

## Physicochemical and antioxidant activity of rubber honey powder prepared by foam-mat vacuum drying

<sup>1,\*</sup>Jaya, F., <sup>1</sup>Radiati, L.E., <sup>2</sup>Estiasih, T., <sup>3</sup>Lastriyanto, A., <sup>4</sup>Masyithoh, D., <sup>1</sup>Maharani, A.R. and <sup>1</sup>Aryandra, N.A.

<sup>1</sup>Universitas Brawijaya, Department of Animal Products Technology, Faculty of Animal Science, Malang 65145, East Java, Indonesia

<sup>2</sup>Universitas Brawijaya, Department of Food Science and Biotechnology, Faculty of Agricultural Technology, Malang 65145, East Java, Indonesia

<sup>3</sup>Universitas Brawijaya, Department of Agricultural Engineering, Faculty of Agricultural Technology, Malang 65145, East Java, Indonesia

<sup>4</sup>Islamic University of Malang, Department of Animal Husbandry, Faculty of Animal Husbandry, Malang 65144, Indonesia

### Article history:

Received: 27 February 2025

Revised: 9 April 2025

Accepted: 21 August 2025

Published: 7 March 2026

### Keywords:

Gum Arabic,

Honey powder,

Maltodextrin,

Tween 60,

Vacuum foam mat drying

### DOI:

[https://doi.org/10.26656/fr.2017.10\(2\).220](https://doi.org/10.26656/fr.2017.10(2).220)

This open access article is licensed under the CC BY 4.0



### Abstract

Producing powdered honey remains a technical challenge for both industry and researchers due to honey's inherent stickiness and thermal sensitivity. Foam mat drying is the process of converting materials from liquid to stable foam before air drying, enhancing drying efficiency and reducing product loss. Tween 60 is a low molecular surfactant that can absorb water well at the air-water interface and reduce tension, increasing the surface area of the drying material. This study aimed to develop honey powder from rubber (*H. brasiliensis*) using maltodextrin (MD) and gum Arabic (GA) as carrier agents. Foam-mat drying under vacuum conditions was applied, and the resulting honey powders were evaluated for their physicochemical properties, antioxidant capacity, and bioactive compound contents. The results showed that MD-based honey powder exhibited significantly lower moisture content (1.53%), faster dissolving time (43.05 s), higher solubility (99.34%), bulk density (0.65 g/mL), tapped density (1.81 g/mL), and powder yield (96%) than its GA-based counterpart. In contrast, GA-based honey powder had a higher hygroscopic rate (0.015 g.H<sub>2</sub>O/g solid.h), glass transition temperature (45.3°C), diastase activity (6.09 DN), total phenolic content (107.70 mg GAE/100 g), total flavonoid content (48.07 µg QE/100 g), and stronger antioxidant activity (lowest IC<sub>50</sub> = 5.68 mg/mL). GA-based honey powders also lower hydroxymethylfurfural (HMF) content (11.81 mg/100 g), Hausner ratio (2.32) and Carr Index (56.90%) than the MD-based counterpart. Thus, the results concluded that GA had a higher potential as a carrier for producing honey powder using vacuum foam mat drying than MD.

## 1. Introduction

Honey is a nutritious natural product with unique organoleptic properties and numerous health-promoting properties (Shi *et al.*, 2013). However, the industrial application of honey is restricted by its stickiness and high viscosity properties (Samborska *et al.*, 2015). Honey frequently contains supersaturated sugar (composed of fructose and glucose) and is prone to crystallization over time because of its highly viscous sugar solution. Sugar crystallization in honey has several disadvantages because of the formation and coexistence of two phases (crystalline and liquid), including

disapproval from consumers due to altered appearance and homogeneity loss, difficulty in handling and pouring, and an increase in water activity (*A<sub>w</sub>*), which are prone to microbial fermentative processes (Krishnan *et al.*, 2021). Honey powder is less complicated to transport, has less volume or weight, and has storage requirements (Samborska and Czelejewska, 2012).

However, manufacturing powdered honey remains challenging for both industry and researchers to enable its incorporation into a wider range of food products (such as beverages, bakery items, and dry mixes), where liquid honey is less compatible due to its moisture

\*Corresponding author.

Email: [firmanjaya@ub.ac.id](mailto:firmanjaya@ub.ac.id)

content and viscosity. The problem related to the low glass transition temperature ( $T_g$ ) of a particular amorphous material is called "stickiness behavior" (Nurhadi *et al.*, 2022). The fructose and glucose in honey have  $T_g$  of  $5^\circ\text{C}$  and  $31^\circ\text{C}$ , respectively (Samborska and Czelejewska, 2012). Suitable carrier materials have become a common practice in drying sticky materials (Azhar *et al.*, 2021). High-molecular-weight carrier materials, such as maltodextrin (MD) and gum arabic (GA), were added to dry liquid honey and put into a powder. Honey converts liquid into powder (Farahnaky *et al.*, 2016; Islam *et al.*, 2016). Recently, efforts have been made to facilitate the honey-drying process (Nurhadi *et al.*, 2012; Suhag *et al.*, 2016; Machado De-Melo *et al.*, 2018; Samborska *et al.*, 2019). Thus, a technology for producing excellent honey powder with good physicochemical characteristics and functional activity is under development.

Spray-drying and freeze-drying methods were used to create honey powder. However, neither method applies to small- and medium-scale industries because of their low yields and relatively expensive equipment (Ganaie *et al.*, 2021). In the vacuum drying and microwave vacuum drying methods, water evaporates at a lower temperature and absolute pressure (under vacuum conditions) than under normal conditions (ambient pressure, 1 atm). However, honey powder can be lost during vacuum oven drying because of clinging or spilling off the container or difficult grinding (Samborska *et al.*, 2019; Mutlu *et al.*, 2020).

Foam mat drying is an affordable, applicable, and novel way to minimize the stickiness of small and medium industries. In foam mat drying, the surface area of the drying material increases in a foamed state. The foam structure was dispersed as thin foam lamellae to prevent hardening. The substance persists in its permeability even after being completely dried. In addition to accelerating the drying process, the inner surface of the material increases (Kudra and Ratti, 2006). Sramek *et al.* (2015) investigated vacuum foam-dried honey powder using a glucose syrup formulation and whey protein isolate (WPI) as an emulsifier. The disadvantage of using glucose syrup is its hygroscopic property, and WPI is a more costly ingredient than low-molecular-weight surfactants. Tween 60 is a type of low molecular surfactant with a characteristic odor, a warm feeling, and a brownish-yellow liquid with a hydrophilic lipophilic balance (HLB) value of 14.9. The HLB value of Tween 60 is high; therefore, it is hydrophilic or soluble in water (Rowe *et al.*, 2003). An excellent foaming agent must be able to absorb water well at the air-water interface, reduce tension, and act as a viscoelastic film that can withstand heat due to the

movement of the foaming device (Sangamithra *et al.*, 2015).

Ustadi *et al.* (2017) reported that rubber nectar honey throughout the year in Indonesia contains various bioactive compounds (including phenolic acids and flavonoids) and exhibits higher antioxidant activity than certain other Indonesian honeys, such as calliandra honey (*Calliandra calothyrsus*) and kapok honey (*Ceiba pentandra*). However, honey powder has only been produced from sunflower (Suhag *et al.*, 2016), multiflora (Sramek *et al.*, 2015; Samborska *et al.*, 2017), buckwheat (Samborska *et al.*, 2015), and *Azadirachta indica* (Meliaceae) (Devi *et al.*, 2016). No studies have reported rubber honey being used to produce honey powder. Given its bioactive potential and nutritional profile, rubber honey powder is particularly promising for functional food applications. In this research, MD and GA at different concentrations combined with tween-60 as a surfactant were used to study the effect of vacuum foam mat drying on producing honey powder. Therefore, this study aimed to develop powdered rubber honey using foam-mat vacuum drying with MD and GA carriers and to evaluate the resulting powder's physicochemical and antioxidant properties.

## 2. Materials and methods

### 2.1 Raw materials

A honey sample from a rubber tree (*Hevea brasiliensis*) was obtained from PT. Kembang Joyo Sriwijaya, Malang, Indonesia. The plant origins of rubber honey were based on the pollen spectrum (45% and above), which is the ratio of the frequency of each pollen type in honey, determined using both melissopalynology (Von der Ohe *et al.*, 2004) and sensory analysis (Persano Oddo and Piro, 2004; Piana *et al.*, 2004). Gum Arabic (GA) carriers were purchased from Ingredion Sweetener and Starch Company Limited, Thailand, and maltodextrin (MD) 12 DE from Sorini Agro Asia Corporindo Tbk, Indonesia. The foaming agent Tween-60 was from Muby Chemicals, Ankleshwar, Gujarat, India.

