honey are glucose and fructose. Glucose tends to crystallize faster due to its lower solubility in water when compared to fructose, which is 4.4 times more soluble (Amarieri et al., 2020; Escuredo et al., 2014). Initially, glucose levels (G%) ranged from 20.76 to 33.89% (bracatinga and eucalyptus, respectively), while fructose levels (F%) ranged from 24.08 to 37.82% (coffee and eucalyptus, respectively). There was an increase in F% and G% in all varieties between T0 and T180 at both storage temperatures. Additionally, fructose content was higher than the glucose content. The coffee, cipó-uva, laranjeira, and bracatinga varieties showed higher fructose and glucose values when stored at daytime temperatures.

Present and discuss results concisely, using figures and tables as needed (but not the same information in both figures and tables). Compare results to those previously reported, and indicate what new information is contributed herein. Place figures and tables at the end of the document, after references. Alternatively, it is okay to upload figures and tables as separate files, but be sure that they appear after the main text file when you upload them.

Another important parameter in honey is moisture content (M%), which initially varied from 16.83% in laranjeira honey to 19.47% in silvestre honey. Over the 180-day period, M% ranged from 17.23% in laranjeira honey to 20.60% in silvestre honey when stored at the daytime temperature. Meanwhile, it ranged from 17.67% (coffee) to 20.93% (silvestre) when stored at nighttime temperatures. Only silvestre honey at both tested temperatures and over a period of 180 days exceeded the 20% limit recommended by international standards (Codex Alimentarius Commission, 2001).

The F/G ratio is used to characterize the crystallization rate of honeys, distinguishing between fast and slow crystallization. Coffee honey at T0 (1.10); eucalyptus at T0 (1.12) and at T180 for daytime temperature (1.12); and gurucaia on T180 for both day (0.82) and night (0.84) temperatures showed rapid crystallization since F/G ≤ 1.14 (Dobre et al., 2012; Escuredo et al., 2014; Venir et al., 2010). The remaining varieties can be classified as having slow crystallization.

Rather than the F/G ratio, different studies indicate that a honey's tendency to crystallize can be better predicted by the G/M ratio (Amarieri et al., 2020; Dobre et al., 2012). All honey varieties, regardless of time point or storage temperature, showed slow crystallization (G/M < 1.7), except for eucalyptus honey at T0 (1.84) and at T180 for day (1.91) and night (1.85) temperatures; bracatinga honey at T180 for daytime temperature (1.99); and assa-peixe at T180 for nighttime temperature (1.90).

Table 1. Fructose, glucose, moisture, and fructose/glucose and glucose/moisture ratios in honeys of different botanical origins before and after 180 days of storage at average day and night temperatures.

		Monofloral						Polyfloral	Honeydew
		Assa-peixe	**Coffee**	**Cipó-uva**	**Eucalyptus**	**Gurucaia**	**Laranjeira**	**Silvestre**	**Bracatinga**
F (%)	**T0**	32.33 ± 0.02^{Cc}	24.08 ± 0.07^{Hc}	27.46 ± 0.01^{Fc}	37.82 ± 0.01^{Ac}	33.38 ± 0.02^{Bb}	31.75 ± 0.10^{Dc}	29.14 ± 0.01^{Ec}	25.74 ± 0.32^{Gc}
	T180 D	37.39 ± 0.01^{Db}	38.12 ± 0.01^{Ca}	39.86 ± 0.02^{Ba}	39.63 ± 0.23^{Bb}	35.27 ± 0.04^{Ga}	36.71 ± 0.09^{Fa}	34.83 ± 0.23^{Hb}	41.73 ± 0.18^{Aa}
	T180 N	44.38 ± 1.15^{Aa}	29.83 ± 0.67^{Gb}	36.82 ± 0.03^{Db}	41.08 ± 0.02^{Ba}	35.32 ± 0.03^{Ea}	32.97 ± 0.27^{Fb}	38.22 ± 0.63^{Ca}	30.74 ± 0.04^{Gb}
G (%)	**T0**	24.94 ± 0.01^{CDc}	21.89 ± 0.01^{Fc}	22.83 ± 0.02^{Ec}	33.89 ± 0.01^{Ab}	26.77 ± 0.00^{Bc}	24.70 ± 0.06^{Dc}	25.23 ± 0.01^{Cc}	20.76 ± 0.29^{Gc}
	T180 D	30.65 ± 0.02^{Db}	30.23 ± 0.01^{Ea}	31.17 ± 0.02^{Ca}	35.43 ± 0.18^{Ba}	28.88 ± 0.00^{Fb}	28.33 ± 0.03^{Ga}	27.05 ± 0.10^{Hb}	36.69 ± 0.14^{Aa}
	T180 N	34.48 ± 0.85^{Aa}	24.47 ± 0.51^{Eb}	28.81 ± 0.02^{Cb}	35.25 ± 0.01^{Aa}	29.76 ± 0.01^{Ba}	25.71 ± 0.24^{Db}	30.10 ± 0.15^{Ba}	24.35 ± 0.01^{Eb}
M (%)	**T0**	17.40 ± 0.00^{CDb}	17.33 ± 0.12^{DEa}	17.40 ± 0.00^{CDb}	18.40 ± 0.35^{Ba}	17.60 ± 0.00^{CDa}	16.83 ± 0.25^{Eb}	19.47 ± 0.12^{Ab}	17.87 ± 0.12^{Ca}
	T180 D	18.50 ± 0.56^{BCa}	17.83 ± 0.23^{CDa}	18.40 ± 0.36^{BCa}	18.57 ± 0.31^{BCa}	18.27 ± 0.21^{BCa}	17.23 ± 0.23^{Dab}	20.60 ± 0.12^{Aa}	18.40 ± 0.15^{Ba}
	T180 N	18.10 ± 0.36^{CDab}	17.67 ± 0.64^{Da}	17.93 ± 0.25^{Dab}	19.07 ± 0.50^{Ba}	18.20 ± 0.53^{CDa}	18.57 ± 0.83^{BCa}	20.93 ± 0.59^{Aa}	18.57 ± 0.38^{BCa}
F/G	**T0**	1.30 ± 0.00^{Aa}	1.10 ± 0.00^{Gc}	1.20 ± 0.00^{Db}	1.12 ± 0.00^{Fb}	1.25 ± 0.00^{Ca}	1.28 ± 0.00^{Bb}	1.16 ± 0.00^{Eb}	1.24 ± 0.00^{Cb}
	T180 D	1.22 ± 0.00^{Eb}	1.26 ± 0.00^{Da}	1.28 ± 0.00^{Ba}	1.12 ± 0.00^{Gb}	1.22 ± 0.00^{Eb}	1.30 ± 0.00^{Aa}	1.29 ± 0.01^{ABa}	1.14 ± 0.00^{Fc}
	T180 N	1.29 ± 0.00^{Aa}	1.22 ± 0.00^{Cb}	1.28 ± 0.00^{Aa}	1.17 ± 0.00^{Ea}	1.19 ± 0.00^{Dc}	1.28 ± 0.00^{Ab}	1.27 ± 0.02^{ABa}	1.26 ± 0.00^{Ba}
G/M	**T0**	1.43 ± 0.00^{Dc}	1.26 ± 0.00^{Fc}	1.31 ± 0.00^{Ec}	1.84 ± 0.00^{Ab}	1.52 ± 0.00^{Bc}	1.47 ± 0.00^{Cb}	1.30 ± 0.00^{Eb}	1.16 ± 0.00^{Gc}
	T180 D	1.66 ± 0.00^{Db}	1.70 ± 0.00^{Ca}	1.69 ± 0.00^{Ca}	1.91 ± 0.01^{Ba}	1.58 ± 0.00^{Eb}	1.64 ± 0.00^{Da}	1.31 ± 0.00^{Fb}	1.99 ± 0.00^{Aa}
	T180 N	1.90 ± 0.05^{Aa}	1.38 ± 0.03^{Eb}	1.61 ± 0.00^{Cb}	1.85 ± 0.00^{Bb}	1.63 ± 0.00^{Ca}	1.38 ± 0.01^{Ec}	1.44 ± 0.01^{Da}	1.31 ± 0.00^{Fb}

