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Characterisation of physicochemical properties of gum arabic powder at various particle sizes

[1]Rosland Abel, S.E, [1, 2,]*Yusof, Y.A., [1]Chin, N.L., [3]Chang, L.S., [3]Mohd Ghazali, H. and [2]Manaf, Y.N.

[1]*Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[2]*Laboratory of Halal Services, Halal Products Research Institute, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*
[3]*Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

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Abstract

Plant gum exudate, such as gum arabic, is extensively used in a variety of industrial applications due to their emulsification, microencapsulation and stabilisation properties. The present study is aimed to investigate the effect of particle size on the proximate composition, the density and the physicochemical properties of the gum arabic powder. The classification of particle size based on the mean diameter (d_{50}) ranged between 30 to 800 µm. Based on the proximate composition results, the coarse (414 µm) and very coarse (790 µm) particles yielded a similar moisture content of 13.8%, which was higher than that of the commercial gum (11.1%). Meanwhile, the medium coarse (208 µm) particles contain higher fiber content (97.9%) as compared to other particle sizes. The bulk and tapped density of the gum were significantly affected by the particle size. Water activity analysis indicated that the gum arabic is microbiologically safe, as it has poor condition or environment for microbial growth. From the hygroscopicity analysis, it was found that the very fine (37 µm) particles obtained the highest hygroscopicity value of 40%. The swelling index of medium coarse (208 µm) particles was closed to that of the commercial gum. The emulsion capacity (*EC*) and emulsion stability (*ES*) analyses observed that the very coarse (790 µm) and very fine (37 µm) particles recorded the highest *EC* and *ES* values of 93% and 89%, respectively. The glass transition temperature was not significantly affected by the particle size. The colour analysis indicated that the commercial gum is lighter (71.4) than the other particle sizes. Meanwhile, the very fine (37 µm) and fine (85 µm) particles exhibited similar redness (a^*) value with that of the commercial gum, with a value recorded at 3.7. The morphology analysis observed that the gum exhibited irregular shape with rough granule surfaces. The present work revealed that coarse (208 to 414 µm) particles showed better characteristics compared to that of the commercial gum arabic that is available in the market.

1. Introduction

Gum exudates are used as an ingredient in many applications, including food, pharmaceutical, cosmetic, and paper industries (Whistler, 1993; Nussinovitch, 1997; Tan, 2004; Bhushette and Annapure, 2018; Zhang *et al.,* 2019). In the food industry, gum arabic is being widely used either as an emulsifier, a foaming agent or an encapsulating material. Gum arabic is believed to have a higher ability to hydrate, swell, dissolve, and interact with water; resulting in an improved effectiveness in emulsion stability (Elizalde *et al.,* 1988; Al-Assaf *et al.,* 2007; Li *et al.,* 2018; Moradi and Anarjan, 2019). It is extensively used as emulsifiers in the manufacture of soft drinks and oil-in-water emulsions, such as the orange-oil beverage (Tan, 2004; Pua *et al.,* 2007). As a foaming agent, gum arabic is mostly used in confectionary and beverages due to its lower viscosity and higher solubility characteristics (Makri and Doxastakis, 2006; Walsh *et al.,* 2008; Jiang *et al.,* 2013). In spray drying process, the most common carrier agents used for microencapsulation are the maltodextrin and gum arabic (Righetto and Netto, 2005; Gabas *et al.,* 2007; Mosquera *et al.,* 2011; Liang *et al.,*

*Corresponding author.
Email: *yus.aniza@upm.edu.my*

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2012; Niu *et al.,* 2018). Gum arabic is often selected as the encapsulating material due to its good emulsifying capacity, which increases the microencapsulation efficiency.