### 2.2 Carrier material solution and foaming preparation

The carrier material solutions were prepared by combining 100 mL of honey with carrier material at ratios of 2:1, 1:1, and 2:3. The amounts of honey, maltodextrin (MD), or gum arabic (GA) were calculated from the initial solids contents of raw honey ( $\approx 80\%$  w/w) and each carrier so that the final mixtures contained 60, 80, or 100% total solids on a dry-basis (db). A 50 g of honey and a carrier material solution were mixed with 0.5% w/w tween-60 (Muby Chemicals, India). The mixture was homogenized using a planetary mixer

(Miyako 5M-625). Aeration was performed by normalizing Tween 60 in the honey-carrier material formulation using an outer and inner stirring rate of 460 rpm for 3 min.

### 2.3 Vacuum drying and powder preparation

The mixture was placed on the trays with a 0.5–1.0 cm thickness, and the trays were placed in a vacuum dryer (B-One VOV-50, China) equipped with a water jet vacuum system and a water chamber with dimensions of 188×122×62 cm. The oven vacuum conditions included a drying room measuring 41.5 cm × 37 cm × 34 cm, drying temperature set at 70°C, a vacuum pressure of 29.35 in Hg (with an absolute pressure of 5.807 in Hg), sample weight of 100 g, and drying time of 5 h. Drying trials were performed in duplicate. The dried material was stored at 18°C in glass bottles for 10 h before being ground in a grinder (GM-800S1, China) at room temperature under atmospheric conditions. The Ground samples were then stored at 18°C in vacuum plastic bags for further analysis.

### 2.4 Characterization of rubber honey

The physicochemical properties of rubber honey were analyzed using standard procedures, with results expressed as mean values from three replicates.

#### 2.4.1 Moisture content

Moisture content was determined by oven-drying 2.0±0.1 g honey at 105°C for 4 h according to AOAC Official Method 969.38. The sample was cooled in a desiccator and reweighed. Moisture content was determined using the following equation:

$$\text{Moisture (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100\% \quad (1)$$

#### 2.4.2 Diastase number

Diastase number (DN) was determined by diluting honey in acetate buffer (pH 5.3), incubating with 1% starch at 40°C, and measuring absorbance (660 nm) after iodine addition every 5 min. The DN value was calculated using  $DN = 300/t$ , where  $t$  is the time to reach  $A_{660 \text{ nm}} < 0.235$  (Kuc et al., 2017).

#### 2.4.3 Hydroxymethylfurfural

Hydroxymethylfurfural (HMF) was quantified by dissolving 5 g honey in 25 mL water, treating with Carrez I and II, filtering, and measuring absorbance at 284 and 336 nm. The HMF value was calculated using the method from the International Honey Commission IHC (1999).

$$\text{HMF (mg/100 g)} = (A_{284} - A_{336}) \times 149.7 \times 5 \times D/W \quad (2)$$

Where  $A_{284}$  is the absorbance at 284 nm,  $A_{336}$  is the absorbance at 336 nm,  $149.7 = (126 \times 1000 \times 1000) / (16,830 \times 10 \times 5)$  is constant, 126 is molecular weight of HMF, 16,830 is molar absorptivity  $\epsilon$  of HMF at  $\lambda = 284$  nm, 1000 is conversion g into mg, 10 is conversion 5 into 50 mL, 1000 is conversion g of honey into kg, 5 is the theoretical nominal sample weight,  $D$  is dilution factor in case dilution is necessary, and  $W$  is the weight in g of the honey sample.

#### 2.4.4 Reducing sugar

Reducing sugars were analyzed through Lane-Eynon titration following clarification with lead acetate and titration with Fehling's solution using methylene blue indicator according to AOAC Official Method 920.183.

#### 2.4.5 Free acidity

Free acidity was determined by titrating 10 g of honey diluted in 100 mL of water with 0.05 N NaOH to pH 8.30. Free acidity value was calculated using the method from AOAC Official Method 962.19 (2023).

$$\text{Free acidity (mEq/kg)} = V \times N \times 1000 / \text{sample weight} \quad (3)$$

Where  $V$  is the volume of NaOH,  $N$  is the normality of NaOH, and the value 1000 is a conversion factor to express the result in milliequivalents per kilogram (mEq/kg).

#### 2.4.6 Antioxidant activity (DPPH-IC<sub>50</sub>)

Antioxidant activity (DPPH IC<sub>50</sub>) was evaluated by mixing 0.2 mL of 10% (w/v) honey solution with 1.8 mL of 0.1 mM DPPH methanolic solution. The mixture was incubated in the dark at 25°C for 60 min. Absorbance was measured at 515 nm, and % inhibition was calculated. IC<sub>50</sub> was obtained through linear regression between concentration and inhibition values (Cinkmanis et al., 2017).

#### 2.4.7 Total phenolic content

Total phenolic content (TPC) was measured by reacting 0.5 mL of 0.1 g/mL honey solution with 2.5 mL 0.2 M Folin-Ciocalteu reagent and, after 4 min, adding 2 mL of 7.5% Na<sub>2</sub>CO<sub>3</sub>. The mixture was incubated for 1 h at 25°C in the dark, and absorbance was measured at 750 nm. Results were expressed as mg gallic acid equivalents (GAE) per 100 g dry basis (Keke and Cinkmanis, 2021).

#### 2.4.8 Total flavonoid content

Total flavonoid content (TFC) was determined by mixing 2 mL of 0.2 g/mL honey solution with 3 mL of 5% AlCl<sub>3</sub> solution. After 30 min of incubation at room temperature, absorbance was measured at 437 nm.

Values were expressed as mg quercetin equivalents (QE) per 100 g dry basis (Pontis *et al.*, 2014)

## 2.5 Honey powder analysis

### 2.5.1 Bulk density

Bulk density (g/mL) was defined as the ratio of the sample weight to the initial volume of the sample, as displayed on the measuring cylinder, and after gently tapping 20-25 times, the volume was recorded. In contrast, the tapped bulk density refers to the actual solid density, which does not include inter-particle gaps. The bulk density was compared with voids and spaces during the analysis. The tapped bulk density of the immiscible liquid ethanol (99%) was calculated using a pycnometer as the average of three replicates (Suhag *et al.*, 2021).

### 2.5.2 Hygroscopic

The hygroscopic rate (g.H<sub>2</sub>O/g solid. h) was calculated according to the procedure described by Nurhadi *et al.* (2012). A portion of the powder sample weighing 0.5 g was placed in a desiccator at an RH of 70%. Its weight was recorded every 60 min for a total duration of 240 min. The moisture uptake was calculated as the difference between initial and subsequent weights at each interval. The hygroscopic rate (g H<sub>2</sub>O/g solid·h) was calculated as the slope of the linear regression line of moisture content (on a dry basis) against time, indicating the rate at which the powder absorbs moisture under specified RH conditions. All results are expressed as the average of three replicates.

### 2.5.3 Solubility

The solubility of honey powder in water was determined following a modified method of Suhag *et al.* (2021). A 1 g sample in 100 mL of water (a) was homogenized with a magnetic stirrer at speed dial position 3 to produce a homogeneous solution. The samples were then filtered after complete dissolution. The residue on the filter paper was heated to 105°C for 3 h (b). The sample was then placed in a desiccator for 15 min, weighed, and recorded as the residual weight (c). All results are expressed as the average of three replicates. The following equation expresses solubility (%):

$$\text{Solubility (\%)} = \left( 1 - \frac{c-b}{\frac{100-\%WC(w.b) \times a}{100}} \right) \times 100\% \quad (4)$$

### 2.5.4 Flow properties

The determination of flow properties and the classification of flowability were conducted based on the Hausner Ratio (HR) and Carr Index (CI) values, as described by Gorle and Chopade (2020). The Carr index (CI) was used to classify powder flowability, and the

Hausner Ratio (HR) was used to classify the cohesiveness of the powder as the average of three replications using the following formula:

$$\text{Carr Index (CI)} = \frac{\text{Tapped density} - \text{Bulk density}}{\text{Tapped density}} \times 100 \quad (5)$$

$$\text{Hausner Ratio (HR)} = \frac{\text{Tapped density}}{\text{Bulk density}} \quad (6)$$

### 2.5.5 Dissolution time

The dissolution time of the honey powder was estimated according to the method described by Nurhadi *et al.* (2012). Briefly, 250 g of aqueous solution was added to 1 g of the sample and stirred using a blender at a 3-speed dial. The dissolving time was calculated from the time it dissolved entirely in water. The data are the average of three replicates.

