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Co-crystallized Honey with Sucrose: Storage Evaluation and Sensory Acceptance

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ABSTRACT

Honey is widely consumed due to its flavor and health characteristics. It is viscous and can crystallize inside the package, making it difficult to handle. This work aimed to obtain co-crystallized honey with sucrose, study its physico-chemical properties during 100 days of storage, evaluate its microbiological stability and sensory acceptance. The standard and co-crystallized honey with 5% maltodextrin was stored in glass and polypropylene flasks and multilayer polyethylene film in vacuum. During storage, samples water activity ranged from 0.396 to 0.491, repose angle from 23.36 to 40.47°, density from 0.42 to 0.55 g cm^{-3} and hygroscopicity from 5.330 to 7.952%, showing no interference regarding to packaging material used. Microbiological analyzes of salmonella, molds and yeasts attended the legislation. Pineaple juice sweetened with honey co-crystallized with sucrose showed good sensory acceptance and purchase intention, indicating possibilibty for use in food formulations.

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Introduction

Honey is largely consumed due to its nutritional value, flavor characteristic and its medicinal properties (Bogdanov, Jurendic, Sieber, & Gallmann, 2008). It is normally used as a natural sweetener, source of energy and to treat flu symptoms and various diseases (Aparna & Rajalakshmi, 1999; Richter, Jansen, & Borges, 2006; Silva, Gauche, Gonzaga, Costa, & Fett, 2016). There is a great diversity of honey species bees in Brazil, and depending on the region and available natural resources, each honey has unique characteristics (Barth, 2004; Gois, De Lima, Da Silva, & Evangelista-Rodrigues, 2013). After manipulation, honey continues changing its physical, chemical and sensory characteristics. The monitoring of honey process guarantees the product quality (Edelky et al., 2010) and reduces significant changes during its storage (Iurlina

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& Fritz, 2005). Traditionally, honey is commercialized in polypropylene or glass packaging and used in its pure form. In a study with the insertion of honey in the school brunch, 91% of the approached children, appreciate honey and wanted to consume it more frequently; however, when the honey was offered in pure form or in drink preparations, there was rejection by the children (Staron et al., 2015). Some studies evaluated sensory characteristics of pure honey (Alves, Silva, Meneses, & Holanda-Neto, 2011; Aparna & Rajalakshmi, 1999; Pinto, Cunha, Lima, & Santos, 2017) and honey with juice (Back et al., 2019; Silva et al., 2008). However, there is a lack of information regarding sensory studies of co-crystallized honey with sucrose and its use for food products formulations. The inclusion of honey in its pure form may require changes in the production processes due to its high viscosity, density and intermediate humidity (Aparna & Rajalakshmi, 1999; Subramanian, Hebbar, & Rastogi, 2007).

Dried honey can be obtained using co-cristallization process, which consists in the concentration of a sucrose solution until its super saturation. The honey to be encapsulated is added to the solution and agitated until nucleation and re-crystallization. In general, sucrose, maltodextrin and other sugars are used as encapsulating agents. Sucrose is a disaccharide widely used in food processing and maltodextrin is widely used to obtain powdered products due to its high solubility, low hygroscopicity and low cost (Bhandari, Datta, & Howes, 2007; Cavalcante, Rodrigues, Afonso, & Costa, 2017; Jedlinska et al., 2019; Oliveira, Costa, & Afonso, 2014; Samborska et al., 2019). The main factors that influence this process are the proportions of sugar:honey:water, mixing speed, time and process temperature (Astolfi-Filho, Souza, Reipert, & Telis, 2005; Bhandari, Datta, D'Arcy, & Rintoul, 1998; Maulny, Beckett, & Mackenzie, 2006).

Co-crystallization of honey with sucrose in the proportions of 90:10, 85:15 and 80:20 (sucrose: honey) resulted in a product with aroma and flavor similar to honey (Bhandari et al., 1998). Using microwave technique associated with vacuum (Cui, Sun, Chen, & Sun, 2008) and spray drier (Jedlinska et al., 2019; Nurhadi & Roos, 2017) it was possible to obtain dried honey with matodextrin resulting in a product with physicochemical characteristics similar to powders.