Gelatin is a substantially pure protein food ingredient obtained through the thermal denaturation of collagen, in which it is a structural mainstay and the most common protein in the animal kingdom (Bailey and Paul, 1998). Recently, there is a trend on the increasing number of new applications of gelatin in the food industry. The food industry uses gelatin for various purposes, such as an ingredient in jellies, desserts, yogurts, ice creams, and marshmallows (Venien and Levieux, 2005). On the other hand, gelatin is also used as a biodegradable matrix material in implantable delivery systems, a binder in tablets, as well as a matrix in the microencapsulation of drugs in the pharmaceutical industry. According to Ahmad and Benjakul (2011), it was learnt that the highest production of gelatin was from pigskin (44%), followed by bovine hides (28%), bovine bones (27%), and other sources (1%). However, the use of products containing gelatin from pigskin are prohibited for followers of religions such as Islam and Judaism. Therefore, gum arabic was proposed to replace gelatin in various product applications. Gum arabic has its own unique properties and functionalities that can benefit the end consumer in a food development process. To select industry-appropriate particle sizes, a clear understanding on the physical and functional properties is important. There are limited reports available on particle size dependency in the physicochemical properties of food materials. Hence, a comprehensive understanding of the above-mentioned properties could help in handling applications and quality control, avoid potential flow issues, and aid the ingredient selection for manufacturing purposes. Overall, this study is aimed to investigate the effects of different particle sizes on the physical properties of gum arabic powder, and to compare it with that of the commercial gum arabic that is available in the market.

2. Materials and methods

2.1 Sample preparation

The dried exudate gum arabic and commercial gum was purchased from a local dry market located in Selangor, Malaysia. The gum arabic was washed under running tap water to remove the surface dirt. Then, it was dried in an oven (Memmert Oven, Germany) at 60±2°C for 24 hrs. Mortar and pestle were used to grind the dried material, which was followed by a sieving process for 20 mins using a vertical vibratory sieve shaker (Labortechnik GmbH, Ilmenau). Five different sieves with an aperture size of 63, 125, 250, 500 and 1000 µm were used to collect the varying particle sizes required for this study. Finally, the powder was packed in polyethylene zipped bags (12 cm x 12 cm) and stored at 4±2°C prior to analysis.

2.2 Particle size analyzing

The particle size distribution of gum arabic powder was determined using a dry dispersion unit of Malvern Mastersizer 2000 particle size analyzer (Malvern Instrument Ltd, Worcestershire, UK). About 1 g of powder was placed in a stirring cell (volume 10 mL) with an obscurity value of 0.12 to 0.18 with the air pressure set to 2.0 bars. The classification of particle sizes is shown in Table 1.

Table 1. Classification of particle sizes

Classification of powder	Sieve opening (µm)[a]	Mesh size (µm)[b]	d_{50} (µm)
Very coarse	>1000	230	790±0.14
Coarse	355-1000	120	414±0.07
Moderately fine	180-355	60	208±0.37
Fine	125-180	35	85±0.05
Very fine	<125	18	37±0.02

[a]The United States Pharmacopeia Convention, Inc. Chapter (811), [b]American National Standard for Industrial Wire Cloth (American Standard ASTM-E11)

2.3 Proximate analysis

The proximate analyses of moisture, ash, crude protein, crude lipid, and dietary fiber of the gum arabic powder were analysed according to the AOAC methods (AOAC, 2002). The moisture content of the sample was measured using the oven drying method at 105°C for 24 hrs. In order to determine the ash content, the samples were incinerated at 550°C for 6 hrs. Whereas, Kjeldahl method (N x 6.25), Soxtech (Model-2050 Foss, Denmark) and Fibertech (Model-2010 Foss, Denmark) were used to measure the total protein, fat and fiber contents, respectively. Total carbohydrate content was determined by the difference [100 - (moisture + ash + protein + lipid)].

2.4 Density analysis

2.4.1 True density

A gas pycnometer (AccuPyc II 1340, Micromeritics, Norcross, USA) was used to measure the true density. This device used the gas displacement method for an accurate volume measurement. Once the sample was placed in a chamber with a known volume, the helium gas was released and allowed to expand into the other precision internal volume. The sealed chamber with the sample in it was then pressurised to achieve the desired pressure with gas displacement. The pressure was recorded upon stabilisation. Once stabilised, the gas was

allowed to expand into a reference chamber with a known volume when the valve is opened. Once the pressure in the reference chamber stabilised, the second pressure was recorded. The solid phase volume was calculated based on the pressure record of the sample chamber and the reference chamber. Next, the gas displacement density was measured by dividing the solid phase volume into the sample weight. The sample weight was estimated when the helium molecules had filled pores that are as small as one angstrom in diameter, whereby the gas was displaced only by the solid phase of the sample.