Results are expressed as mean value ± standard deviation (n = 3). T0 = initial time; T180 = 180 days. D: day; N: night; F: fructose; G: glucose; M: moisture; F/G: fructose/glucose; and G/M: glucose/moisture. Equal uppercase letters in the same row have no significant difference using the Tukey test at 5% significance. Equal lowercase letters in the same column have no significant difference using Tukey's test at 5% significance.

3.2 Evaluation of honey samples during storage

The results for the analysis of water activity (aw), absorbance, and electrical conductivity of honeys stored under different temperature conditions for T0, T90, and T180 days are presented in Table 2.

Water activity is a parameter that represents the fraction of water not strongly bound to solids (Tarapoulouzi et al., 2023). In honey, those solids are mainly sugars, and aw typically ranges from 0.50 to 0.65. The higher the water activity of the honey, the greater the chances of fermentation and deterioration by osmophilic yeasts (Gleiter et al., 2006).

During the crystallization of honey, the bonds between the sugar (mainly glucose) and water molecules change, forming glucose monohydrate. Fructose, which is also present in honey, remains in solution for longer due to its solubility. This transformation of glucose releases previously trapped water molecules, thus increasing the water activity of the honey (Gleiter et al., 2006; Ji et al., 2023).

According to Table 2, all honeys analyzed showed a gradual increase in water activity between T0, T90, and T180 in both storage conditions, except for laranjeira (0.54) and bracatinga (0.55) honeys stored at day temperature, which had the same water activity at T90 and T180. This increasing trend was also identified by other authors (Schiassi et al., 2021; Venir et al., 2010). Before storage (T0), values ranged from 0.49 (cipó-uva) to 0.54 (bracatinga). Despite the gradual increase, the water activity values found for day and night temperature storage were very similar.

Osmophilic yeasts require high concentrations of sugar and are capable of growing when aw ≥ 0.6 (Gleiter et al., 2006). Such values were found only for laranjeira honey (0.62) stored under night temperature at T180, facilitating the action of these yeasts, which can cause fermentation and undesirable changes in the quality of the honey.

For absorbance, Table 2 shows a trend of gradual increase over time in both conditions. According to Costa et al. (2015), the turbidity of honey increases as crystallization occurs; therefore, the increase in absorbance at 660 nm can be considered indicative of crystallization.

Lower absorbance values were observed at night temperature, except for assa-peixe honey at T180 (0.87). Since variations in absorbance values are directly linked to the formation of crystals and changes in sample opacity (Schiassi et al., 2021), it can be said that lower temperatures resulted in fewer physical changes in the honeys. On the other hand, higher absorbance values were observed at daytime temperatures for eucalyptus (0.49), gurucaia (0.54), and bracatinga (0.56), indicating greater crystallization during storage for 180 days.

Regarding the results of the electrical conductivity analysis, the values initially varied from 186.40 in laranjeira honey to

Table 2. Water activity, absorbance, and electric conductivity in honeys of different botanical origins before, during, and after storage (T0, T90, and T180 days) at average day and night temperatures.