Co-crystallization process allows to obtain dry product, which facilitates the transport, commercialization and storage, as well as the application in several products and formulations that traditionally contains sucrose on its formulation, without significant changes in the equipment. Foods with high sucrose content, glucose and fructose, are generally hygroscopic and have reduced flowability in contact with humidity (Bhandari et al., 2007; Cavalcante et al., 2017; Jedlinska et al., 2019; Samborska et al., 2019). Pure honey is usually sold in clear plastic or glass jars (Gois et al., 2013).

The packaging used for food interferes on its quality (Galic, Scetar, & Kurek, 2011). The glass packaging is impermeable to gases and vapors, while plastic

has different characteristics, according to the polymeric material used for its manufacture. Polypropylene (PP) is a polymer widely used, with easy molding, welding, high mechanical resistance and low water vapor permeability (Kim, Min, & Kim, 2014). This polymer does not offer good oxygen barrier and for vacuum packaging, multilayer materials are used, with the inclusion of polyamides and ethylene-vinyl acetate copolymer (EVOH) (Rodrigues, Brunelli, De Luca Sarantopoulos, & De Oliveira, 2018).

The objective of this work was obtain co-crystallized honey with sucrose and evaluate physical and chemical characteristics of the samples with and without the addition of maltodextrin, stored in different packages for 100 days and verify their microbiological characteristics and sensory acceptance.

Materials and methods

Materials

The experiments were carried out using floral honey from *Apis melífera* (Association of Cantuquiriguaçu – Paraná – Brazil, latitude 25° 24' 28" S, longitude 52° 24' 58" W, altitude 840 m), refined sucrose (Usina Alto Alegre®, Brazil) and maltodextrin 20DE (dextrose equivalent) MOR-REX 1920® (Ingredion, Brazil). Honey was stored at 8°C until use.

Physical-chemical characterization of raw material

Honey moisture was determined using refractometric method (AOAC, 2016), water activity (aw) using an electronic analyzer (Novasina®-LabMaster, Lachen, Switzerland) at 25°C with a control system temperature, pH at 25°C, with a calibrated pH meter (HI 2221®-Hanna, São Paulo, Brazil), titratable acidity, reducing sugars, ash and hydroxymethylfurfural (HMF) according to the methodologies defined by the Ministry of Agriculture (Federative Republic of Brasil, 2000). All determinations were made in triplicate.

Co-crystallization process

The co-crystallization tests were conducted according to Bhandari et al. (1998) with some adaptations. Sucrose (300 g) and water (50 g) were mixed in an open system for 6 min from 25 to 124°C. At the end of heating, 15% (45 g) of honey was added to the solution under manual stirring until a crystallized mass was obtained. The co-crystallized product was dried in an oven (Solab®, Piracicaba, Brazil) with forced circulation and renewal air at 45°C for 48 h and milled in a knife mill (Willye Starft-50®-Fortinox, São Paulo, Brazil) with four fixed and four adjustable knives. The ground product was sieved to obtain particles smaller than 1 mm.

Maltodextrin, 5% (w/w), was added to the dry product after sieving. Both samples, co-crystallized without maltodextrin (standard) and 5% of maltodextrin, were packaged (100 g each) in transparent glass containers (circular opening of 4.86 cm with sealed metallic lid), rigid polypropylene (PP) (circular with 6.92 cm opening and plastic cover) and flexible multilayer polyethylene (PE) bag (with 0.15–0.18 μm nylon) under vacuum. Samples were stored, in duplicate (real test), in a BOD incubator (TE-371®-Tecnal, Piracicaba, Brazil) in the absence of light, at 25°C for 100 days and analyzed every 20 days. After the analysis, the samples did not return to the BOD.

Samples evaluation during storage

Samples were evaluated for aw (methodology described on 2.2), apparent density (50 g of product deposited in a 250 mL beaker on a flat surface), static repose angles (free flow product from a fixed height of 9 cm through a stainless steel funnel with 2 cm diameter, into a petri dish with a radius of 5.6 cm). Repose angles was calculated using the radius of the petri dish and the height of the cone formed by the powder (Astolfi-Filho et al., 2005).