2.4.2 Bulk density

Approximately 2 g of gum arabic powder, *m*, was transferred to a 10 mL graduated cylinder and the volume of the sample powder occupied (V_b) was recorded. The bulk density (ρ_b) was determined using the following equation:

$$\rho_b = \frac{m}{V_b} \quad (1)$$

2.4.3 Tapped density

Approximately 2 g of gum arabic powder, *m*, was transferred to a 10 mL graduated cylinder and the cylinder was mechanically tapped up and down 100 times. Then, the volume that the sample powder occupied (V_t) was recorded. The tapped density (ρ_t) was calculated using the following equation:

$$\rho_t = \frac{m}{V_t} \quad (2)$$

2.4.4 Hausner ratio

Hausner ratio (*HR*) is an index that corresponds to the flowability of a powder or granular material (Hausner, 1967). It was determined using the following equation:

$$HR = \frac{\rho_t}{\rho_b} \quad (3)$$

Where, ρ_t is tapped density, ρ_b is bulk density.

2.4.5 Carr index

Carr index (*CI*) or Carr's compressibility index is an indication of the compressibility of a powder (Carr, 1965). It was determined using the following equation:

$$CI = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (4)$$

Where, ρ_t is tapped density, ρ_b is bulk density.

2.4.6 Angle of repose

The angle of repose was determined manually by calculating the dimensions of the powder pile. The powder was passed through a lifted funnel to form a powder heap. Then, the angle of repose (θ) was calculated by measuring the radius (*r*) of the base and height (*h*) of the conical powder heap formed using the formula below:

$$\tan\theta = \frac{h}{r} \quad (5)$$

2.5 Water activity

Water activity of gum arabic was measured using a water activity meter (Model 3TE, Aqualab, WA). Approximately 2 g of the powdered sample was filled into a sample cup and the water activity was determined at room temperature (25±1°C).

2.6 Hygroscopicity

Approximately 1 g of gum arabic powder was placed in a sealed humidity desiccator containing a saturated sodium chloride solution (76±2% relative humidity) and was incubated at 25±1°C for one week. The hygroscopicity (*HG*) value was determined using the following equation:

$$HG = \frac{W_2 - W_1}{W_1} \times 100 \quad (6)$$

Where, W_2 is the weight of powder after equilibrium and W_1 is the initial mass of powder.

2.7 Swelling index

Approximately 5 g of gum arabic powder was transferred gently into a 200 mL measuring cylinder where the bulk volume, V_1 was measured. Then, distilled water was added to disperse the gum until the volume reaches the 100 mL mark. The dispersion was allowed to stand for 24 hrs and the volume of the swollen gum, V_2 was recorded. All measurements were performed in duplicates. The swelling index (*SI*) was determined using the following equation:

$$SI = \frac{V_2}{V_1} \quad (7)$$

2.8 Emulsion capacity

The emulsification capacity (*EC*) yielded from the gum arabic used in this study was compared with the commercial gum. Gum arabic aqueous solutions were prepared with water to produce 5 dispersions. Commercial corn oil (1% v/v) was added to these dispersions. The amount of gum arabic in each dispersion was adjusted to yield 0.1, 0.25, 0.50, 0.75, 1.0% w/v concentration in the final mixture. A vortex was used to homogenize each mixture for 1 min. Finally, all 5 dispersions were centrifuged at 800 x *g* for 10 mins. The *EC* was calculated using the following equation (Sciarini *et al.,* 2009):

$$EC = \frac{e_v}{t_v} \times 100 \quad (8)$$

where, e_v is the emulsion volume and t_v is total volume.