### 2.5.6 Powder yield

The ratio of the yield of the produced honey powder to the product of the honey-carrier material solution was used to calculate the production yield of honey powder, and the results were expressed as percentages (Suhag *et al.*, 2021). The data represent the average of three replicates.

### 2.5.7 Glass transition temperature (T<sub>g</sub>)

A differential scanning calorimeter (ASTM F 2625-10) (mode DSC 214 Polyma, Bayern, Germany) was used to measure the glass transition temperature (T<sub>g</sub>) of the powdered honey. A 10 mg samples were sealed hermetically in aluminum pans and analyzed at ambient temperature. The standard was an empty aluminium pan. The procedure consisted of the following steps: initial cooling from room temperature (25°C) to -40°C at a rate of 10°C/min, followed by an isothermal hold at -40°C for 5 min; heating to 90°C at 10°C/min, with another isothermal hold for 5 min at 90°C; re-cooling to -40°C at 10°C/min and holding again for 5 min; finally, the sample was reheated to 160°C (or to 200°C for pure MD and GA powders) at 10°C/min. This method utilizes a double scanning program of samples to improve the accuracy of T measurements on DSC thermograms.

### 2.5.8 Moisture content and water activity determination

Moisture content of honey powder was determined by drying 1 g of the sample at 105°C for 4 h (Chegini and Ghobadian, 2005). Water loss after treatment generated a weight change that was expressed as a percentage of the sample's initial weight and calculated as the average of duplicate samples. The water activity (a<sub>w</sub>) of the vacuum foam mat dried honey powder was measured using an AquaLab 3TE Series water activity meter (Decagon Devices, Inc., Pullman, WA, USA). The

temperature was held at 24.5°C plus or minus 0.5°C during the measurement.

### 2.5.9 Hydroxymethylfurfural

Hydroxymethylfurfural was determined using a spectrophotometric method (International Honey Commission, 1999). A 50-mL volumetric flask was filled with 5 g of honey powder dissolved in 25 mL of water. Then, 0.5 mL of Carrez solutions I and II (0.5 mL) were added, and water was used to fill the flask to a total volume of 50 mL. After filtering the solution through a paper, the first 10 mL of the filtrate was removed. Approximately 5 mL of Distilled water (sample solution) and 5 mL of sodium bisulfite solution (0.2% concentration) were added to two test tubes, each containing an aliquot of 5 mL. UV-Vis spectroscopy was used to calculate the absorbance of the solutions at 284 and 336 nm. The standard external technique (99% Sigma-Aldrich, Milan) and the suggested formula for the method reported by the International Honey Commission were used to determine the quantitative value of HMF (Bogdanov *et al.*, 1999). All results are expressed as the average of three replicates.

### 2.5.10 Diastase number

Diastase activity was based on the distribution of starch by  $\alpha$ -amylase, according to Kuc *et al.* (2017), with a modification. Five grams of honey was added to 10-15 mL of distilled water and 2.5 mL of acetate buffer. The solution was stirred until homogeneous and transferred to a 25 mL volumetric flask containing 1.5 mL NaCl. Distilled water was added until the limit mark was reached, and 10 mL of solution was added to 5 mL of starch solution. Heating was done in a water bath at 40±20°C for 15 min. At every 5 min interval, 1 mL of the solution was added to 10 mL of iodine solution, mixed, and diluted with 20 mL of water. The absorbance of the sample was measured at a wavelength of 660 nm. The reaction time was recorded from the time the honey was mixed with the starch solution until the iodine solution was added. The solution was continued until  $A < 0.235$  was obtained within a specific time interval. The determination of DN was made using the following formula

$$DN = \frac{300}{t} \quad (7)$$

Where DN = diastase number and t = time taken to reach the absorbance value.

### 2.5.11 Antioxidant activity

The antioxidant activity of honey powder and honey was assessed using the DPPH (Sigma Aldrich®, Germany) assay according to Cinkmanis *et al.* (2017),

with a slight modification. The honey powder was diluted in water to reach a concentration of 10%. The solution of 0.2 mL was mixed with 1.8 ml methanolic DPPH solution (0.1 mM) and left to stand for 60 min in the dark and at room temperature. The absorbance of the sample mixture (A1) was measured at 515 nm with the control of methanol (A0). The measurement was conducted in three replications. The antioxidant activity was measured with the following formula:

$$\text{DPPH radical scavenging activity \%} = \frac{A_0 - A_1}{A_0} \times 100\% \quad (8)$$

A 3.5 mL of methanol and dissolved honey powder solutions of the same concentrations as before were used to create a blank solution. The 1.5 mL of 0.1 mM DPPH solution and 3.5 mL of methanol (Sharlab S.L., Spain) were added to create the control solution. The IC<sub>50</sub> values were determined using linear regression plots, where the concentration of produced solutions is shown on the abscissa, and the antioxidant activity is shown on the ordinate. The IC<sub>50</sub> values were calculated by linear regression of plots, where the concentration of the prepared solutions was represented on the abscissa, and the antiradical activity of the prepared solutions was plotted on the ordinate (Pontis *et al.*, 2014).

### 2.5.12 Total phenolic content

The Folin–Ciocalteu method, modified by Keke and Cinkmanis (2021), was used to determine the total phenolic compound content. The powder and liquid of honey were diluted in deionized water to a concentration of 0.1 g/mL. The 0.5 mL sample volume was added by 2.5 mL of 0.2 M Folin-Ciocalteu reagent (Sigma Aldrich®, Germany). Approximately 2 mL of a 7.5% Na<sub>2</sub>CO<sub>3</sub> solution were mixed with the sample and stirred for 5 min. The reaction mixture was maintained at ±20°C in the dark for 1 h. A UV/Vis spectrophotometer (Shimadzu 1280, Japan) with absorbance at 750 nm was used to measure the total phenolic content after incubation. Deionized water was used as a blank solution. Data are presented as gallic acid equivalents (µg GAE 100/g dry matter) as the average of three replicates.

### 2.5.13 Total flavonoids

The total flavonoid content was determined using aluminum chloride according to the method described by Pontis *et al.* (2014). Stock honey solution of 0.2 g/mL (2 mL) was dissolved in 3 mL AlCl<sub>3</sub> 5% solution. After incubation for 30 min, the absorbance was measured at 437 nm with methanol as a blank. The data are presented as quercetin equivalents (mg QE.100 g-1 dry basis). The data represent the average of three replicates.

## 2.6 Data analysis

All experiments were conducted in three replications. Statistical analysis used SPSS software (v.24.00, IBM SPSS., Chicago, Illinois, USA). The difference among treatments was analyzed by two-way variance analysis of variance followed by Duncan's honest significant difference test at 5% significance level. Data were presented in the mean±standard deviation (SD).

## 3. Results and discussion

### 3.1 Characteristics of rubber honey

The physicochemical properties, antioxidant activity, total flavonoids and phenolic contents of rubber honey (*H. brasiliensis*) are presented in Table 1. The data show that rubber honey meets both the Indonesian National Standard (2018) and the Codex Alimentarius Commission (2019) in terms of key parameters such as moisture content, diastase number, and HMF. In particular, the diastase number of  $21.17 \pm 0.78$  and HMF of  $5.41 \pm 2.59$  mg/100 g are consistent with high-quality honey indicators, while the reducing sugar, sucrose, and total sugars confirm the typical sugar profile of monofloral honeys. The free acidity of  $18.01 \pm 1.43$  mEq/100 g also underscores the freshness and acceptable acidity level of the rubber honey. Moreover, the antioxidant activity (IC<sub>50</sub>) of rubber honey was  $125.41 \pm 5.70$  mg/mL, which means it is classified as having weak antioxidant activity because it is not sufficiently effective to reduce free radicals by 50%. Ustadi et al. (2017) reported that the DPPH IC<sub>50</sub> of rubber honey from West Java was stronger ( $15.08 \pm 1.49$  mg/mL) than that observed in the present study. This difference may be attributed to variations in geographical locations, rubber tree varieties, and the different harvest seasons, all of which can influence the nectar

Table 1. Characteristics of raw rubber honey.

