Honey Properties and Postharvest Handling

Subjects: Food Science & Technology

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In ancient Greece, people said that “honey is the Food of the Gods”, and they were right. They believed that honey fell from the sky, with the morning dew, on the flowers and leaves, and from this point, the bees collected it. Honey is one of the most nutritious food products, which can be found in most homes. A lot of honey products are stored in different types of packaging materials, including plastics. Plastic packaging has been studied for the migration of plasticizers, chemical compounds, and microplastics (MPs) and nanoplastics (NPs) in foodstuffs. Most of them have been achieved through food simulations, while some studies managed to detect and isolate MPs/NPs. There are evidence for the presence of MPs/NPs in honey products but not directly connected to food packaging or to the different types of honey and their properties (viscosity, pH value, and moisture content) or their storing conditions (temperature, humidity, light, and time).

Keywords: microplastics ; nanoplastics ; honey ; food packaging

1. Introduction

Honey is a highly appreciated natural food due to its essential properties for human health [1]. It consists mainly of sugars (predominantly the monosaccharides fructose and glucose, small amounts of the disaccharide sucrose and other oligosaccharides, and higher sugars) [2]; enzymes; vitamins; minerals; organic acids; essential oils; esters; pollens; and proteins [3]. It has been famous for its therapeutic properties for centuries [4]. As reported recently, a combination of lime or green tea with honey had anti-inflammatory and antimicrobial effects during the COVID-19 period [2]. The presence of phenolic compounds, flavonoids, carotenoid derivatives, and organic acids transfuses this anti-inflammatory and antioxidant characteristic of honey. Vitamins and minerals are likewise meaningful, variated upon geographical origins of honey [5]. Furthermore, honey has been used in medicine for epidermic wounds as an antimicrobial and healing agent, due to some characteristics in combination, such as osmolarity, low water content and pH, high viscosity, high sugar, phenolic acids, and flavonoid levels. Finally, the presence and action of glucose oxidase on the glucose of honey produces H_2O_2, which has antibacterial potential [6][7].

Honey, as a viscous nonhomogeneous colloid substance, has a lot of different properties. The multiple different types of honey are based on their floral origin, presenting varying properties such as pH, water content, viscosity, sugar content, and color parameters. When honey is stored, all these properties are affected by the following main factors: temperature, moisture content, light, and time of storage. Long periods of honey storage influence the color, the optical density, the refractive index of honey [8], and, also, the humidity of honey, which is a very important parameter in honey quality, delineating the stability against fermentation and granulation [9]. The moisture content of honey, in its turn, strongly influences the flavor, preservation, viscosity, specific weight, crystallization, and flavor, contributing to the development of fermenting microorganisms [10]. All the aforementioned parameters, especially in long periods of storage, cause different polymer degradation and could potentially affect plastic migration from plastic packaging.

2. Types of Honey

There is a plethora of honey types around the world [11]. Their differences are based on their floral, geographical origin, mode of production, and/or presentation [12][13]. Usually, it is labeled after the botanical source it is produced from, like Acacia, Linden, Floral, Buckwheat, Heather, Rape, Honeydew, and Nectar honeydew [14]. Honey can be discriminated according to origin or postharvest manipulation.

Finally, a lot of studies have been conducted the last two decades concerning the examination of honey properties from different honey types from all over the word. Asian honeys such as red pine honey from Turkey [15], Malaysian honeys [16], Iranian honeys [17][18], European honeys such as Polish honeys [19], Greek honeys [20], Belgium honeys [21], American honeys such as Yatei honey from Argentina [22], Apis mellifera L. honey from Central Brazil [10], African Moroccan honeys [23], and bitter and sweet honey from the Mediterranean coast of Algeria [24] have been examined for their special properties, both physical and chemical. The list is enormously large and unending.

3. Honey Properties

Each type of honey has special properties due to their unique physicochemical parameters, such as electrical conductivity; water content; total acidity; total sugar; sucrose; viscosity; pH; and color parameters such as L*, α*, and b* [14]. Additionally, different honeys have different phenolic and flavonoid contents, which has a high correlation with their antioxidant activity [13][16] and with their antimicrobial activity [8][20]. Factors such as low pH, hydrogen peroxide, and high osmolarity contribute to the high antibacterial activity of honey [20].