	Water activity (a_w)				
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	0.52 ± 0.00^{Cd}	0.53 ± 0.02^{BCbc}	0.54 ± 0.00^{DEab}	0.54 ± 0.00^{Ebc}	0.56 ± 0.00^{Ea}
Coffee	0.53 ± 0.00^{Bd}	0.54 ± 0.00^{BCcd}	0.56 ± 0.00^{Ba}	0.54 ± 0.00^{Fc}	0.55 ± 0.00^{Fb}
Cipó-uva	0.49 ± 0.00^{Fe}	0.52 ± 0.00^{Cd}	0.56 ± 0.00^{BCb}	0.53 ± 0.00^{Fc}	0.57 ± 0.00^{Da}
Eucalyptus	0.52 ± 0.00^{Ce}	0.53 ± 0.00^{BCd}	0.57 ± 0.00^{Aa}	0.55 ± 0.00^{Cc}	0.56 ± 0.00^{Eb}
Gurucaia	0.51 ± 0.00^{De}	0.53 ± 0.00^{BCd}	0.56 ± 0.00^{BCb}	0.54 ± 0.00^{Ec}	0.57 ± 0.00^{Da}
Laranjeira	0.50 ± 0.00^{Ee}	0.54 ± 0.00^{ABCc}	0.54 ± 0.00^{Ed}	0.55 ± 0.00^{Db}	0.62 ± 0.00^{Aa}
Polyfloral					
Silvestre	0.53 ± 0.00^{Bd}	0.56 ± 0.00^{Ac}	0.57 ± 0.00^{Ab}	0.56 ± 0.00^{Ac}	0.60 ± 0.00^{Ba}
Honeydew					
Bracatinga	0.54 ± 0.00^{Ab}	0.55 ± 0.02^{ABb}	0.55 ± 0.01^{CDb}	0.56 ± 0.00^{Bb}	0.58 ± 0.00^{Ca}
	Absorbance				
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	0.05 ± 0.00^{Ee}	0.12 ± 0.00^{Ed}	0.23 ± 0.00^{Eb}	0.20 ± 0.00^{Dc}	0.87 ± 0.00^{Aa}
Coffee	0.08 ± 0.00^{De}	0.12 ± 0.00^{Fc}	0.17 ± 0.00^{Da}	0.09 ± 0.00^{Gd}	0.14 ± 0.00^{Fb}
Cipó-uva	0.10 ± 0.00^{Ce}	0.15 ± 0.00^{Dd}	0.25 ± 0.00^{Da}	0.17 ± 0.00^{Ec}	0.19 ± 0.00^{Eb}
Eucalyptus	0.20 ± 0.00^{Be}	0.38 ± 0.00^{Bc}	0.49 ± 0.00^{Ca}	0.32 ± 0.00^{Bd}	0.40 ± 0.00^{Cb}
Gurucaia	0.21 ± 0.02^{Abe}	0.34 ± 0.00^{Cc}	0.54 ± 0.00^{Ba}	0.30 ± 0.00^{Cd}	0.46 ± 0.00^{Bb}
Laranjeira	0.04 ± 0.00^{Ed}	0.08 ± 0.00^{Gb}	0.13 ± 0.00^{Fa}	0.06 ± 0.00^{Hc}	0.07 ± 0.00^{Hc}
Polyfloral					
Silvestre	0.09 ± 0.01^{CDd}	0.12 ± 0.00^{Fc}	0.24 ± 0.00^{Da}	0.13 ± 0.00^{Fb}	0.11 ± 0.00^{Gc}
Honeydew					
Bracatinga	0.23 ± 0.01^{Ae}	0.42 ± 0.00^{Ab}	0.56 ± 0.00^{Aa}	0.33 ± 0.00^{Ad}	0.38 ± 0.00^{Dc}
	Electric conductivity (μS/cm)				
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	300.30 ± 0.80^{Ee}	317.07 ± 0.67^{Ec}	329.43 ± 0.35^{Ea}	311.60 ± 0.46^{Ed}	323.57 ± 0.55^{Eb}
Coffee	416.97 ± 0.95^{Dc}	413.77 ± 0.38^{Dd}	431.00 ± 0.17^{Db}	410.23 ± 0.06^{De}	447.90 ± 0.87^{Da}
Cipó-uva	215.80 ± 0.69^{Fd}	219.47 ± 0.45^{Fc}	240.33 ± 0.06^{Fa}	218.83 ± 0.64^{Fc}	229.50 ± 0.82^{EFb}
Eucalyptus	977.23 ± 0.21^{Ba}	976.50 ± 1.01^{Ba}	990.88 ± 0.40^{Ba}	971.63 ± 0.42^{Ba}	985.97 ± 0.15^{Ba}
Gurucaia	213.07 ± 0.93^{Gc}	211.40 ± 0.10^{Gcd}	223.43 ± 0.42^{Ga}	210.53 ± 0.25^{Gd}	219.50 ± 0.87^{Fb}
Laranjeira	186.40 ± 0.46^{He}	202.63 ± 0.72^{Hd}	210.43 ± 0.23^{Ha}	204.37 ± 0.67^{Hc}	206.17 ± 0.38^{Fb}
Polyfloral					
Silvestre	822.57 ± 0.60^{Cab}	807.07 ± 0.67^{Cc}	836.10 ± 0.70^{Ca}	801.30 ± 1.11^{Cbc}	832.60 ± 0.53^{Ca}
Honeydew					
Bracatinga	1308.00 ± 1.00^{Ad}	1351.33 ± 0.58^{Ab}	1366.33 ± 0.58^{Aa}	1330.00 ± 1.00^{Ac}	1350.33 ± 0.58^{Ab}

Note(s): Results are expressed as mean value ± standard deviation (n = 3). Water activity: aw; T0 = initial time; T90 = 90 days; T180 = 180 days. Equal capital letters in the same column have no significant difference using the Tukey test at 5% significance. Equal lowercase letters in the same row have no significant difference using the Tukey test at 5% significance.

1308.00 μS/cm in bracatinga honey. Electrical conductivity is a parameter correlated with the mineral content, organic acids, and proteins in honey, along with the storage time (Kędzierska-Matysek et al., 2016; Raweh et al., 2022). Honeys from different botanical origins have different compositions, leading to differences in electrical conductivity values.

Eucalyptus, silvestre, and bracatinga honeys had electrical conductivity values above the international standard limit of 800 μS/cm (Codex Alimentarius Commission, 2001), based on the analysis from T0 to T180, for both daytime and nighttime conditions.

Furthermore, two distinct behaviors were identified: a decrease in the conductivity value between T0 and T90 followed by an increase between T90 and T180 (coffee, eucalyptus, gurucaia, and silvestre), and a gradual increase from T0 to T180 (assa-peixe, cipó-uva, laranjeira, and bracatinga). Raweh et al. (2022) also found a behavior like the second trend observed in our study (i.e., an increase in electrical conductivity over storage time).

Table 3 presents the mean values for the colorimetric parameters (L*, C*, and h°) of the honey samples at different storage time points (T0, T90, and T180 days) and conditions (average day and night temperatures). Table 4 shows the regression equations for the color parameters and their respective coefficients of determination (R2). The p-value for all honey varieties in both storage conditions was lower than 0.0001, indicating a significant difference.

For the color parameter h°, the honeys showed varying results between 55.44 for gurucaia at T0 to 117.61 and 118.03 at T180 for laranjeira at day and night temperatures, respectively. Values for this parameter increased between T0 and T180, indicating a shift towards a yellowish tone. All honeys stored under night temperature had higher when compared to those stored under daytime temperature at T180. This indicates that by the

Table 3. Colorimetric analysis (L*, C*, and h° parameters) of honeys of different botanical origins before, during, and after storage (T0, T90, and T180 days) at average day and night temperatures.