Parameters	Concentration
Physicochemical properties	
Moisture content (%)	19.40±0.20
Diastase number (DN)	21.17±0.78
HMF (mg/100 g)	5.41±2.59
Reducing sugar (%)	56.75±4.88
Sucrose (%)	0.84±0.32
Total sugars (g/100 g)	73.09±0.81
Free acidity (mEq/100 g)	18.01±1.43
Antioxidant activity	
DPPH IC <sub>50</sub> (mg/mL)	125.41±5.70
Bioactive compounds	
Total phenolic content (mg GAE/100 g)	48.21±0.61
Total flavonoid content (mg QE/100 g)	31.22±1.21

Values are presented as Mean±SD

composition and bioactive compounds contributing to honey's antioxidant capacity.

Jaya et al. (2022) reported that the total phenols and flavonoids in rubber honey are lower than those in other types of honey, such as calliandra honey (*Calliandra calothyrsus*) and kapok honey (*Ceiba pentandra*). Adalina et al. (2020) stated that rubber honey from *A. mellifera* with an actual phenolic content is weak compared to that of *A. dorsata*, which is moderately positive. According to Alvarez-Suarez (2018), the location of the apiaries or the geographical origin where the bees collect nectar may influence the composition of polyphenols in honey because these compounds act as protectors against environmental stress, such as changes in temperature, light intensity, moisture content, UV exposure, and mineral nutrient deficiency. These compounds may vary depending on the environmental exposure of the plants.

### 3.2 Rubber honey powder properties

The final product produced by milling was obtained from the weight of the sample relative to the initial volume of the sample, whether closed or open to the surrounding atmosphere (Fitzpatrick, 2013). The actual solid density is called the tapped bulk density (Suhag et al., 2021). The different carrier materials and levels affected the bulk and tapped densities of the vacuum foam-dried powders ( $p < 0.05$ ). An increase in MD and GA total solid level in the feed concentration from 20 to 40% led to a decrease in powder bulk density (Table 2). Based on these results, the best treatment for producing rubber honey powder, in terms of balancing flow properties and yield, was GA at 40%, as it resulted in a desirable bulk density with comparatively favorable solubility, yield, and flow characteristics. Samborska et al. (2019) obtained similar results. The increasing honey concentration decreased the bulk density of the MD-based powders. This relationship could be related to the low degree of agglomeration of the carriers, which may be related to their lower bulk density with increasing carrier levels, thus increasing the volume of the powder particles (Suhag et al., 2021). The trapped density is equivalent to the actual solid density (as opposed to the bulk density), which accounts for all empty spaces between the particles. The present study's tapped density ranged between 1.26 g/mL and 1.81 g/mL (Table 2). These findings align with the research of Suhag et al. (2021), who observed that the honey powder with MD and GA additions exhibited densities of 1.80 and 1.64 g/mL, respectively. Samborska et al. (2019) also reported that honey powders obtained by low-temperature dehumidified air spray drying with honey-to-MD solid ratios of 60:40, 70:30, and 80:20 were 1.51, 1.50, and

Table 2. The rubber honey powder's physical properties with different levels of carrier materials.

Parameters	Maltodextrin (MD)			Gum Arab (GA)		
	20%	40%	60%	20%	40%	60%
Bulk density (g/mL)	0.65±0.01 <sup>d</sup>	0.52±0.03 <sup>a</sup>	0.50±0.02 <sup>a</sup>	0.62±0.02 <sup>cd</sup>	0.58±0.01 <sup>bc</sup>	0.56±0.04 <sup>b</sup>
Tapped density (g/mL)	1.81±0.04 <sup>c</sup>	1.51±0.01 <sup>c</sup>	1.26±0.01 <sup>a</sup>	1.45±0.01 <sup>b</sup>	1.79±0.02 <sup>c</sup>	1.57±0.03 <sup>d</sup>
Hygroscopic rate (g.H <sub>2</sub> O/g solid.h)	0.037±0.002 <sup>b</sup>	0.045±0.002 <sup>d</sup>	0.019±0.005 <sup>c</sup>	0.015±0.001 <sup>a</sup>	0.014±0.001 <sup>a</sup>	0.013±0.001 <sup>ab</sup>
Solubility (%)	98.77±0.10 <sup>a</sup>	99.34±0.47 <sup>b</sup>	99.09±0.23 <sup>ab</sup>	98.85±0.09 <sup>ab</sup>	99.12±0.16 <sup>ab</sup>	99.07±0.31 <sup>b</sup>
Hausner ratio	2.71±0.04 <sup>ab</sup>	2.91±0.15 <sup>b</sup>	2.54±0.02 <sup>ab</sup>	2.32±0.09 <sup>a</sup>	2.49±0.44 <sup>a</sup>	2.48±0.15 <sup>a</sup>
Carr index (%)	63.15±0.54 <sup>bc</sup>	65.63±1.81 <sup>c</sup>	60.85±0.38 <sup>abc</sup>	56.90±1.66 <sup>a</sup>	59.07±6.60 <sup>ab</sup>	61.28±1.17 <sup>abc</sup>
Dissolving time (s)	73.78±0.24 <sup>f</sup>	49.88±0.12 <sup>d</sup>	43.05±0.10 <sup>a</sup>	50.99±0.09 <sup>c</sup>	45.26±0.10 <sup>b</sup>	47.02±0.08 <sup>c</sup>
Glass transition temperature T <sub>g</sub> (°C)	13.7	21.2	17.8	20.8	21.1	45.3

Values are presented as mean±SD, n = 3. Values with different superscripts in the same row are statistically significantly different (p<0.05).

1.50, respectively. In this study, the MD-based honey powder showed a slightly higher tapped bulk density than the GA-based honey powder. Suhag *et al.* (2021) suggested that MD has more interparticle spaces than GA, which has relatively fewer.

Amorphous products are more hygroscopic than crystalline products. GA with higher levels had higher hygroscopic rates. GA is believed to have a greater capacity for hydration, swelling, dissolution, and interaction with water. The hygroscopic rate of GA ranges from 0.013 to 0.015 g.H<sub>2</sub>O/g solid.h, with the highest level of 60%, indicating a significant water absorption and retention capacity. Hygroscopicity increased with decreasing particle size, suggesting that GA with a smaller size has a higher propensity to absorb water from the environment (Rosland Abel *et al.*, 2020). At the same time, Fabra *et al.* (2011) stated that adding MD decreased the powder's ability to absorb water due to its lower hygroscopicity. The hygroscopic rate at MD 40% was 17.77% lower than at MD 20%, whereas MD 60% showed a 57.77% reduction in hygroscopic rate. The hygroscopic rate for GA 20% was reduced by 6.66% and 13.33% when compared to GA 40% and GA 60%, respectively.

Solubility is crucial for predicting the behavior of a powder in an aqueous phase. Food powders have distinct water solubilities. As shown in Table 2, the solubility of the powders increased with increasing carrier levels because of their naturally high water solubility. The honey powder with MD had the highest solubility compared to GA. The results were similar to those of MD- and GA-based spray-dried powders reported by Suhag *et al.* (2021) and vacuum-dried powders reported by Mutlu and Erbas (2021). The highest solubility was achieved with MD (98.77± 0.10 s), while the lowest was 99.34±0.10 s. This result matched honey powder spray

drying with MD (28-148 s) (Samborska and Bieñkowska, 2013). These findings follow those of Osés *et al.* (2021), who reported that the lower moisture content of vacuum-dried powder using MD showed the best solubility. Similarly, Mutlu and Erbas (2021) also reported that solubility increases as the moisture content decreases because of the lower chance of powder clumping. Nevertheless, these findings contradict those of Samborska and Bieñkowska (2012). The water solubility decreased with increasing powder moisture content.