Hygroscopicity (Equation 1) was determined according to Tonon, Brabet, and Hubinger (2009) with some adaptations. The co-crystallized product (about 1 g) was poured in a 9 cm diameter petri dish and the samples were placed in a desiccator with 75% relative humidity (saturated NaCl solution) at 25°C for 10 days.

$$Hygroscopicity = \left(\frac{final\ mass - initial\ mass}{initial\ mass}\right)100 \quad (1)$$

All analyses were done in real duplicate.

Microbiological analyzes

The s*almonella* sp. analyses was performed following ISO (International Organization for Standardization 6579) method (Silva et al., 2010), homogenizing 25 g of each sample in 225 mL of buffered peptone water (BPW-Himedia) in a stomacher and incubated at 37 ± 1°C for 18 ± 2 h, followed by transferred 1 mL to 10 mL Müller-Kauffmann tetrathionate broth (MKTTn-Himedia) and incubated to 37 ± 1°C for 24 ± 3 h and 0.1 to 10 mL Rappaport-Vassilidis Soya broth (RVS-Oxoid) and incubated to 41.5 ± 1°C for 24 ± 2 h. The content of each tube was transferred to xylose lysine desoxycholate agar (XLD-Himedia) and Bismuth Sulfite agar (BS-Biolog) and incubated at 37 ± 1°C for 24 ± 3 h. Finally in case of presumptive salmonella colonies, further biochemical tests were performed: Citrate and urease and glucose (TSI), Voges-Proskauer, urease, indole.

The total and thermotolerant coliforms were determined according to APHA (Amercian Public Health Association) using most probable number (MPN) technique, in series of three tubes. A sample of 10 mL of each tenfold was transferred to 10 mL of lauryl sulfate tryptose broth (LST-Himedia) and incubated at 35 ± 0.5°C for 24–48 h. The positive tubes were transferred to 10 mL brilliant green bile 2% broth (Himedia) incubated to 35 ± 0.5°C for 24–48 h and 10 mL EC broth (Himedia) at confirmatory test to 44.5 ± 0.2°C for 24 ± 2 h. The sequence, eventual positive tubes of EC were transferred to handle to methylene blue eosin agar (EMB-Himedia) to isolate *Escherichia coli*, determined using a IMVIC biochemical test (Indole test, MR/VP test and citrate utilization test-Himedia), and GRAM stain.

Molds and Yeasts were determined by plate count using 1 mL of tenfold in dichloran rose bengal chloramphenicol agar (DRBC-Merck), incubated to 22–25°C for 5 days (American Public Health Association – APHA) (Silva et al., 2010). These analyses were performed on samples at 100 days of storage.

Sensory evaluation

Sensory analysis, approved by the Ethics Committee of the Federal University of Fronteira Sul (CAAE: 97265618.8.0000.5564), were performed in a sensorial laboratory at 23°C, with white light, free from noise or odors. The analysis included 54 untrained evaluators, between 18 and 45 years, 70.37% female and 29.63% male, usual consumers of honey, sucrose and pineapple juice. The subjects received a sample with 10 g of standard co-crystallized honey, served in a disposable plastic cup closed with aluminum foil to ensure the sample did not lose aroma. The sample at 23°C was evaluated for color, flavor, taste and overall impression using a 9-point hedonic scale (1 corresponds to extremely not like and 9 extremely like) and purchase intention using 5-point hedonic scale (1 certainly not buy and 5 certainly buy). The acceptability index (AI) was determined through Equation 2, as suggested by Dutcosky (2011). .

$$\mathrm{AI}(\%) = \frac{A}{B} * 100 \tag{2}$$

Where: A is the average of the scores for the attribute and B is the maximum score for the attribute.

Additionally, 3 more samples of pineapple (*Ananas comosus*) juice were served: with commercial refined sucrose, standard co-crystallized honey and pure honey, all samples in a concentration of 177 g of sweetener/L of juice. Juice was prepared using frozen fruit pulp at 25% (v/v) juice/water and served at 15°C, in white disposable plastic cups with 30 mL for each sample, coded with 3 random numerical algarisms and tested from left to right, randomly arranged. The juice was evaluated for flavor attribute using the 9-point structured hedonic scale.