Parameter L*					
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	7.26 ± 0.07^{ABe}	8.47 ± 0.25^{Bd}	14.46 ± 0.07^{Cc}	21.26 ± 0.03^{Ab}	35.65 ± 0.04^{Aa}
Coffee	6.39 ± 0.13^{Ce}	8.88 ± 0.11^{Bd}	16.66 ± 0.13^{Aa}	10.15 ± 0.12^{BCc}	13.86 ± 0.10^{Fb}
Cipó-uva	7.92 ± 0.23^{Ad}	10.95 ± 0.29^{Ac}	16.25 ± 0.05^{Bb}	10.75 ± 0.08^{Bc}	19.28 ± 0.06^{Ba}
Eucalyptus	5.65 ± 0.06^{De}	7.32 ± 0.23^{Cd}	12.77 ± 0.01^{Fb}	7.73 ± 0.06^{Ec}	14.08 ± 0.01^{Fa}
Gurucaia	6.79 ± 0.04^{BCe}	8.48 ± 0.09^{Bd}	13.51 ± 0.29^{Eb}	10.77 ± 0.07^{Bc}	14.57 ± 0.31^{Ea}
Laranjeira	6.79 ± 0.54^{BCd}	10.27 ± 0.10^{Ac}	15.87 ± 0.17^{Bb}	10.01 ± 0.07^{Cc}	17.49 ± 0.01^{Da}
Polyfloral					
Silvestre	7.81 ± 0.33^{Ad}	10.38 ± 0.80^{Ac}	13.96 ± 0.06^{Db}	8.46 ± 0.66^{Dd}	18.51 ± 0.36^{Ca}
Honeydew					
Bracatinga	6.41 ± 0.06^{Ce}	7.19 ± 0.02^{Cd}	12.46 ± 0.07^{Fa}	7.79 ± 0.15^{DEc}	11.51 ± 0.00^{Gb}
Parameter C*					
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	4.36 ± 0.06^{Cd}	4.90 ± 0.23^{Dd}	7.30 ± 0.50^{ABCc}	13.52 ± 0.10^{Ab}	33.65 ± 0.71^{Aa}
Coffee	3.97 ± 0.42^{Cc}	5.07 ± 0.16^{CDb}	6.96 ± 0.18^{ABCa}	4.50 ± 0.12^{Ebc}	6.34 ± 0.23^{Fa}
Cipó-uva	5.48 ± 0.24^{Be}	8.05 ± 0.06^{Ac}	8.85 ± 0.54^{ABb}	6.41 ± 0.03^{Cd}	13.27 ± 0.06^{Ba}
Eucalyptus	6.52 ± 0.16^{Ad}	8.24 ± 0.31^{Ab}	10.06 ± 0.50^{Aa}	7.38 ± 0.32^{Bc}	8.59 ± 0.06^{Cb}
Gurucaia	5.76 ± 0.13^{Abc}	6.35 ± 0.93^{Bbc}	8.90 ± 0.08^{ABCa}	6.34 ± 0.28^{Cbc}	7.37 ± 0.12^{Db}
Laranjeira	5.44 ± 0.38^{Bb}	6.16 ± 0.11^{Bca}	6.58 ± 0.12^{ABCa}	6.48 ± 0.20^{Ca}	6.75 ± 0.08^{DEa}
Polyfloral					
Silvestre	4.40 ± 0.27^{Cc}	6.03 ± 0.02^{BCb}	9.67 ± 0.87^{Ca}	5.56 ± 0.23^{Dbc}	6.06 ± 0.43^{Fb}
Honeydew					
Bracatinga	5.74 ± 0.22^{Bb}	6.25 ± 0.28^{Bab}	6.80 ± 0.36^{BCa}	6.08 ± 0.20^{CDb}	6.26 ± 0.03^{Fab}
Parameter hº					
Botanical origins	**Day**			**Night**	
	T0	**T90**	**T180**	**T90**	**T180**
Monofloral					
Assa-peixe	82.70 ± 0.11^{Ee}	88.43 ± 0.92^{Cd}	96.55 ± 0.33^{Eb}	85.31 ± 0.11^{Dd}	104.98 ± 0.84^{Da}
Coffee	86.12 ± 0.83^{Dd}	92.44 ± 0.82^{Bc}	104.81 ± 0.57^{Db}	103.31 ± 0.72^{Bb}	107.23 ± 0.24^{Ca}
Cipó-uva	92.87 ± 0.07^{Bbc}	93.43 ± 0.01^{Babc}	108.27 ± 0.09^{Cab}	96.90 ± 0.61^{Cc}	113.35 ± 0.80^{Ba}
Eucalyptus	62.45 ± 0.60^{Gd}	69.10 ± 0.93^{Db}	71.96 ± 0.63^{Ga}	65.63 ± 0.96^{Fc}	69.57 ± 0.36^{Fb}
Gurucaia	55.44 ± 0.28^{He}	59.78 ± 0.61^{Ed}	67.24 ± 0.12^{Ha}	60.90 ± 0.50^{Gc}	64.51 ± 0.12^{Gb}
Laranjeira	98.86 ± 0.69^{Ad}	101.17 ± 0.43^{Ac}	117.61 ± 0.41^{Aa}	107.02 ± 0.31^{Ab}	118.03 ± 0.32^{Aa}
Polyfloral					
Silvestre	89.45 ± 0.52^{Ce}	92.12 ± 0.76^{Bd}	109.54 ± 0.60^{Ba}	97.59 ± 0.61^{Cc}	104.23 ± 0.64^{Db}
Honeydew					
Bracatinga	65.56 ± 0.48^{Fd}	69.00 ± 0.94^{Dc}	73.81 ± 0.14^{Fa}	70.51 ± 0.88^{Eb}	73.71 ± 0.60^{Ea}

Results are expressed as mean value ± standard deviation (n = 3). T0 = initial time; T90 = 90 days; T180 = 180 days. Equal capital letters in the same column have no significant difference using the Tukey test at 5% significance. Equal lowercase letters in the same row have no significant difference using the Tukey test at 5% significance.

Table 4. Regression equations for colorimetric parameters (L*, C*, and h°) of honeys of different botanical origins before, during, and after storage (T0, T90, and T180 days) at average day and night temperatures.