2.9 Emulsion stability

The emulsion stability (*ES*) against high temperature was estimated by incubating the solution at 80°C for 30 mins in a water bath. The solution was centrifuged at 800 x *g* for 10 mins following incubation. The calculation involved to determine *ES* is shown below (Sciarini *et al.,* 2009).

$$ES = \frac{f_{ev}}{i_{ev}} \times 100 \quad (9)$$

where, f_{ev} is final emulsion volume, and i_{ev} is initial emulsion volume.

2.10 Glass transition temperature

A differential scanning calorimetry (DSC7 Perkin Elmer, Norwalk, Conn., U.S.A.) equipped with a temperature control system using liquid nitrogen (Perkin Elmer Intra Cooler 2 control cooling accessory) were used for the measurement of the glass transition temperature. An empty reference pan was prepared. Then, saturated salt solutions in a desiccator at 25°C was used to equilibrate the 5 mg of gum arabic powder which was placed in DSC aluminum pans until the equilibrium was achieved. Upon reaching equilibrium, the samples were sealed using hermetic lids for further analysis and weighing. The cooling system using liquid nitrogen was employed for test temperatures below 70°C. Meanwhile, for test temperatures above 70°C, a mechanical refrigerated cooling accessory system (RCS) was used. Dry helium at 250 mL/min, was used as the purge gas. Once the sample was cooled to -60°C, the scanning was performed by heating the sample at a rate of 10°C/min from -60°C to 100°C. The results of the glass transition temperature exhibited an endothermic shift in the specific heat capacity, which yielded a discontinuity in the baseline. Each sample was also subjected to a second scanning to reduce the enthalpy relation of the amorphous powder, which appears in the first scan. Every measurement was done in duplicates where all the readings were recorded.

2.11 Colour analysis

The Hunter Colour Lab (Colorflex) was used to measure the colour analysis. The results were expressed as *L**, *a** and *b**, where *L** (lightness), *a* as* redness (+) and greenness (-), and *b** as yellowness (+) and blueness (-). The standard black and white tile was used for the calibration of the instrument (*L**= 90.55, *a**= -0.71, *b**= 0.39), prior to sample measurements.

2.12 Morphological analysis

The surface texture and morphology of gum arabic powder were studied using the Field Emission Scanning Electron Microscope (FESEM), Carl Zeiss Supra 55VP, and JEOL JSM-7600F. The morphological characterisation was performed by mounting a small amount of powder on the FESEM stubs, and the accelerating voltage and magnification were set at 5.0 kV and 100x for observation.

2.13 Statistical analysis

The measurements were done in duplicates and expressed as arithmetic mean data (± standard deviations). The Minitab Statistical Software (Version 16, Minitab Corp, USA) was used to perform the regression analysis of variance (ANOVA). The Tukey's test was employed to determine sample groups with a significant difference at 95% confidence level (P <0.05).

3. Results and discussion

3.1 Proximate composition

Table 2 represents the proximate composition of gum arabic at various particle sizes. The proximate compositions measured are the moisture, ash, protein, lipid, fiber and carbohydrate contents. The moisture content had ranged from 11.1 to 11.7% and the values observed were within the international specifications of 11 to 15%. It can be seen that, the very coarse (790 µm) particles yielded a higher moisture content of 13.8% compared with that of the commercial gum (11.1%). Meanwhile, the ash content that varied from 3.6 to 3.9% was also within the acceptable range of less than 4% for food and pharmaceutical quality of gum arabic (FAO, 1998). This finding was in agreement with Jani *et al.* (2016), which recorded the values of 13.40% and 3.42% for moisture and ash contents, respectively. On the other hand, Dziki (2011) also indicated that the moisture content of wheat kernels was found to have increased with increasing particle size. The moisture content of wheat kernels had ranged between 10 and 20% for particle size within the range of 0.25 to 2.00 mm. For dietary fiber analysis, the values obtained had ranged from 89.1 to 97.9%, where the very coarse (790 µm) particles contained the lowest dietary fiber when compared to other particle sizes. Meanwhile, the protein, lipid and carbohydrate contents had ranged from 22.0 to 2.4%, 0.1 to 0.6% and 79.9 to 82.1%, respectively. It was observed that the protein, lipid and carbohydrate contents were not significantly affected by the particle size. The proximate analysis shows that the very fine (37 µm) particles indicated no significant difference (P > 0.05) with the commercial gum arabic, whereas, the coarse (414 µm) and very coarse (790 µm) particles showed