The *Hausner* ratio and *Carr* index results of honey powder by vacuum-foam drying differed significantly (p < 0.05), and they changed between 2.32±0.09 -2.91±0.09 0.15 and 56.90±1.66-65.63±1.81%, respectively (Table 2). These flow properties of vacuum-foam dried honey powder are "very, very poor" based on the category by Gorle and Chopade (2020). The harmful flowing properties of honey powder might be related to sticky substances from carrier materials, which are hygroscopic and quickly absorb water from the surroundings. Thus, the anti-caking acts as a barrier to water. Ortega-Rivas *et al.* (2005) stated that an anti-caking agent (or free-flowing agent) improves the host stability and preserves its free-flowing characteristics. The anti-caking chemicals protect the host material by water barrier formation, surface friction elimination, and crystal development restriction. Therefore, the stability of sugar-rich powders, such as honey powder, can be maintained using an anti-caking agent (Welti-Chanes *et al.*, 2008).

The dissolution time is required to dissolve an object evenly throughout the solution. Table 2 shows that the dissolving time of honey powders ranged from 43.05±0.10 s to 73.78±0.24 s and decreased due to the emulsifying abilities of carrier agents and the amphiphilic molecular structures of aids. In this study,

the dissolving time was higher than that of vacuum-dried powders with MD and GA (Nurhadi *et al.*, 2012) and with the rewetting method using polyvinylpyrrolidone (PVP) (Nurhadi *et al.*, 2022). The discrepancies may be caused by variations in the drying conditions and carrier material level, affecting the solution viscosity. Mutlu and Erbas (2021) stated that a long vacuum drying time would result in the formation of crystalline rather than amorphous solids. Crystalline solids are less soluble than amorphous solids because of the hydrogen bonds between solid crystal molecules. The dissolving time of honey powder containing MD requires more time to disperse in water than that of GA. Similar behavior was observed with GA-based spray drying (Suhag *et al.*, 2021). In contrast, Nurhadi *et al.* (2012) reported that GA in vacuum-dried honey powder was more challenging to wet and required longer to disperse in water.

The glass transition temperature ( $T_g$ ) of honey powder ranged from 13.7 to 45.3°C (Table 2). Higher  $T_g$  values were achieved with honey powders with GA than with MD as the carrier material. Ganaie *et al.* (2021) obtained a similar result. Honey powder containing WPI was successfully transformed into a glassy, free-flowing form compared with powders with MD carriers. The  $T_g$  value increased with the molecular weight of the material. The lower  $T_g$  values of the powders with MD suggest that they should be stored in high-barrier packaging under refrigeration (Bhatta *et al.*, 2020). The  $T_g$  values of MD and GA were higher than those obtained by other researchers, who described  $T_g$  values between 6.5 and 26.1°C (Jedlińska *et al.*, 2019) and ranged from 6.5 to 20.3 (Samborska *et al.*, 2019). However, the current study's  $T_g$  values in vacuum drying are lower than those obtained using spray drying, falling between 42.6 and 49.86°C (Sahu, 2008) and spray drying between 47.5 and 82.14°C (Samborska *et al.*, 2020). Despite having low  $T_g$  values, all treatments were successfully transformed into powder. This phenomenon also occurred in the research conducted by Samborska *et al.* (Samborska *et al.*, 2019). Amorphous materials achieve their critical viscosity, which causes stickiness and caking at temperatures 10–20°C higher than the  $T_g$  value (Samborska *et al.*, 2020). However, amorphous ingredients are not stable at temperatures above the  $T_g$ . Therefore, honey powders with low  $T_g$  values (close to room temperature) should be stored in high-barrier packaging under refrigerated conditions (Jedlińska *et al.*, 2019).

### 3.3 Physicochemical properties of rubber honey powder

The powder yield from this study (Table 3) was higher (from 53% to 96%) than that from a previous

study on honey drying. This finding is comparable to Nurhadi *et al.* (2012), who reported that the recovery of vacuum-dried honey powder was 73.0–73.8%. The lowest powder recovery was MD 20% (53±1%) and GA 20% (57±2%), which contained the lowest carrier material level. GA 20% yielded more powder than MD 20% because GA has a higher transition temperature than MD. According to Nurhadi *et al.* (2012), GA can encapsulate or cover honey more effectively than MD. Therefore, the honey powder with GA had a higher yield than MD. This result was higher than that of honey powder using spray drying, ranging from 5% (Shi *et al.*, 2013) to a maximum of 77.1% (Samborska *et al.*, 2017). The water added to the mixture (honey + carrier) during spray-drying tends to lower its  $T_g$ , which may cause the mixture to stick to the drying chamber. Product loss can also occur during drying by spilling off the container and grinding (Nurhadi *et al.*, 2012).

Moisture values were between 1.53±0.24 and 5.26±0.15%, and the type of carrier material had a significant difference ( $p < 0.05$ ). This report indicated that the residual moisture of honey powders dried using vacuum foam mat drying is affected by the initial total solid concentration. This value was higher than that reported by Nurhadi *et al.* (2012), who found that the moisture in vacuum-dried honey powder was between 1.1–2%. Mutlu *et al.* (2020) also reported that honey powder produced by vacuum-drying using GA and MD was 1.40% and 1.92%, respectively. The concentration of honey or the drying process resulted in a lower moisture content despite using the same honey samples. The present study compared MD and GA using different levels of honey as a carrier for each treatment. According to Samborska *et al.* (2019), the amount of water in the final product increased with the carrier material concentration. Honey powder with GA as a carrier material showed higher moisture content than that with MD (Table 3). GA in vacuum-dried honey powder had a higher moisture content than MD (Nurhadi *et al.*, 2012). The carrier material causes variations in the hydrophilic and hydrophobic balance (Gabas *et al.*, 2007).  $A_w$  values were between 0.31±0.01 and 0.38±0.01 with a significant statistical difference ( $p < 0.05$ ). Similar values were obtained by Nurhadi *et al.* (2012), Nurhadi and Roos (2017), and Mutlu *et al.* (2020) using vacuum drying, while higher water activity (0.066–0.138) was obtained in spray-dried powders with GA or MD. This variation might be due to the variation in honey types, time spent before analysis, and storage conditions (Oses *et al.*, 2021). The honey powder used in this study was classified as a stable food because of its low  $A_w$  value. Abramovič *et al.* (2008) reported that most microbial activities are inhibited if the water activity of honey is less than 0.6.

Table 3. Physicochemical properties of rubber honey powder using different levels of carrier materials.

Parameters	Maltodextrin (MD)			Gum Arab (GA)		
	20%	40%	60%	20%	40%	60%
Powder yield (%)	53±1 <sup>a</sup>	73±1 <sup>c</sup>	96±3 <sup>f</sup>	57±2 <sup>b</sup>	78±2 <sup>d</sup>	90±5 <sup>e</sup>
Moisture (%)	2.66±0.12 <sup>b</sup>	1.53±0.24 <sup>a</sup>	2.80±0.11 <sup>bc</sup>	2.83±0.09 <sup>bc</sup>	3.01±0.11 <sup>c</sup>	5.26±0.15 <sup>d</sup>
Water activity (A <sub>w</sub> )	0.38±0.01 <sup>c</sup>	0.31±0.01 <sup>a</sup>	0.36±0.01 <sup>c</sup>	0.31±0.01 <sup>bc</sup>	0.33±0.01 <sup>c</sup>	0.32±0.01 <sup>d</sup>
HMF (mg/100 g)	21.52±1.22 <sup>b</sup>	35.87±1.34 <sup>d</sup>	50.73±3.32 <sup>e</sup>	31.25±0.64 <sup>c</sup>	24.04±0.43 <sup>b</sup>	11.81±0.49 <sup>a</sup>
Diastase number (DN)	3.97±0.24 <sup>c</sup>	3.14±0.35 <sup>b</sup>	2.50±0.07 <sup>a</sup>	4.21±0.13 <sup>c</sup>	5.58±0.39 <sup>d</sup>	6.09±0.11 <sup>f</sup>

Values are presented as mean±SD, n = 3. Values with different superscripts in the same row are statistically significantly different (p<0.05).

HMF values of honey powders were between 21.52±1.22 and 50.73±3.32 mg/100 g, and carrier material types and their level are significantly different (p < 0.05). The highest and lowest HMF contents were the honey powders containing MD 60% and 20%, respectively. Hydroxymethylfurfural (HMF) content and diastase number (DN) indicate the heating effects during honey powder drying. HMF is a derivative of glucose and fructose produced by overheating (Chmielewska, 2003). HMF could also indicate the inverted sugar content in honey produced from the oligo- and polysaccharides added to honey (Mutlu and Erbas, 2021). The HMF content in this study complies with the National Standardization Agency of Indonesia (2018) and the Codex Alimentarius Commission (2019), which has a maximum of 40 mg/kg. Unlike MD 60%, the HMF content of honey should be lower than 40 mg/kg. According to Nurhadi *et al.* (2012), honey powder produced by vacuum drying using GA and MD is 0 and 30.4 mg/kg, respectively. Mutlu and Erbas (2021) also reported that the highest HMF content was found in vacuum-dried samples compared with spray-dried samples. The amount of HMF in the honey powder might have increased due to prolonged drying.