L* – Regression model – Y = *a* + *bx*						
Botanical origins	**Day**			**Night**		
	a	***b***	***R²***	***a***	***b***	***R²***
Monofloral						
Assa-peixe	6.4617	0.0400	0.8715	7.1944	0.1577	0.9999
Coffee	5.5100	0.0570	0.9184	6.4022	0.0415	1.0000
Cipó-uva	7.5406	0.0463	0.9761	6.9678	0.0631	0.9227
Eucalyptus	5.0222	0.0396	0.9138	4.9417	0.0468	0.9212
Gurucaia	6.2122	0.0379	0.9217	6.8156	0.0433	0.9998
Laranjeira	6.4411	0.0504	0.9822	6.0833	0.0594	0.9498
Polyfloral						
Silvestre	7.6428	0.0342	0.9909	6.2461	0.0594	0.7952
Honeydew						
Bracatinga	5.6578	0.0336	0.8448	6.0161	0.0284	0.9343
C* – Regression model – Y = *a* + *bx*						
Botanical origins	**Day**			**Night**		
	a	***b***	***R²***	***a***	***b***	***R²***
Monofloral						
Assa-peixe	4.0478	0.0164	0.8835	2.5289	0.1627	0.9554
Coffee	3.8417	0.0166	0.9772	3.7533	0.0131	0.9060
Cipó-uva	5.7750	0.0187	0.9158	4.4911	0.0433	0.8378
Eucalyptus	6.5061	0.0196	0.9997	6.4628	0.0115	0.9898
Gurucaia	5.4367	0.0174	0.8851	5.6883	0.0089	0.9744
Laranjeira	5.4856	0.0064	0.9787	5.5672	0.0073	0.8935
Polyfloral						
Silvestre	4.0656	0.0293	0.9538	4.5094	0.0092	0.9506
Honeydew						
Bracatinga	5.7300	0.0059	0.9995	5.7628	0.0029	0.9710
hº – Regression model – Y = *a* + *bx*						
Botanical origins	**Day**			**Night**		
	a	***b***	***R²***	***a***	***b***	***R²***
Monofloral						
Assa-peixe	82.2872	0.0774	0.9896	79.8550	0.1238	0.8364
Coffee	85.1100	0.1039	0.9664	88.3294	0.1173	0.8836
Cipó-uva	90.4944	0.0855	0.7727	90.8022	0.1138	0.8907
Eucalyptus	63.0822	0.0529	0.9497	62.3239	0.0395	0.9962
Gurucaia	54.9222	0.0656	0.9771	55.7517	0.0504	0.9863
Laranjeira	96.3689	0.1051	0.8462	98.2472	0.1074	0.9936
Polyfloral						
Silvestre	86.9917	0.01116	0.8471	89.7000	0.0821	0.9966
Honeydew						
Bracatinga	65.3306	0.0458	0.9911	65.9261	0.0448	0.9861

Storage times (0, 90, and 180 days); *Y*: dependent variable, *x*: storage time (days), *a* and *b*: estimated model coefficients, R^2: coefficient of determination

end of the storage period, all honeys at night temperatures lost some color due to the lower temperatures.

According to Tappi et al. (2021), the color of honey is related to the botanical origin and the content of some components that appear in smaller proportions, such as minerals and polyphenols. The color may also change due to processing and storage operations, which justify the changes observed in our study between the two temperatures. Other authors (Chou et al., 2020; Raweh et al., 2022) reported that prolonged storage and exposure to heat may cause the Maillard reaction, a non-enzymatic browning reaction involving sugars and free amino acids. This reaction promotes a gradual increase in color, making this parameter a possible indicator of quality (Misto et al., 2019).

3.3 Rheological behavior

The rheological profile of honey samples was best described by Newton's law model (μ, Newtonian viscosity – Pa.s), showing a high coefficient of determination ($0.947 \leq R^2 \leq 1.000$) and low root mean square error values ($0.057 \leq RMSE \leq 5.158$). This indicated that all honey samples displayed a Newtonian flow profile, regardless of their storage temperature. According to Faustino and Pinheiro (2021), most honeys behave like Newtonian fluids, meaning that their viscosity does not change when different shear rates are applied. These authors further state that such behavior is common across honeys, independent of their botanical or geographic origin or their maturation or storage conditions. Furthermore, the constant viscosity of honeys can be attributed to their composition as concentrated solutions of low molecular weight compounds, which commonly exhibit Newtonian behavior (Santos et al., 2014).

The Newtonian viscosity values (μ) of honeys at different temperatures and storage times were subjected to regression analysis. Second-degree polynomial models were fitted with $p < 0.05$, describing the viscosity behavior (dependent variable) as a function of storage time (independent variable) for each type of honey at day and night temperatures (Table 5 and 6).

In Table 5, it is observed that differences in storage temperatures caused variations in honey viscosity. In general, samples stored under daytime conditions showed an increase in viscosity over time, which may be related to crystallization during storage. Schiassi et al. (2022) and Šopík et al. (2022) also found

Table 5. Regression equations for honeys of different botanical origins before, during, and after storage (T0, T90, and T180 days) at average day and night temperatures.

Botanical origins	Newtonian viscosity (μ – Pa·s) Regression model: $Y = a + bx + cx^2$							
	Day				Night			
	a	*b*	*C*	R^2	*a*	*b*	*c*	R^2
Monofloral								
Assa-peixe	16.4490	0.2270	−0.0016	0.9879	16.4490	−0.2384	0.0033	0.9732
Coffee	21.8650	−0.1565	0.0019	0.9918	21.8650	−0.2691	0.0014	0.9929
Cipó-uva	36.5090	−0.4247	0.0155	0.9880	36.5090	−0.0398	−0.0009	0.9889
Eucalyptus	15.2770	0.7070	−0.0053	0.9982	15.277	−0.2068	0.0014	0.9919
Gurucaia	15.8430	−0.4985	0.0051	0.9979	15.8430	−0.1870	0.0009	0.9951
Laranjeira	21.6840	0.4933	−0.0023	0.9885	21.6840	−0.3122	0.0021	0.9927
Polyfloral								
Silvestre	5.2416	0.3050	−0.0010	0.9984	5.2416	0.0276	−0.0002	0.9586
Honeydew								
Bracatinga	28.8590	−0.3624	0.0083	0.9985	28.8590	−0.4852	0.0051	0.9912

Storage times (0, 60, and 120 days); *Y*: dependent variable, *x*: storage time (days); *a*, *b*, and *c*: estimated model coefficients; R^2: coefficient of determination.