Statistical analysis

The results were statistically evaluated using Action Stat 3.7® by the analysis of Variance (ANOVA) and Tukey's test at the 95% confidence level.

Results and discussion

Honey moisture was 15.74 ± 0.00%, characteristic for floral honey wich vary from 14.25 to 20% (Aroucha, Oliveira, De, Nunes, Maracajá, & Santos, 2008; Richter et al., 2006). The moisture in honey influence its taste, viscosity, fluidity, crystallization and conservation. A high water content in honey facilitates the proliferation of yeasts, causing fermentation and makes the product undesirable for consumption and commercialization (Aroucha et al., 2008; Ribeiro & Starikoff, 2019). Honey moisture content below 17% is considered safe to delay yeast activity, however, the chances of crystallization increase with a reduction in the moisture content (Subramanian et al., 2007).

Honey aw was 0.630 ± 0.000. The glucose crystallization process occours during honey storage, leading to a reduction in soluble solids, resulting in the dilution of the amorphous solution and causing the separation of phases. This separation promotes the formation of a crystalline phase at the bottom and a liquid phase at the top. The top layer contains high amount of water, increasing its aw and the risk of honey degradation by fermentation of osmophilic yeasts that grow in aw above 0.60. Honey usually has water activity between 0.50 and 0.65. The legislation does not indicate a reference value for aw in honey; however, its monitoring is important to predict product qualityt (Escuredo, Míguez, Fernández-González, & Carmen Seijo, 2013; Gleiter, Horn, & Isengard, 2006; Silva et al., 2016; Tornuk et al., 2013; Tosi, Ciappini, Ré, & Lucero, 2002; Yücel & Sultanoğlu, 2013; Zamora, Chirife, & Roldán, 2006). Gleiter et al. (2006) evaluated 249 samples of honey (aw ranging from 0.53 and 0.63) and verify a tendency of water activity increasing with honey moisture.

Ash content in honey was 0.34 ± 0.08% and is related to the presence of minerals, floral origin, climatic conditions and management (Evangelista-Rodrigues, Mônica, Silva, Beserra, & Rodrigues, 2005), resulting in a large range on its determination of 0.01%–0.30% (Abadio Finco, Moura, & Silva, 2010) and 0.08–0.49% (Kumar et al., 2018).

Honey titratable acidity was 15.74 ± 1.30 meq Kg^{-1} and is influenced by various acids as citric, present in the nectar of flowers, and glyconic, produced by the action of glucose oxidase on glucose. Other factors such as the production of acids by bacteria in the maturation and presence of minerals, influence the acidity (Ribeiro & Starikoff, 2019; Silva et al., 2016), which can lead to a wide range of variation in these values, from 14.83 to 40.17 meq kg^{-1} (Kumar et al., 2018).

The honey average pH was 3.19 ± 0.00, considered as acid product. The variations observed in the pH are probably due to the particularities of the floral composition, since the pH of the honey can be influenced by the pH of the flowers nectar. Differences in soil composition or the association of plant species can also influence the pH (Crane, 1983).

High levels of hydroxymethylfurfural (HMF) may indicate adulteration of honey, inadequate storage, overheating and development of volatile and toxic compounds (Evangelista-Rodrigues et al., 2005; Silva et al., 2016). Honey presented HMF of 11.68 ± 0.45 mg kg^{-1}, according to the parameters required by Brazilian legislation (Federative Republic of Brasil, 2000).

The concentration of main reducing sugars (fructose and glucose) was 73.6 ± 2.70%. Concentrations of 60% up to 80.1% were reported by Almeida-Filho, Machado, Alves, Queiroga, and Cândido (2011), with 60% being the minimum established for floral honeys (Federative Republic of Brasil, 2000; Codex Alimentarius, 2019).

Co-crystallized dry products showed aw ranging from 0.396 to 0.491 (Table 1). Even with statistical variations ($p < .05$), there is no trend in aw and different packagings, treatments and storage time. Aw values of the standard samples and 5% maltodextrin were less than (0.63). The decrease was due to the heating and drying step in the co-crystallization process. After 100 days of storage, samples have physical-chemical and microbiological stability with aw below 0.6, which inhibit undesirable reactions such oxidation, Maillard reaction, action of enzymes and development of microorganisms that influence products quality (Fellows, 2006; Silva et al., 2016). Dried honey with maltodextrin (20% to 40%) obtained by spray drying, resulting in power honey with aw from 0.134 to 0.178 (Samborska et al., 2019), lower than the results of this work. The differences can be explained according to drying process and proportion of raw materials used.