3.1. Viscosity/Crystallization

One of the most important rheological properties of honey is viscosity, influenced by several factors such as temperature, moisture content, and composition [25]. Different types of honey have widely different viscosities due to the possible presence of colloids and differences in the moisture contents [26]. In general, the viscosity increases when decreasing the moisture content [25]. Additionally, most honeys are glucose-supersaturated solutions, so crystallization may spontaneously occur at room temperature with a crystallization peak between 10 and 15 °C, forming a glucose monohydrate [26].

In 2013, important research about viscosity of honey was conducted in four types of honeys (Brazilian, Australian, Chinese, and Romanian Acacia honey), chosen for their different crystallization rates and compositions. For the viscosity measurements, the crystallized samples were incubated constantly at 14 °C. The viscosity of Chinese and Brazilian honeys increased after 24 h processing due to the rapid crystal growth. However, the viscosity change in Acacia honey was slower due to the lower rate of crystal growth and the initial viscosity [25]. Interestingly, although the viscosity of the Australian honey was high compared to the Brazilian and the Chinese honey, the change in the viscosity was higher than the Acacia honey as time progressed. Based on the literature, honey crystallizes faster with a greater glucose content (above 30%). Despite this, Acacia honey with a glucose content of 28.5% was found to have a lower crystallization rate than the Brazilian, Chinese, and Australian honeys. “Glucose content of the honey sample has no consistency in predicting the crystallization tendency and honey crystallizes more rapidly when this glucose/fructose ratio is less than 1.14”. Additionally, at low temperatures (14 °C), the crystallization phenomenon is limited by the viscosity, which means that as the viscosity of the honey increases, the crystallization rate decreases [25].

The viscosity influences the rate of crystallization, because it directly alters the diffusivity of glucose through the honey solution [25]. The solubility of glucose is increased when the temperature is also increased, while this lowers the honey’s tendency to crystallize. Lowering the temperature also lowers the diffusion coefficient of glucose, resulting in delayed crystallization. However, as mentioned before, there is an optimal temperature for the crystallization rate; this temperature is found to be between 10 and 15 °C [25]. The most important factor for the crystallization rate in honey is the glucose/water ratio [26]. However, the presence of fructose in honey is an especially important factor, because it inhibits glucose crystallization. Furthermore, the crystal growth rate was found to be related to the glucose content and inversely related to the viscosity of the honey [25]. Glucose has been investigated for its ability to degrade polymers [27][28], so it is worth mentioning it as a possible factor for polymeric migration in foodstuffs.

3.2. Viscosity/Heat

In a related research, it was shown that dynamic viscosity was affected by the heating of raw rape honey at various temperatures (30, 40, 50, 60, 70, and 80 °C). The viscosity after 20 °C started to significantly decrease at 30, 40, and 50 °C for all individual samples. The effect of temperature was remarkable for temperatures up to 30 °C but was not significant above that temperature [29].

3.3. Viscosity/Water Activity

In another study, 35 samples of *Apis mellifera* L. honey were collected, stored at room temperature, and kept in dry, airy conditions to wait for yeast and mold analyses. There was no direct relationship between the moisture content levels and the presence of these microorganism, but it was revealed that the moisture content influences honey viscosity [10]. The molal concentration of the main sugars determines, in a significant way, the water activity of the honey, mainly by the monosaccharides fructose and glucose and not so much by the disaccharides maltose and/or sucrose. In a research work regarding water activity focused on 49 crystallized and redissolved honey samples from Argentina, the water activity of the crystallized honey samples was higher than the redissolved ones upon heating. When the temperature was increased, the solubility of glucose was also increased, so its tendency toward crystallization was lower [25]. As the glucose concentration increased, all sugar solutions became increasingly viscous, and the mobility of the sugar molecules decreased as the viscosity increased. As crystallization occurred at room temperature, the glucose concentration in the liquid phase was lowered, and thus, the water activity increased as the viscosity was lowered [26].

3.4. pH

The acidity of honey is partly responsible for its characteristic taste. Honey is considered mildly acidic due to the minor acid content (mainly amino acids and organic acids), with an average pH of 3.9. Honey from tropical countries has lower acidity due to its water content, resulting in increased fermentation and a further decrease in the pH. More acidic values (pH < 3.24) indicate, in some cases, the existence of impurities in the samples or improper storage [30].