Table 6. Results of Newtonian viscosity values (μ) for honeys of different botanical origins before, during, and after storage (T0, T60, and T120 days) at average day and night temperatures.

Botanical origins	Day			Night	
	T0	T60	T120	T60	T120
Monofloral					
Assa-peixe	16.45±0.65^{Dd}	24.13±0.15^{Cb}	19.94±0.18^{Fc}	14.14±1.67^{Cd}	35.83±2.68^{Ba}
Coffee	21.87±0.13^{Cb}	19.41±0.40^{Dc}	30.82±0.79^{Da}	10.85±0.86^{Dd}	10.08±0.24^{Ee}
Cipó-uva	36.51±0.45^{Ac}	37.75±1.71^{Bb}	66.94±2.55^{Aa}	30.73±1.17^{Ad}	18.18±1.03^{Ce}
Eucalyptus	15.28±0.30^{Ec}	38.65±0.46^{Ba}	23.95±0.61^{Eb}	7.77±0.18^{Ee}	10.08±0.45^{Ed}
Gurucaia	15.84±0.21^{DEb}	4.36±0.64^{Ee}	29.73±0.68^{Da}	7.97±0.52^{Ec}	6.78±0.03^{Fd}
Laranjeira	21.68±0.41^{Cc}	43.10±1.48^{Ab}	48.14±1.94^{Ba}	10.49±0.67^{De}	14.38±0.11^{Dd}
Polyfloral					
Silvestre	5.24±0.06^{Fd}	20.12±0.62^{Db}	28.16±0.45^{Da}	6.22±0.31^{Fc}	5.27±0.08^{Fd}
Honeydew					
Bracatinga	28.86±0.11^{Bc}	25.42±0.18^{Cd}	36.86±0.31^{Cb}	17.94±0.60^{Be}	43.39±1.87^{Aa}

Note(s): Results are expressed as mean value ± standard deviation ($n = 4$). T0: initial time; T60: 60 days; T120: 120 days. Equal capital letters in the same column have no significant difference using the Tukey test at 5% significance. Equal lowercase letters in the same row have no significant difference using the Tukey test at 5% significance.

that storage time contributed to an increase in the viscosity of fluids. According to these authors, this increase occurred due to the rise in dry matter, crystallization, and the structure of the sugar crystals formed in the honey, which hampers the flow of the product.

On the other hand, samples kept under night conditions showed an unexpected reduction in viscosity over time. These results may be related to the vast number of factors that affect the honey flow profile. According to Faustino and Pinheiro (2021), viscosity is also influenced by the concentration, shape, and type of sugars, as well as the presence of components such as dextran proteins, organic acids, essential oils, vitamins, minerals, and pollen grains. Even in low concentrations, these components have a significant effect on the rheological behavior of honey. In this sense, Ribeiro et al. (2018) found similar results in their work. When storing Tiúba honey at low temperatures for 180 days, they observed that the final viscosity was lower than the initial value. They attributed it to the presence of high molecular mass substances and the amount of solids in the fluid phase, which can remain suspended or settle, thus influencing viscosity. Therefore, the reduction in viscosity during storage at nighttime temperature may have been generated by the decantation of suspended solids, contributing to a less concentrated fluid phase. This also justifies why the viscosity of honeys under night conditions is lower when compared to honeys under daytime conditions.

Finally, a considerable variation in honey viscosity was observed among honeys of different botanical origins. Cipó-uva and silvestre honeys had the highest and lowest viscosity values over time, respectively, for both day and night temperatures. These results confirm that the botanical origin of honey directly influences the composition and viscosity of these products, as previously reported by Schiassi et al. (2021), Faustino and Pinheiro (2021), and Schiassi et al. (2022).

3.4 Microscopic analysis

Figure 1 represents the results of the microscopic analyses conducted to evaluate the formation of crystals in honey samples during storage (T90 and T180), under different temperature conditions (average day and night temperatures).

The formation of crystals in honey is related to its botanical origin, as well as its storage after processing. As crystallization progresses, the crystals spread throughout the honey, grow larger, and increase the honey's viscosity (Escuredo et al., 2014; Schiassi et al., 2021). Microscopic analyses (Figure 1) show the formation of crystals in all honey varieties under both conditions at T90, indicating a similar behavior between honey varieties. Crystal formation can be confirmed by the absorbance and color (L*, C*, and h°) analyses, which showed increasing values (Tables 2 and 3) and could be an indication of crystallization (Costa et al., 2015).

Honey from assa-peixe and cipó-uva had the same crystallization pattern, but the effect was more pronounced in assa-peixe honey. At T90 and T180 under daytime temperature, both had few, small crystals. However, under night temperature, large crystals were formed in greater quantities at T120 and grew even larger by T180. Finally, silvestre honey showed a unique behavior, with an increasing number of small crystals forming from T120 to T180 under daytime temperature. On the other hand, the same honey when stored at night temperature had few, small crystals at T120 that grew larger and more numerous at T180.

For the assa-peixe, cipó-uva, and silvestre varieties, storage at night temperature, particularly at T180, resulted in greater crystallization. As temperature decreases, the sugar solubility also decreases, promoting crystallization (Schiassi et al., 2022; Zaizuliana et al., 2017). Costa et al. (2015) found similar results, with a higher crystallization rate in honeys stored at 15°C and lower rates in honeys stored at 25°C, indicating a more pronounced crystallization at lower temperatures.

Furthermore, there is a temperature range (13–15.5°C) in which crystal nucleation is more intense and crystallization is favored (Costa et al., 2015; Zaizuliana et al., 2017). Therefore, honeys stored within this temperature range will show greater crystallization when compared to honeys stored at other temperatures, whether lower or higher.

4 CONCLUSIONS

In general, assa-peixe and cipó-uva honeys showed greater changes during storage, especially at night temperatures. Based on the absorbance, colorimetric (L* and C* parameters), and microscopy analyses, these two varieties showed intense and more pronounced crystallization.

The honeys had the rheological behavior of a Newtonian fluid, with viscosity being directly influenced by botanical origin, storage time, and temperature. Samples stored at daytime temperature showed increased viscosity, while honeys stored at nighttime temperature experienced a decrease in viscosity over time.