Apparent density of co-crystallized products (Table 2) ranged from 0.42 to 0.55 g cm^{-3}, with an average of 0.48 g cm^{-3}. The density of dried honey can vary from 0.32 g cm^{-3} to 0.61 g cm^{-3}, and these variations are related to the methods used, operational conditions and physicochemical characteristics (Samborska, 2019). Visually, samples of co-crystallized honey (standard and 5% maltodextrin) in vacuum films were more cohesive and difficult to withdraw from packaging. Industrially, this behavior could be an obstacle to final consumer or even if used as an ingredient in automated processes. The apparent density values were close to those reported by Nurhadi and Roos (2017), for honey dehydrated with maltodextrin in the proportions of 60% and 40% whose initial density was 0.49 and 0.59 g cm^{-3}.

Co-crystallized products stored in the different packages have repose angles varying from 23.36 and 40.47° (Table 3). The standard product stored in polypropylene bottles showed a difference ($p < .05$) after 60 days of storage. The addition of 5% of maltodextrin did not change flow properties. However, even with the differences observed in the repose angles (exception the sample

Table 1. Aw of standard and co-crystallized honey and 5% maltodextrin during storage.

	Standard			5% of maltodextrin		
Storage (days)*	Glass	PP	PE	Glass	PP	PE
0	$0.426 \pm 0{,}000^{bAB}$	0.440 ± 0.004^{abB}	0.432 ± 0.004^{abB}	0.431 ± 0.004^{abB}	0.463 ± 0.019^{aA}	0.437 ± 0.007^{abB}
20	0.424 ± 0.016^{aAB}	0.426 ± 0.004^{aCD}	0.424 ± 0.001^{aB}	0.438 ± 0.001^{aAB}	0.436 ± 0.00^{aA}	0.438 ± 0.002^{aB}
40	0.420 ± 0.013^{aAB}	0.434 ± 0.002^{aBC}	0.431 ± 0.004^{aB}	0.433 ± 0.013^{aB}	0.445 ± 0.002^{aA}	0.437 ± 0.002^{aB}
60	0.450 ± 0.010^{aA}	0.457 ± 0.001^{aA}	0.466 ± 0.002^{aA}	0.458 ± 0.000^{aA}	0.491 ± 0.03^{aA}	0.473 ± 0.009^{aA}
80	0.438 ± 0.001^{aAB}	0.429 ± 0.004^{aBCD}	0.396 ± 0.012^{bC}	0.440 ± 0.004^{aAB}	0.443 ± 0.002^{aA}	0.418 ± 0.012^{abB}
100	0.402 ± 0.005^{cB}	0.419 ± 0.001^{bD}	0.429 ± 0.000^{abB}	0.430 ± 0.006^{abB}	0.431 ± 0.001^{abA}	0.435 ± 0.004^{aB}

* Average of two determinations ± standard deviation. Lower cases comparison between lines for the different types of packaging in the standard sample and 5% maltodextrin and upper case comparison in columns for each type of packaging during storage at 95% confidence level by Tukey test.

Table 2. Apparent density (g cm^{-3}) of standard and co-crystallized honey and with 5% maltodextrin during storage.