Diastase number values in this research were between 2.50±0.07 and 6.09±0.11 DN (Table 3), with significant differences (p < 0.05) among treatments. Except for MD 60%, all diastase numbers from MD and GA at various levels were higher than the minimum for diastase numbers of three (The National Standardization Agency of Indonesia, 2018). Vacuum-dried honey powder had a DN of 0-7.2 DN (Nurhadi *et al.*, 2012) and 2.61±0.32-10.48±10.48 DN (Mutlu and Erbas, 2021). However, based on the Codex Alimentarius Commission standard (2019), these values were also lower than the minimum legal limit for diastase number eight. Honey powder with GA as a carrier material revealed a higher diastase number than MD. GA offers better protection during drying than MD with DE 12. Mutlu and Erbas (2021) reported similar results for lower DN in MD-containing honey powders. Nurhadi *et al.* (2012) reported that GA had a lower heating destruction effect than MD when using vacuum and spray drying. The

drying method did not affect DN. Mutlu and Erbas (2021) found similar results for producing honey powder using blossom honey. Drying methods did not affect diastase enzyme activities. In conclusion, vacuum foam mat drying techniques can maintain diastase enzyme activity.

### 3.4 Antioxidant activity

The IC<sub>50</sub> value was used to express the free radical scavenging activity, indicating the sample's capacity to inhibit 50% of free radicals. The capacity of the sample to neutralize free radicals increased with decreasing IC<sub>50</sub> values. The obtained IC<sub>50</sub> values of the honey powders with MD and GA ranged from 5.68±1.60 to 47.47±2.93 mg/mL (Table 4). Honey powder with GA as the carrier material showed better antioxidant activity than that with MD. In a previous study, Mutlu and Erbas (2021) also examined *Apis mellifera* honey under different drying methods (spray-drying and vacuum-drying) and reported that antioxidant capacity was influenced by both the processing technique and the type of carrier used, underscoring the importance of technological parameters in preserving honey's bioactive compounds. Ali *et al.* (2020) reported that GA possesses anti-inflammatory and antioxidant properties through its derivative butyrate and contains naturally occurring polyphenols. MD and GA significantly increased the antioxidant potential of the honey powder.

### 3.5 Bioactive compounds of rubber honey powder

The total phenolic content (TPC) ranged from 50.15±0.47 to 107.70±0.84 mg GAE 100 g dry matter (Table 4). High TPC was found in the honey containing 20% carrier material. These findings follow the research of Osés *et al.* (2021), who reported that honey powder containing GA showed higher total phenolic content after spray drying than MD. The drying procedure, carrier, and interactions significantly influenced the TPC.

The total flavonoid in honey powder prepared by vacuum foam-mat drying with varying levels of MD and GA ranged from 9.95±1.09 to 48.07±1.77 µg QE/100 g. GA had higher concentrations of flavonoids compared

Table 4. Antioxidant activity and bioactive compounds of rubber honey powder using different levels of carrier material materials.

Parameters	Maltodextrin (MD)			Gum Arab (GA)		
	20%	40%	60%	20%	40%	60%
DPPH IC <sub>50</sub> (mg/mL)	25.06±1.34 <sup>d</sup>	31.27±2.23 <sup>a</sup>	47.47±2.93 <sup>f</sup>	5.68±1.60 <sup>a</sup>	12.89±1.59 <sup>b</sup>	18.25±1.64 <sup>c</sup>
Total phenolic content (µg GAE/100 g)	61.55±0.52 <sup>c</sup>	53.06±0.20 <sup>b</sup>	50.15±0.47 <sup>a</sup>	107.70±0.84 <sup>f</sup>	102.95±0.06 <sup>c</sup>	97.82±0.10 <sup>d</sup>
Total flavonoid content (µg QE/100 g)	26.52±0.35 <sup>c</sup>	11.62±0.34 <sup>b</sup>	9.95±1.09 <sup>a</sup>	48.07±1.77 <sup>a</sup>	39.88±2.59 <sup>b</sup>	36.68±1.41 <sup>c</sup>

Values are presented as mean±SD, n = 3. Values with different superscripts in the same row are statistically significantly different (p<0.05).

with MD. Moreover, the nectar content in rubber flowers can vary in phenolic and flavonoid profiles, thereby affecting the final bioactive compound content of the resulting honey powder. Factors such as climate, rubber tree variety, and harvesting conditions influence the nectar's phytochemical composition, which ultimately impacts phenolic and flavonoid concentrations in the powder. Alawi *et al.* (2018) reported that GA contains various secondary metabolites such as flavones, catechins, polyphenols, tannins, chalcones, alkaloids, and flavonoids. In conclusion, honey powder prepared using GA has more bioactive compounds than honey powder prepared using MD.

#### 4. Conclusion

In conclusion, tween 60 is a type of low molecular surfactant which can act as a foam mat drying and holds promising potential for producing honey powder containing MD and GA as carrier materials. Foam mat drying of honey powder using GA at 40% concentration is recommended based on overall quality. While increasing the level of MD and GA on physicochemical properties could increase powder yield and glass transition temperature, it reduces the quality of moisture, water activity, HMF, and Diastase Number, although still following honey standards. Good antioxidant potential was achieved by increasing the level of MD and GA of the honey powder. Foam mat dried honey powder can be applied in many food products, such as snacks, yogurt, and dietary supplements and can be used as a substitute for artificial sugar.

#### Conflict of interest

The authors declare no conflict of interest.

#### Acknowledgments

This research was financially supported by the RISPRO LPDP (Indonesia Endowment Fund for Education), Ministry of Finance of the Republic of Indonesia, with research project no. PRJ-45/LPDP/2019.

#### References

- Abramovič, H., Jamnik, M., Burkan, L. and Kač, M. (2008). Water activity and water content in Slovenian honeys. *Food Control*, 19(11), 1086–1090. <https://doi.org/10.1016/j.foodcont.2007.11.008>
- Adalina, Y., Kusmiati, E. and Pudjiani, M. (2020). Phytochemical test and physical chemical properties of rubber honey from three types of bees (*Apis mellifera*, *Apis dorsata* and *Trigona itama*). *IOP Conference Series: Materials Science and Engineering*, 935, 012007. <https://doi.org/10.1088/1757-899x/935/1/012007>
- Alawi, S.M.A., Hossain, M.A. and Abusham, A.A. (2018). Antimicrobial and cytotoxic comparative study of different extracts of Omani and Sudanese Gum acacia. *Beni-Suef University Journal of Basic and Applied Sciences*, 7(1), 22–26. <https://doi.org/10.1016/j.bjbas.2017.10.007>
- Ali, N.E., Kaddam, L.A., Alkarib, S.Y., Kaballo, B.G., Khalid, S.A., Higawee, A., Abdelhabib, A., AlaaAldeen, A., Phillips, A.O. and Saeed, A.M. (2020). Gum Arabic (*Acacia senegal*) Augmented Total Antioxidant Capacity and Reduced C-Reactive Protein among Haemodialysis Patients in Phase II Trial. *International Journal of Nephrology*, 2020, 7214673. <https://doi.org/10.1155/2020/7214673>
- Alvarez-Suarez, J.M., Giampieri, F., Brenciani, A., Mazzoni, L., Gasparini, M., González-Paramás, A.M., Santos-Buelga, C., Morroni, G., Simoni, S., Forbes-Hernández, T.Y., Afrin, S., Giovanetti, E. and Battino, M. (2018). *Apis mellifera* vs *Melipona beecheii* Cuban polifloral honeys: A comparison based on their physicochemical parameters, chemical composition and biological properties. *LWT*, 87, 272–279. <https://doi.org/10.1016/j.lwt.2017.08.079>
- AOAC INTERNATIONAL. (2023). Moisture in Honey (AOAC Official Methods 969.38). Official Method of the Analysis of AOAC INTERNATIONAL. 22nd ed. Rockville, USA: AOAC INTERNATIONAL
- AOAC INTERNATIONAL. (2023). Sugars (Reducing) in Honey (AOAC Official Method 920.183). Official Method of the Analysis of AOAC INTERNATIONAL. 22nd ed. Rockville, USA:

- AOAC INTERNATIONAL.
- AOAC INTERNATIONAL. (2023). Acidity (Free, Lactone, and Total) of Honey: Titrimetric Method (AOAC Official Methods 962.19). Official Method of the Analysis of AOAC INTERNATIONAL. 22nd ed. Rockville, USA: AOAC INTERNATIONAL
- Azhar, M.D., Hashib, S.A., Ibrahim, U.K. and Rahman, N.A. (2021). Development of carrier material for food applications in spray drying technology: An overview. *Materials Today: Proceedings*, 47, 1371–1375. <https://doi.org/10.1016/j.matpr.2021.04.140>
- Bhatta, S., Stevanovic, T. and Ratti, C. (2019). Freeze-drying of maple syrup: Efficient protocol formulation and evaluation of powder physicochemical properties. *Drying Technology*, 38 (9), 1138–1150. <https://doi.org/10.1080/07373937.2019.1616751>
- Bogdanov, S., Lüllmann, C., Martin, P., von der Ohe, W., Russmann, H., Vorwohl, G., Oddo, L.P., Sabatini, A.-G., Marcazzan, G.L., Piro, R., Flamini, C., Morlot, M., Lhéritier, J., Borneck, R., Marioleas, P., Tsigouri, A., Kerkvliet, J., Ortiz, A., Ivanov, T., D'Arcy, B., Mossel, B. and Vit, P. (1999). Honey quality and international regulatory standards: review by the International Honey Commission. *Bee World*, 80(2), 61–69. <https://doi.org/10.1080/0005772x.1999.11099428>
- Chegini, G.R. and Ghobadian, B. (2005). Effect of Spray -Drying Conditions on Physical Properties of Orange Juice Powder. *Drying Technology*, 23(3), 657–668. <https://doi.org/10.1081/drt-200054161>
- Chmielewska, H.R. (2003). Honey. In Tomasik, P. (Ed.) Chemical and functional properties of food saccharides. 1<sup>st</sup> ed., p. 87–94. USA: CRC Press. <https://doi.org/10.1201/9780203495728-10>
- Cinkmanis, I., Dimins, F. and Mikelsons, V. (2017). Influence of lyophilization and convective type drying on antioxidant properties, total phenols and flavonoids in pollens, presented at 11<sup>th</sup> Baltic Conference on Food Science and Technology. FoodBalt. Jelgava, 2017. Jelgava, Latvia: Latvia University of Agriculture. <https://doi.org/10.22616/foodbalt.2017.038>
- Codex Alimentarius Commission. (2019). Standard for Honey CXS 12-1981. Retrieved from FAO website: [fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXS%2B12-1981%252Fcxs\\_012e.pdf](https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252Fstandards%252FCXS%2B12-1981%252Fcxs_012e.pdf)
- Devi, K.D., Paul, S.K. and Sahu, J.K. (2016). Study of sorption behavior, shelf life and colour kinetics of vacuum puffed honey powder at accelerated storage conditions. *Journal of Food Science and Technology*, 53(5), 2334–2341. <https://doi.org/10.1007/s13197-016-2204-1>
- Fabra, M. J., Márquez, E., Castro, D. and Chiralt, A. (2011). Effect of maltodextrins in the water-content–water activity–glass transition relationships of noni (*Morinda citrifolia* L.) pulp powder. *Journal of Food Engineering*, 103(1), 47–51. <https://doi.org/10.1016/j.jfoodeng.2010.09.018>
- Farahnaky, A., Mansoori, N., Majzoobi, M. and Badii, F. (2016). Physicochemical and sorption isotherm properties of date syrup powder: Antiplasticizing effect of maltodextrin. *Food and Bioprocess Processing*, 98, 133–141. <https://doi.org/10.1016/j.fbp.2016.01.003>
- Fitzpatrick, J. (2013). Powder properties in food production systems. Handbook of Food Powders. p. 285–308. Cork, Ireland: University College. <https://doi.org/10.1533/9780857098672.2.285>
- Gabas, A.L., Telis, V.R.N., Sobral, P.J.A. and Telis-Romero, J. (2007). Effect of maltodextrin and arabic gum in water vapor sorption thermodynamic properties of vacuum dried pineapple pulp powder. *Journal of Food Engineering*, 82(2), 246–252. <https://doi.org/10.1016/j.jfoodeng.2007.02.029>
- Ganaie, T.A., Masoodi, F.A., Rather, S.A. and Gani, A. (2021). Exploiting maltodextrin and whey protein isolate macromolecules as carriers for the development of freeze dried honey powder. *Carbohydrate Polymer Technologies and Applications*, 2, 100040. <https://doi.org/10.1016/j.carpta.2021.100040>
- Gorle, A.P. and Chopade, S.S. (2020). Liquidolid Technology: Preparation, Characterization and Applications. *Journal of Drug Delivery and Therapeutics*, 10(3-s), 295–307. <https://doi.org/10.22270/jddt.v10i3-s.4067>
- Indonesian National Standard. (2018). Honey (SNI 8664:2018). Retrieved from website: <https://pesta.bsn.go.id/produk/detail/13137-sni86642018>
- International Honey Commission (IHC). (1999). Harmonised methods of the European Honey Commission. Retrieved from IHC website: <https://ihc-platform.net/ihcmethods2009.pdf>
- Islam, M.Z., Kitamura, Y., Yamano, Y. and Kitamura, M. (2016). Effect of vacuum spray drying on the physicochemical properties, water sorption and glass transition phenomenon of orange juice powder. *Journal of Food Engineering*, 169, 131–140. <https://doi.org/10.1016/j.jfoodeng.2015.08.024>
- Jaya, F., Radiati, L.E., Estiasih, T., Rosyidi, D.,