As mentioned before, acidic foods, especially liquids, contribute to plastic oxidation and degradation [31][32]. Researchers observed that, when the moisture level is higher, the development of microorganisms is greater, so the total acidity increases due to fermentation. Osmophilic yeasts ferment glucose and fructose in honey, forming alcohol and carbon dioxide, where, in the presence of oxygen, alcohol is broken down into acetic acid and water, further decreasing the pH of the honey. However, a high level of acidity is not always due to fermentation by microorganisms. Acidity in honey is dependent on many factors, such as floral sources, amount of minerals, and gluconic acid [10].

The temperature also contributes to the pH of honeys. Recently, it was reported that, by increasing the heating temperature of honey, the pH decreases rapidly due to the chemical reaction between sugars and amino acids [9]. According to a honey study, the researchers found that the pH at 20 °C of the honey types tested was quite lower compared to the general honeys, due to an enzymatic action that caused a great amount of organic acids. The honeys had different botanical and geographical origins, such as Acacia (native to Hungary), orange (United Mexican States), lavender (Spain), blueberry (Canada), litchi (People’s Republic of China), and coffee (Guatemala) [33].

In another study of Yatei honey, stored at 15–38 °C and at refrigeration temperatures 7–10 °C using glass and PP translucent containers, it was found that the pH decreased after 15 days. Later, in time, the acidity increased in the samples stored at room temperature [22].

3.5. Color

Honey color is influenced by the honey contents (phenolics [34], carotenoids, sugars, minerals, and pollens); water content; floral and geographical origin; temperature; age; time; and conditions of storage [17][35]. The same types of honey at different ages have differences in L* and chroma [35]. An example of a color determination measurement study in honeys was made in 2021, where 31 Acacia (*Robinia pseudoacacia*), 10 Linden (*Tilia* spp.) 7 chestnut (*Castanea sativa*), 7 honeydew, 7 sunflower (*Helianthus annuus*), 5 silkgrass (*Asclepias syriaca*), and 6 rapeseeds (*Brassica napus*) honeys were stored in darkness at room temperature and measured based on the UV–Vis transmission spectra. [35].

In another study, it was confirmed that the Maillard reaction occurs in unheated Polish-originated honeys, where the BPF was strongly correlated with antioxidant activity. Floral, Acacia (*Acacia* Mill.), buckwheat (*Fagopyrum esculentum* Moench.), heather (*Calluna vulgaris* Hull), linden (*Tilia cordata* Mill.), rapeseed (*Brassica napus* L.), and multiflorous honey samples were collected during the 2017 season in the Warmia and Mazury region in the northeastern part of Poland and were kept in a jar in darkness at room temperature (20–22 °C) before analysis. Dark honeys such as buckwheat and heather showed better antioxidant activity and higher melanoidin contents compared to light honeys. Additionally, linden and rapeseed had greater values in the L* and b* parameters, and a* was higher in buckwheat and heather honeys [19].

3.6. Optical Properties

Different types of honey usually have different RI, even among the same types of honey samples. For example, red pine honeys from different locations of Mugla Province in Turkey have RI between 1.4944 and 1.4996, depending on the moisture and maturity degree of the honey [15]. For Moroccan honey samples, the RI was found to be 1.49028 for the eucalyptus type and 1.49300 for the herbal type of honey [23]. For bitter and sweet honey from the Mediterranean coast of Algeria, the RI was found to be 1.4845 and 1.4915, respectively [24].

The RI and water content in honey samples are correlated with each other [18]; this is the reason why human have to know the RI value of a honey sample, because a high amount of water causes a major loss of flavor and quality in the honey due to the higher fermentation rate [24]. Generally, when researchers have a loss of the water content, the RI increases [36]. In some cases, the RI increases with the solid content of honey, and the moisture content is negatively correlated to the RI; if honey is less solid, light moves faster through it [34]. The RI is an accurate indicator of the total soluble solid concentration in liquid samples such as honey [36].