	Standard			5% of maltodextrin		
Storage (days)*	Glass	PP	PE	Glass	PP	PE
0	0.52 ± 0.03^{aA}	0.52 ± 0.02^{aA}	0.55 ± 0.01^{aA}	0.48 ± 003^{aA}	0.48 ± 0.03^{aAB}	0.52 ± 0.01^{aA}
20	0.48 ± 0.01^{aA}	0.47 ± 0.00^{aB}	0.53 ± 0.04^{aA}	0.48 ± 0.01^{aA}	0.49 ± 0.01^{aA}	0.49 ± 0.01^{aA}
40	0.48 ± 0.04^{abA}	0.46 ± 0.00^{abB}	0.52 ± 0.00^{aA}	0.48 ± 0.04^{abA}	0.42 ± 0.00^{bB}	0.52 ± 0.02^{aA}
60	0.46 ± 0.00^{aA}	0.46 ± 0.00^{aB}	0.54 ± 0.03^{aA}	0.48 ± 0.02^{aA}	0.43 ± 0.00^{aAB}	0.49 ± 0.07^{aA}
80	0.46 ± 0.01^{abA}	0.43 ± 0.02^{bB}	0.53 ± 0.00^{aA}	0.46 ± 0.01^{abA}	0.46 ± 0.00^{abAB}	0.48 ± 0.04^{abA}
100	0.45 ± 0.00^{bA}	0.46 ± 0.00^{bB}	0.49 ± 0.01^{aA}	0.46 ± 0.00^{bA}	0.45 ± 0.01^{bAB}	0.50 ± 0.00^{aA}

* Average of two determinations ± standard deviation. Lower cases comparison between lines for the different types of packaging in the standard sample and 5% maltodextrin and upper case comparison in columns for each type of packaging during storage at 95% confidence level by Tukey test.

with 5% maltodextrin in glass after 100 days of storage), all samples showed values below 40º, indicating free flow, while angles above 50º indicate cohesiveness or flow problems (Astolfi-Filho et al., 2005; Bhandari et al., 1998). The repose angles values was close to pure sucrose (encapsulating matrix), of 34º (Astolfi-Filho et al., 2005; Karangutkar & Ananthanarayan, 2020). The fluidity is an important attribute to select the type and format of the packaging. During the experiments, it was observed that the removal of the product is easy in glass containers and polypropylene jars, both with circular openings of at least 5 cm in diameter.

Regarding hygroscopicity (Table 4), all samples presented no variation ($p > .05$) during 100 days of storage. The hygroscopicity of a dehydrated food is related to its physical, chemical and microbiological stability. Maltodextrin is a material with low hygroscopicity and widely used as a carrier agent in drying processes (Samborska et al., 2019; Tonon et al., 2009). The average hygroscopicity (co-crystallized with 15% honey) was 6.885%, higher than 0.11% for pure sucrose (Karangutkar & Ananthanarayan, 2020) and less than 19.3% (dry product with 60% honey and maltodextrin) (Jedlinska et al., 2019).

Microbiological analyses of sucrose and co-crystallized samples after 100 days of storage (Table 5) were based on microbiological standards (Salmonella sp absence in 25 g and total coliforms, thermotolerant and E. coli at 45°C g^{-1} maximum tolerance of 102 NMP g^{-1}) established for unrefined crystal sucrose, brown and demerara sugar, molasses, brown sugar (ANNEX I. Group 11 of RDC nº 12) from Federative Republic of Brasil (2001) and Count of molds and yeasts. Based on these results, all samples are within the parameters established by this legislation.

Sensory analysis were carried out with the standard co-crystallized honey. The parameters color and flavor, showed scores of 7.4 ± 1.6 and 7.9 ± 1.2, which were higher than 7 (moderately liked). The acceptance index for these attributes was 81.8% and 88.3%, respectively. The subjects reported that the sample had a flavor similar to honey, which may have contributed to its good acceptance. There is a large diversity of honey from *Apis* bees species in Brazil, that result in different sensory atributes depending on the location, blooming,

Table 3. Repose angle of standard and co-crystallized honey with 5% maltodextrin during storage.