- Lastriyanto, A., Junus, M., Batoro, J., Erwan, E., Lamerkabel, J.S.A., Masyithoh, D., Ustadi, U. and Pinandita, E.P. (2022). Honey moisture reduction using several thermal methods and their effects on its quality. *E3S Web of Conferences*, 335, 00026. <https://doi.org/10.1051/e3sconf/202233500026>
- Jedlińska, A., Samborska, K., Wieczorek, A., Wiktor, A., Ostrowska-Ligeża, E., Jamróz, W., Skwarczyńska-Maj, K., Kielczewski, D., Błażowski, Ł., Tułodziecki, M. and Witrowa-Rajchert, D. (2019). The application of dehumidified air in rapeseed and honeydew honey spray drying - Process performance and powders properties considerations. *Journal of Food Engineering*, 245, 80–87. <https://doi.org/10.1016/j.jfoodeng.2018.10.017>
- Keke, A. and Cinkmanis, I. (2021). Total phenolic content and antiradical activity of honey powders. *Research for Rural Development*, 36, 104–110. <https://doi.org/10.22616/rrd.27.2021.015>
- Krishnan, R., Mohammed, T., Kumar, G.S. and SH, A. (2021). Honey crystallization: Mechanism, evaluation and application. *The Pharma Innovation*, 10(5S), 222–231. <https://doi.org/10.22271/tpi.2021.v10.i5Sd.6213>
- Kuc, J., Grochowalski, A. and Kostina, M. (2017) Determination of the diastase activity in honeys. *Czasopismo Techniczne*, 8, 29-35. <https://doi.org/10.4467/2353737xct.17.126.6877>
- Kudra, T. and Ratti, C. (2006). Foam-mat drying: Energy and cost analyses. *Canadian Biosystems Engineering*, 48, 3.27-3.32.
- Machado De-Melo, A.A., Almeida-Muradian, L.B., Sancho, M.T. and Pascual-Maté, A. (2018). Composition of honey from *Apis mellifera*: Quality requirements. (2013). *Acta Veterinaria Brasilica*, 7 (2), 3009. <https://doi.org/10.21708/avb.2013.7.2.3009>
- Mutlu, C., Koç, A. and Erbaş, M. (2020). Some physical properties and adsorption isotherms of vacuum-dried honey powder with different carrier materials. *LWT*, 134, 110166. <https://doi.org/10.1016/j.lwt.2020.110166>
- Mutlu, C. and Erbas, M. (2021). Evaluating the effects of different drying methods, carrier materials and their ratios to produce bioactive honey-like powder. *Journal of Apicultural Research*, 62(2), 364–373. <https://doi.org/10.1080/00218839.2021.1885877>
- Nurhadi, B., Andoyo, R., Mahani, R. and Indiarto, R. (2012). Study the properties of honey powder produced from spray drying and vacuum drying methods. *International Food Research Journal*, 19, 907-912.
- Nurhadi, B. and Roos, Y.H. (2017). Influence of anti-caking agent on the water sorption isotherm and flow-ability properties of vacuum dried honey powder. *Journal of Food Engineering*, 210, 76–82. <https://doi.org/10.1016/j.jfoodeng.2017.04.020>
- Nurhadi, B., Maidannyk, V.A., Djali, M., Herlina Dwiyantri, E., Putrinda Editha, N. and Febrian, M. (2022). Physical and functional properties of agglomerated coconut sugar powder and honey powder using polyvinylpyrrolidone as a binder. *International Journal of Food Properties*, 25(1), 93–104. <https://doi.org/10.1080/10942912.2021.2023177>
- Ortega-Rivas, E., Juliano, P. and Yan, H. (2005). Undesirable phenomena and their relation to processing. In Barbosa-Canovas, G.V. (Ed.) *Food Powders*. Food Engineering Series p. 305-360. Boston, USA: Springer. [https://doi.org/10.1007/0-387-27613-0\\_12](https://doi.org/10.1007/0-387-27613-0_12)
- Osés, S.M., Cantero, L., Crespo, M., Puertas, G., González-Ceballos, L., Vallejos, S., Fernández-Muñoz, M.Á. and Sancho, M.T. (2021). Attributes of ling-heather honey powder obtained by different methods with several carriers. *LWT*, 150, 112063. <https://doi.org/10.1016/j.lwt.2021.112063>
- Persano Oddo, L. and Piro, R. (2004). Main European unifloral honeys: descriptive sheets. *Apidologie*, 35 (Suppl. 1), S38–S81. <https://doi.org/10.1051/apido:2004049>
- Piana, M.L., Persano Oddo, L., Bentabol, A., Bruneau, E., Bogdanov, S. and Guyot Declerck, C. (2004). Sensory analysis applied to honey: state of the art. *Apidologie*, 35(Suppl. 1), S26–S37. <https://doi.org/10.1051/apido:2004048>
- Pontis, J.A., Costa, L.A.M.A.da, Silva, S.J.R.da, and Flach, A. (2014). Color, phenolic and flavonoid content, and antioxidant activity of honey from Roraima, Brazil. *Food Science and Technology*, 34 (1), 69–73. <https://doi.org/10.1590/s0101-20612014005000015>
- Rosland Abel, S.E., Yusof, Y.A., Chin, N.L., Chang, L.S., Mohd Ghazali, H. and Manaf, Y.N. (2020). Characterization of physicochemical properties of gum arabic powder at various particle sizes. *Food Research*, 4(S1), 107–115. [https://doi.org/10.26656/fr.2017.4\(s1\).s32](https://doi.org/10.26656/fr.2017.4(s1).s32)
- Rowe, R.C., Sheskey, P.J. and Weller, P.J. (2003). *Handbook of Pharmaceutical Excipients*. 5th ed. London, UK: Pharmaceutical Press.
- Sahu, J.K. (2008). The Effect of Additives on Vacuum Dried Honey Powder Properties. *International Journal of Food Engineering*, 4, 8. [https://doi.org/10.26656/fr.2017.10\(2\).220](https://doi.org/10.26656/fr.2017.10(2).220)

- doi.org/10.2202/1556-3758.1356
- Samborska, K. and Czelejewska, M. (2012). The Influence of Thermal Treatment and Spray Drying on the Physicochemical Properties of Polish Honey. *Journal of Food Processing and Preservation*, 38(1), 413–419. <https://doi.org/10.1111/j.1745-4549.2012.00789.x>
- Samborska, K. and Bienkowska, B. (2013). Physicochemical properties of spray dried honey preparations. *Zeszyty Problemowe Postępów Nauk Rolniczych*, 575, 91-105.
- Samborska, K., Langa, E. and Bakier, S. (2015). Changes in the physical properties of honey powder during storage. *International Journal of Food Science and Technology*, 50(6), 1359–1365. <https://doi.org/10.1111/ijfs.12797>
- Samborska, K., Sokołowska, P. and Szulc, K. (2017). Diafiltration and agglomeration as methods to improve the properties of honey powder obtained by spray drying. *Innovative Food Science and Emerging Technologies*, 39, 33–41. <https://doi.org/10.1016/j.ifset.2016.10.002>
- Samborska, K., Wiktor, A., Jedlińska, A., Matwijczuk, A., Jamróz, W., Skwarczyńska-Maj, K., Kielczewski, D., Tułodziecki, M., Błażowski, Ł. and Witrowa-Rajchert, D. (2019). Development and characterization of physical properties of honey-rich powder. *Food and Bioproducts Processing*, 115, 78–86. <https://doi.org/10.1016/j.fbp.2019.03.004>
- Samborska, K., Barańska, A., Szulc, K., Jankowska, E., Truszkowska, M., Ostrowska-Ligęza, E., Wołoskiak, R., Szymańska, E. and Jedlińska, A. (2020). Reformulation of spray-dried apple concentrate and honey for the enhancement of drying process performance and the physicochemical properties of powders. *Journal of the Science of Food and Agriculture*, 100(5), 2224–2235. <https://doi.org/10.1002/jsfa.10247>
- Sangamithra, A., Venkatachalam, S., John, S.G. and Kuppaswamy, K. (2015). Foam mat drying of food materials: A review. *Journal of Food Processing and Preservation*, 39(6), 3165-3174. <https://doi.org/10.1111/jfpp.12421>
- Shi, Q., Fang, Z. and Bhandari, B. (2013). Effect of Addition of Whey Protein Isolate on Spray-Drying Behavior of Honey with Maltodextrin as a Carrier Material. *Drying Technology*, 31(13–14), 1681–1692. <https://doi.org/10.1080/07373937.2013.783593>
- Sramek, M., Woerz, B., Horn, H., Weiss, J. and Kohlus, R. (2015). Preparation of High-Grade Powders from Honey-Glucose Syrup Formulations by Vacuum Foam-Drying Method. *Journal of Food Processing and Preservation*, 40(4), 790–797. <https://doi.org/10.1111/jfpp.12660>
- Suhag, Y., Nayik, G.A. and Nanda, V. (2016). Effect of gum arabic concentration and inlet temperature during spray drying on physical and antioxidant properties of honey powder. *Journal of Food Measurement and Characterization*, 10(2), 350–356. <https://doi.org/10.1007/s11694-016-9313-4>
- Suhag, Y., Nayik, G.A., Karabagias, I.K. and Nanda, V. (2021). Development and Characterization of a Nutritionally Rich Spray-Dried Honey Powder. *Foods*, 10(1), 162. <https://doi.org/10.3390/foods10010162>
- The National Standardization Agency of Indonesia. (2018). Honey (SNI 8664-2008). Jakarta, Indonesia: The National Standardization Agency of Indonesia.
- Ustadi, U., Radiati, L. and Thohari, I. (2017). Bioactive Components of Rubber Tree Honey (*Hevea brasiliensis*) and Calliandra (*Calliandra calothyrsus*) and Kapok Honey (*Ceiba pentandra*). *Jurnal Ilmu Dan Teknologi Hasil Ternak*, 12(2), 97–102. <https://doi.org/10.21776/ub.jitek.2017.012.02.6>
- Von Der Ohe, W., Persano Oddo, L., Piana, M.L., Morlot, M. and Martin, P. (2004). Harmonized methods of melissopalynology. *Apidologie*, 35 (Suppl. 1), S18–S25. <https://doi.org/10.1051/apido:2004050>
- Welti-Chanes, J., Prez, E., Guerrero-Beltrn, J.A., Alzamora, S.M. and Vergara-Balderas, F. (2008). Applications of Water Activity Management in the Food Industry. In Barbosa-Canovas, G.V., Fontana Jr., A.J., Schmidt, S.J. and Labuza, T.P. (Eds.) *Water Activity in Foods: Fundamentals and Applications*, p. 341–357. UK: Wiley. <https://doi.org/10.1002/9780470376454.ch13>