Long periods of storage and heating conditions do not only influence the color and optical density of honey but the RI as well. Specifically, the RI was slightly reduced at higher temperatures (40 °C) compared to 20 °C in Egyptian clover honey samples [8]. In another study, Água-mel, a traditional Portuguese honey, was thermally processed, causing a loss of moisture and exponential increase of the RI from 1.38478 at time zero to 1.47285 after 400 min [36]. The RI definition can also help sugar profile investigation in honeys [37], such as Saudi honey examination through a HPLC system equipped with refractive index and diode array detectors [38]. However, an RI detector is typically used for carbohydrates detection [37].

As mentioned before, the optical properties of rape honey can be modified by changing the morphology of the crystalline structure when honey is heated between 60 and 80 °C, causing a lightening of the honey [29]. The browning intensity of different monofloral honey types such as Acacia, orange, lavender, blueberry, litchi, and coffee is affected by the botanical origin of honeys during the heating process at 100 °C for 24 h, resulting in different UV absorbance ratios [2].

4. Factors That Affect Honey Properties

4.1. Storage Time

The storage time is a critical parameter in food preservation. Usually, as the storage time is increased, food preservation is gradually affected due to the development of microorganisms. Additionally, the storage time affects polymer migration into food from their plastic packaging. As an example, mentioned previously, dairy products stored in polystyrene containers present higher migration rates of styrene through time, while the fat content intensifies the migration rate even more compared to storage time [39].

Regarding honey, long periods of honey storage influence the color, optical density, and RI [8]. Generally, honey storage initiates melanoidin formation, resulting in reducing sugars and polyphenols [40]. Specifically, in one study, important volatile compounds such as terpenes were present in higher concentrations in fresh citrus honeys compared to stored honeys; at the same time, it was observed that, during prolonged storage, lower levels of monosaccharides and higher levels of maltose occurred [41]. In another study, it was found that, in almost all the samples, cis- and trans-linalool oxide and hotrienol increased over 540 days, and in total, 24 volatile compounds showed higher abundances during storage [42]. However, the quality of honey is not significantly affected by the storage time for up to two years if the honey is properly harvested, extracted, and preserved at room temperature [43]. Lastly, in bracatinga honeydew honey, long storage conditions cause the formation of brown pigments and, consequently, the degradation of the honey quality [44].

4.2. Temperature

The moisture content, free acidity, and electrical conductivity of raw rape honey are not affected by storage temperatures; freezing temperatures maintain the freshness and color of honey, even though the viscosity is increased. Nevertheless, the storage of honey at room temperature causes color changing [45][46].

Raising the honey temperature reduces its viscosity and water content. Heating or cooling has been found to affect liquid foods by changing their viscosity, pH, acidity, and antioxidant activity [9]. Heat treatment leads to the development of antioxidant activity due to the formation of Maillard reaction products, affecting human health in a positive way [47].

In particular, the heating of raw rape honey for 15 min at a temperature range of 50–80 °C significantly altered its chromatic parameters (increased its L* and b* but decreased its a*) and decreased its dynamic viscosity [29].

The heat treatment of honeys from the Warmia and Mazury region in Poland enhanced the antioxidant activity in all the samples, the melanoidin content, and the TPC of the honey [19][33]. Additionally, the Maillard reaction and melanoidin formation occurred in unheated Polish-originated honeys [19]. Additionally, honeys heated at 100 °C for 24 h presented an increased amino-free group of all the honeys. The sugar contents of lavender, litchi, coffee, Acacia, and blueberry honeys increased with time, but for Acacia and blueberry, it decreased after 6 h of heating. Orange honey showed an increase at 12 h [33]. Additionally, the pHs of different honeys tested at 20 °C were lower compared to the general honeys, due to large amounts of organic acids produced by enzymatic action [33]. Lastly, during the heating process, the browning intensity of the honey types were affected by the botanical origins of different monofloral honeys, resulting in the different UV absorbances at 284 and 420 nm [33].