	Standard			5% of maltodextrin		
Storage (days)*	Glass	PP	PE	Glass	PP	PE
0	2.9.17 ± 3.25^{aAB}	26.82 ± 0.00^{aB}	27.06 ± 3.05^{aB}	26.82 ± 0.00^{aB}	28.24 ± 0.66^{aB}	29.17 ± 1.95^{aA}
20	30.53 ± 2.53^{aAB}	28.01 ± 2.99^{aB}	33.15 ± 3.08^{aAB}	26.82 ± 1.36^{aB}	28.24 ± 0.66^{aB}	33.15 ± 1.20^{aA}
40	23.36 ± 3.60^{aB}	25.36 ± 0.70^{aB}	29.63 ± 0.00^{aAB}	30.08 ± 3.19^{aB}	29.63 ± 2.58^{aAB}	29.17 ± 3.25^{aA}
60	33.57 ± 1.78^{aA}	35.21 ± 0.60^{aA}	35.21 ± 1.71^{aA}	36.40 ± 0.00^{aAB}	32.29 ± 3.66^{aAB}	30.53 ± 1.27^{aA}
80	31.86 ± 0.62^{abAB}	35.61 ± 1.1^{aA}	24.86 ± 1.40^{bB}	31.42 ± 5.9^{abAB}	35.61 ± 0.00 ^{aAB}	32.72 ± 1.81^{abA}
100	33.15 ± 1.20^{cdA}	34.81 ± 0.00^{bcA}	37.18 ± 1.08^{abA}	40.47 ± 0.49^{aA}	36.40 ± 1.11^{bcA}	30.98 ± 0.63 ^{dA}

* Average of two determinations ± standard deviation. Lower cases comparison between lines for the different types of packaging in the standard sample and 5% maltodextrin and upper case comparison in columns for each type of packaging during storage at 95% confidence level by Tukey test.

Table 4. Hygroscopicity (%) of standard and co-crystallized honey and with 5% maltodextrin during storage.

	Standard			5% of maltodextrin		
Storage (days)a	Glass	PP	PE	Glass	PP	PE
0	7.700 ± 1.469^{aA}	7.091 ± 0.199^{aA}	7.145 ± 0.180^{aA}	7.242 ± 0.073^{aA}	7.122 ± 0.190^{aA}	6.033 ± 0.185^{aA}
20	6.280 ± 0.236 ^{bA}	6.433 ± 0.105^{abA}	6.333 ± 0.147 ^{bA}	6.974 ± 0.165^{abA}	7.460 ± 0.519^{aA}	6.654 ± 0.270^{abA}
40	6.110 ± 0.544^{aA}	7.001 ± 0.805^{aA}	7.454 ± 0.863^{aA}	5.811 ± 0.296^{aA}	7.617 ± 1.300^{aA}	6.210 ± 0.872^{aA}
60	6.461 ± 0.054^{aA}	6.668 ± 0.114^{aA}	6.820 ± 0.081^{aA}	7.013 ± 0.181^{aA}	6.924 ± 0.389^{aA}	7.350 ± 1.023^{aA}
80	6.943 ± 0.231^{aA}	6.189 ± 0.627^{aA}	6.845 ± 0.084^{aA}	6.994 ± 0.195^{aA}	6.893 ± 0.076^{aA}	6.622 ± 0.254^{aA}
100	5.330 ± 0.098^{aA}	7.894 ± 0.406^{aA}	7.952 ± 0.240^{aA}	7.224 ± 0.788^{aA}	7.714 ± 1.216^{aA}	6.986 ± 0.968^{aA}

aAverage of two determinations ± standard deviation. Lower cases comparison between lines for the different types of packaging in the standard sample and 5% maltodextrin and upper case comparison in columns for each type of packaging during storage at 95% confidence level by Tukey test.

Table 5. Salmonella, thermotolerant coliforms, *E. coli* and molds and yeasts from raw materials and samples of standard and co-crystallized honey and with 5% maltodextrin in the different packages.

Samples	Packaging	Analysis	Results
Sucrose	Commercial packing	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	<10 est*
Standard	PP	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	<10 est*
5% of maltodextrin	PP	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	9×10^{3} UFC g^{-1} est
Standard	Glass	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP $^{-1}$
		Salmonella	Absence in 25 g
		Mold and yeast count	3.5×10^{2} UFC g^{-1} est
5% of maltodextrin	Glass	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	<10 est*
Standard	PE	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	3.3×10^{3} UFC g^{-1}
5% of maltodextrin	PE	Total count thermotolerant coliforms and *E. coli*	<3.0 NMP g^{-1}
		Salmonella	Absence in 25 g
		Mold and yeast count	<10 est

*est – estimated count

clime and harvest and post-harvest manipulation (Barth, 2004; Gois et al., 2013). This diversity is related to difference in chemical composition and physical differences, such as particle sizes of sugar cristals and pollen, resulting in singular characteristics.