Honeys experienced more changes under night temperature than under daytime temperature. This finding is directly related to sugar solubility: as temperature decreases, sugar solubility also decreases, promoting crystallization and triggering other changes such as increased water activity, absorbance, and electrical conductivity, as well as changes in color parameters.

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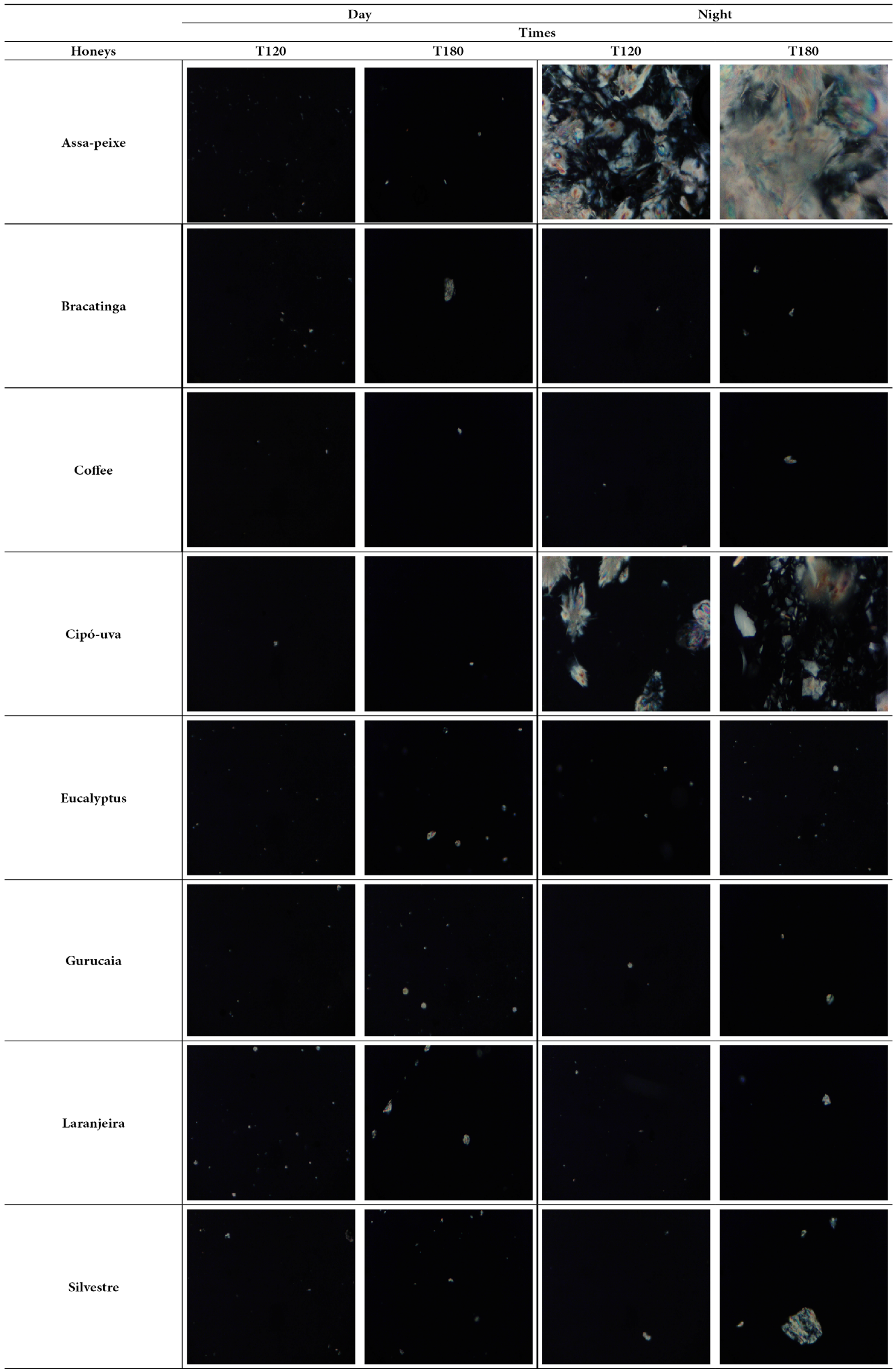

Figure 1. Polarized light microscopic analysis of honeys of different botanical origins during storage at average day and night temperatures for T90 and T180 days; 10 × magnification.

REFERENCES

Amarieri, S., Norocel, L., & Scripcă, L. A. (2020). An innovative method for preventing honey crystallization. *Innovative Food Science & Emerging Technologies*, *66*, Article 102481. https://doi.org/10.1016/j.ifset.2020.102481

Association of Official Analytical Chmists. (2012). *Official Methods of Analysis of AOAC International* (19th ed). AOAC.

Baloš, M., Popov, N., Jakši´C, S., Mihaljev, Ž., Pelić, M., Ratajac, R., & Pelić, D. L. (2023). Sunflower honey—evaluation of quality and stability during storage. *Foods*, *12*(13), Article 2585. https://doi.org/10.3390/foods12132585

Bogdanov, S. (2009). *Harmonised Methods of the European Honey Commission* (3rd ed.). International Honey Commission.

Brasil. (2000). *Instrução Normativa Nº 11, de 20 de outubro de 2000*. Aprova o Regulamento Técnico de Identidade e Qualidade do Mel. Diário Oficial da União. http://www.cidasc.sc.gov.br/inspecao/files/2012/08/IN-11-de-2000.pdf

Chou, W.-M., Liao, H.-C., Yang, Y.-C., & Peng, C.-C. (2020). Evaluation of honey quality with stored time and temperatures. *Journal of Food and Nutrition Research*, *8*(10), 591–599. https://doi.org/10.12691/jfnr-8-10-8

Codex Alimentarius Commission. (2001). *Codex Standard for Honey: Codex Stan12–1981*. https://www.fao.org/input/download/standards/310/cxs_012e.pdf

Costa, L. C. V., Kaspchak, E., Queiroz, M. B., Almeida, M. M., Quast, E., & Quast, L. B. (2015). Influence of temperature and homogenization on honey crystallization. *Brazilian Journal of Food Technology*, *18*(2), 155–161. https://doi.org/10.1590/1981-6723.7314

Dados Mundiais. (2024). *O clima no Brasil*. Retrieved April 20, 2024, from https://www.dadosmundiais.com/america/brasil/clima.php