In another study, it was found that, by increasing the temperature (up to 65 °C) and the heating time, the color of the Jujube honey from Iran was darkened, and the phenolic content in the honey increased with the linear increment of heat (50, 60, and 70 °C) over a period of 12 days [17]. Additionally, studies of Yatei honey, stored at 15–38 °C and in refrigeration temperatures of 7–10 °C using glass and PP translucent containers demonstrated increased acidity and decreased pH at 15 days. The acidity remained unchanged in the samples stored in the refrigerator while increased in the samples stored at room temperature [22]. Furthermore, it was found that the moisture content of the samples was affected by the air humidity; specifically, the moisture content of the samples stored at room temperature increased, while those stored in the refrigerator presented stable moisture content values. Additionally, honey stored at room temperature and kept in a dry place (South Arabia) presented an increased total acidity with a higher moisture level, because fermentation was increased due to the greater development of microorganisms [10][30]. Why research is interested in acidity is because acidic foods, especially liquids, contribute to plastic oxidation and degradation [48][49]. Crystallization can lower the glucose concentration in the liquid phase of the honey, thus increasing the water activity, which can potentially allow the multiplication of naturally occurring yeasts cells, resulting in honey fermentation [26]. Lastly, it was shown that the thermal processing of Água-mel (traditional Portuguese Honey) caused a gradual decrease in the sugars, forming brown pigments [36].

As mentioned before, the heating of honey affects its color. In a related study, the heating of raw rape honey for 15 min at a temperature range of 50–80 °C significantly altered its chromatic parameters, increasing the L* and b* but decreasing the a*. Heating in these temperatures did not significantly degrade the quality of the honey. When the heating was between 25 and 45 °C, the fraction of the smallest crystals was increased from 65.1% to 72.2%. The share of the large crystals decreased from 2.1 to 0.6%, changing the morphology of the crystalline structure of the honey. This occurs especially when heating honey between 60 and 80 °C, where the optical properties of the honey will be modified, such as increasing its lightening [29]. In a commercial floral honey incubated at 50 and 60 °C for 12 days and 70 °C for 10 days, it was observed that the antioxidant activity and BPF [50] and TPC [17] were increased with the treatment temperature and time, which, despite the positive effects of antioxidants on human health, the BPF is not desirable for consumption [47].

In pH studies, the effect of heating time on the browning index was studied in commercially available honey types. Initially, the color of Acacia, orange, lavender, and blueberry honey was glossy and bright clear yellow–orange, where the color of litchi and coffee honey was glossy, bright, clear, and dark brown. Acacia honey had the strongest whiteness and b*, due to its highest levels of L* and b* values. Blueberry honey was strong in its a*, followed by lavender, in contrast to coffee honey, which had strong blackness and weak a* and b* colors due to the lowest L*, a*, and b* values. After honey was heated at 100 °C for 24 h, the UV absorbance and the browning intensity were measured over time at 284 and 420 nm, respectively. The progression of the initial browning in each honey was proven, while the UV absorbance at 284 nm was gradually increased [33].

Lastly, in another study, it was found that, increasing the temperature (50, 60, and 70 °C) and the heating time (up to 12 days), the color of the Jujube honey from Iran was darkened due to the BPF increment, while the phenolic content in the honey was increased. Darker honey samples are associated with greater levels of polyphenols, possibly due to the Maillard reaction that produces different compounds.

4.3. Humidity, Water Activity, and Moisture Content

The moisture content is very important for the preservation of honey properties. The moisture content of honey influences the flavor, preservation, viscosity, specific weight, crystallization, and palatability and contributes to the development of fermenting microorganisms [10]. The higher the moisture level, the greater the development of microorganisms, which increases the total acidity of the honey [10]. The moisture content in honey is typically between 16% and 18%. However, some honeys may have a moisture content as low as 13%, whereas, in others, it can reach up to 29% [10][25][26].

Yatei honey is produced by Apis mellifera. It is a special honey, less viscous and more acidic, with a particular aroma. Some honey samples were obtained from the central zone of the Province of Misiones and examined during different storage conditions. The results for the room temperature storage showed that the humidity of the samples in glass containers increased until reaching a value of 26.5% at 90 days and, in plastic containers, a value of 26.8%. These values remained stable at 120 and 180 days of storage, respectively. For samples preserved in refrigeration, the humidity values were stable, regardless of the type of packaging [22]. Generally, time and temperature significantly affect the humidity of the honey, which is a very important parameter for the honey quality, delineating the stability against fermentation and granulation [9].

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