The product's purchase intention was 4.1 ± 0.7 greater than 4 (would probably buy) in a 5-point scale. Based on the observations of the subjects, they pointed that would exchange conventional sucrose for co-crystallized honey, which shows the possibility of using this product as a substitute for pure sucrose.

The attribute taste (Figure 1) was evaluated in the dried standard sample (8.2 ± 0.9) and also in pineapple juice formulated with: standard samples (7.5 ± 1.4), sucrose (7.7 ± 1.0) and honey (5.4 ± 2.0). The highest score in this attribute was for the dried sample, with an AI of 91.3%, which indicates that this product has potential for applications in food formulations that contain sucrose. The use of co-crystallized honey and pure sucrose to sweeten pineapple juice did not change the taste of the product ($p > .05$), obtaining a higher score than juice sweetened with pure honey ($p > .05$). According to the comments of the subjects, it can be highlighted that one of the negative points in sweetening pineapple juice with honey is the after taste in the drink, which was not well accepted by consumers. Similar behavior was observed in a study with orange juice, sweetened with sucrose, brown sugar and honey, all in the concentration of 11 ºBrix. Orange juice sweetened with sucrose was the widely accepted by consumers, followed by brown sugar and honey, which showed rejection due to after taste present in the drink (Back et al., 2019).

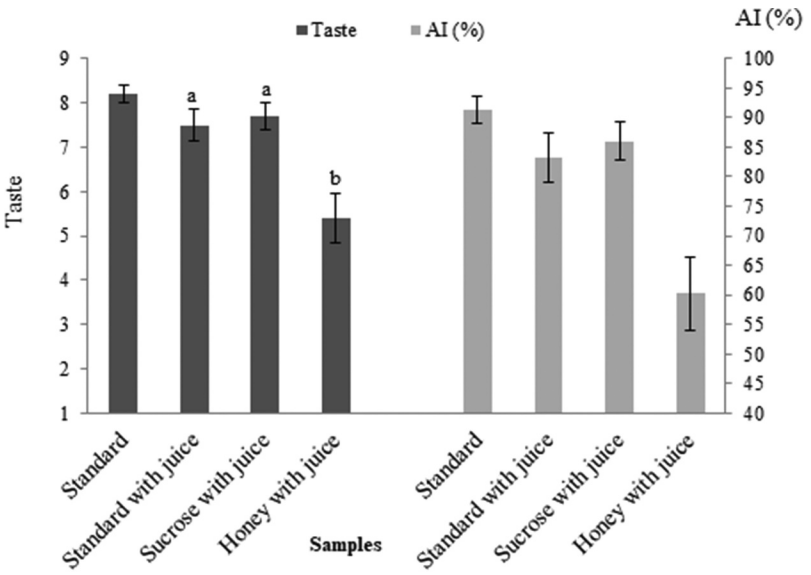

Figure 1.

Consumers have an affective memory for the pineapple taste, since the most commercialized products from this fruit in Brazil is as syrup, pasteurized juice and jellies (Crestani, Barbieri, Hawerroth, Carvalho, & Oliveira, 2010). In this case, the rejection of juice sweetened with honey can be explained due to a different aftertaste, since honey is not commonly uses as sweetener for juices in Brazil. Based on the results, co-crystallized honey with sucrose can represent a potential substitute for sucrose in food formulations, without significant changes in sensory aspects. However, cultural aspects should be considered when combining honey taste with other products.

Conclusion

Co-crystallization of honey with sucrose allows production of a powder product with good fluidity (repose angles from 23.36 to 40.47 °), densities from 0.42 to 0.55 g cm^{-3}, aw from 0.396 to 0.491 and hygroscopicity from 5.330 to 7.952%. The storage for 100 days resulted in a product without significant alterations in the physical-chemical properties, regardless of the type of packaging used. The sensory acceptance index of co-crystallized honey and juice sweetened with this product was over 80%, indicating possibilities of use in food formulations. Additional sensory studies with application of co-crystallized honey with sucrose in different food products such as jellies, candies, deserts, other fruit juices, chew-gums and gummys are relevant, also considering the physico-chemical characteristics.

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