Dobre, I., Georgescu, L. A., Alexe, P., Escuredo, O., & Seijo, M. C. (2012). Rheological behavior of different honey types from Romania. *Food Research International*, *49*(1), 126–132. https://doi.org/10.1016/j.foodres.2012.08.009

Escuredo, O., Dobre, I., Fernández-González, M., & Seijo, M. C. (2014). Contribution of botanical origin and sugar composition of honeys on the crystallization phenomenon. *Food Chemistry*, *149*, 84–90. https://doi.org/10.1016/j.foodchem.2013.10.097

Faustino, C., & Pinheiro, L. (2021). Analytical rheology of honey: a state-of-the-art review. *Foods*, *10*(8), Article 1709. https://doi.org/10.3390/foods10081709

Gleiter, R. A., Horn, H., & Isengard, H.-D. (2006). Influence of type and state of crystallisation on the water activity of honey. *Food Chemistry*, *96*(3), 441–445. https://doi.org/10.1016/j.foodchem.2005.03.051

Ji, P., Liu, X., Yang, C., Wu, F., Sun, J., Cao, W., & Zhao, H. (2023). Natural crystallization properties of honey and seed crystals-induced crystallization process for honey performance enhancing. *Food Chemistry*, *405*(Part B), Article 134972. https://doi.org/10.1016/j.foodchem.2022.134972

Kędzierska-Matysek, M., Florek, M., Wolanciuk, A., & Skałecki, P. (2016). Effect of freezing and room temperatures storage for 18 months on quality of raw rapeseed honey (Brassica napus). *Journal of Food Science and Technology*, *53*(8), 3349–3355. https://doi.org/10.1007/s13197-016-2313-x

Lupano, C. E. (1997). DSC study of honey granulation stored at various temperatures. *Food Research International*, *30*(9), 683–688. https://doi.org/10.1016/S0963-9969(98)00030-1

Misto, M. T., Cahyono, B. E., & Wulandari, E. A. (2019). Measurement of optical parameters and electrical conductivity for determining the quality of besuki local honey using spectrophotometer. *Food Science and Technology*, *7*(4), 57–62. https://doi.org/10.13189/fst.2019.070403

Pniewski, P., Anusz, K., Białobrzewski, I., Puchalska, M., Tracz, M., Kożuszek, R., Wiśniewski, J., Zarzyńska, J., & Jackowska-Tracz, A. (2023). The influence of storage temperature and packaging technology on the durability of ready-to-eat preservative--free meat bars with dried plasma. *Foods*, *12*(23), Article 4372. https://doi.org/10.3390/foods12234372

Raweh, H. S. A., Badjah-Hadj-Ahmed, A. Y., Iqbal, J., & Alqarni, A. S. (2022). Impact of different storage regimes on the levels of physicochemical characteristics, especially free acidity in Talh (Acacia gerrardii Benth.) honey. *Molecules*, *27*(18), Article 5959. https://doi.org/10.3390/molecules27185959

Ribeiro, G. P., Villas-Bôas, J. K., Spinosa, W. A., & Prudencio, S. H. P. (2018). Influence of freezing, pasteurization and maturation on Tiúba honey quality. *LWT*, *90*, 607–612. https://doi.org/10.1016/j.lwt.2017.12.072

Santos, F. K. G., Dantas Filho, A. N., Leite, R. H. L., Aroucha, E. M. M., Santos, A. G., & Oliveira, T. A. (2014). Rheological and some physicochemical characteristics of selected floral honeys from plants of caatinga. *Anais da Academia Brasileira de Ciências*, *86*(2), 981–994. https://doi.org/10.1590/0001-3765201420130064

Schiassi, M. C. E. V., Souza, V. R., Alves, N. A., Lago, A. M. T., Silva, S. H., Carvalho, G. R., Resende, J. V., & Queiroz, F. (2022). Effect of botanical origin on stability and crystallization of honey during storage. *British Food Journal*, *124*(9), 2689–2704. https://doi.org/10.1108/BFJ-06-2021-0680

Schiassi, M. C. E. V., Souza, V. R., Lago, A. M. T., Carvalho, G. R., Curi, P. N., Guimarães, A. S., & Queiroz, F. (2021). Quality of honeys from different botanical origins. *Journal of Food Science and Techonology*, *58*(11), 4167–4177. https://doi.org/10.1007/s13197-020-04884-7

Song, J., Yang, J., & Jeong, B. R. (2023). Difference between day and night temperature (DIF) and light intensity affect growth and photosynthetic characteristics of panax ginseng meyer sprouts. *Plants*, *12*(15), Article 2820. https://doi.org/10.3390/plants12152820

Šopík, T., Lazarková, Z., Buňková, L., Purevdorj, K., Salek, R. N., Talár, J., Novotný, M., Foltin, P., Pachlová, V., & Buňka, F. (2022). Impact of long-term storage on the quality of selected sugar-based foods stored at different temperatures. *LWT*, *157*, Article 113095. https://doi.org/10.1016/j.lwt.2022.113095

Tappi, S., Glicerina, V., Ragni, L., Dettori, A., Romani, S., & Rocculi, P. (2021). Physical and structural properties of honey crystallized by static and dynamic processes. *Journal of Food Engineering*, *292*, Article 110316. https://doi.org/10.1016/j.jfoodeng.2020.110316

Tarapoulouzi, M., Mironescu, M., Drouza, C., Mironescu, I. D., & Agripoulou. (2023). Insight into the recent application of chemometrics in quality analysis and characterization of bee honey during processing and storage. *Foods*, *12*(3), Article 473. https://doi.org/10.3390/foods12030473

Venir, E., Spaziani, M., & Maltini, E. (2010). Crystallization in "Tarassaco" Italian honey studied by DSC. *Food Chemistry*, *122*(2), 410–415. https://doi.org/10.1016/j.foodchem.2009.04.012

Zaizuliana, R. A. N., Anis Mastura, A. F., Abd Jamil, Z., Norshazila, S., & Zarinah, Z. (2017). Effect of storage conditions on the crystallisation behaviour of selected Malaysian honeys. *Internaticonal Food Research Journal*, *24*, S475–S480.

Zheng, Y., Wu, M., Han, F., Wu, D., & Fu, L. (2019). Evaluation of total antioxidant activity of different floral sources of honeys using crosslinked hydrogels. *International Journal of Electrochemical Science*, *14*(2), 1479–1487. https://doi.org/10.20964/2019.02.71