Table 2. Proximate composition of gum arabic powder

d_{50} (μm)	Proximate composition (%)					
	Moisture	Ash	Protein	Lipid	Dietary fiber	Carbohydrate
37	11.7±0.1^{c}	3.6±0.0^{b}	2.3±0.0^{a}	0.3±0.0^{a,b,c}	95.5±1.2^{a,b}	82.1±0.1^{a}
85	13.5±0.1^{b}	3.6±0.0^{b}	2.0±0.0^{b}	0.2±0.1^{b,c}	93.2±0.2^{b}	80.7±0.2^{b,c}
208	13.7±0.1^{a,b}	3.6±0.0^{b}	2.2±0.0^{b}	0.1±0.0^{c}	97.9±0.3^{a}	80.4±0.1^{b,c}
414	13.7±0.0^{a,b}	3.7±0.0^{a,b}	2.0±0.0^{b}	0.6±0.0^{a}	97.8±0.5^{a}	79.9±0.0^{b}
790	13.8±0.1^{a}	3.9±0.0^{a}	2.0±0.0^{b}	0.2±0.0^{b,c}	89.1±0.5^{c}	80.1±0.1^{b,c}
Commercial	11.1±0.1^{d}	3.9±0.0^{a}	2.4±0.0^{a}	0.5±0.1^{a,b}	96.5±0.1^{a,b}	82.0±0.2^{a}

Different letters in the same column indicate significant differences ($P < 0.05$) between the samples

Table 3. Density properties of gum arabic powder

d_{50} (μm)	Powder properties						
	True density, g/cm^3	Bulk density, g/cm^3	Tapped density, g/cm^3	Hausner ratio	Carr index, %	Angle of repose,°	Flow behaviour (Carr, 1965; Hausner, 1967)
37	1.49±0.00^{a}	0.59±0.02^{d}	0.73±0.05^{b}	1.24	19.11	26.28±0.28^{a}	Fair flow
85	1.48±0.01^{a}	0.73±0.02^{a,b}	0.84±0.01^{a}	1.15	13.23	22.62±0.28^{b}	Good flow
208	1.48±0.00^{a}	0.74±0.00^{a,b}	0.84±0.01^{a}	1.13	11.25	21.10±0.06^{c}	Good flow
414	1.48±0.00^{a}	0.70±0.02^{b,c}	0.83±0.01^{a}	1.18	15.59	20.56±0.00^{c}	Good flow
790	1.48±0.00^{a}	0.79±0.02^{a}	0.89±0.01^{a}	1.13	11.89	20.44±0.12^{c}	Good flow
Commercial	1.48±0.00^{a}	0.63±0.01^{c,d}	0.83±0.01^{a}	1.30	22.93	23.13±0.07^{b}	Poor flow

Different letters in the same column indicate significant differences ($P < 0.05$) between the samples

significant differences when compared with the commercial gum.

3.2 Density properties

Table 3 represents the density properties of gum arabic at various particle sizes. The density properties measured are true, bulk and tapped densities. The values obtained were in the range of 1.48 to 1.49 g/cm^3, 0.59 to 0.74 g/cm^3 and 0.73 to 0.84 g/cm^3 for true, bulk and tapped densities, respectively. The findings of this study found that the particle size has a significant effect on the bulk and tapped densities; however, no effect can be seen on the true density of the samples. As predicted, both bulk and tapped densities had significantly increased with an increase in the particle size. The very coarse (790 μm) particles had the highest values of bulk and tapped densities, which were recorded at 0.79 and 0.89 g/cm^3, respectively. The bulk and tapped densities obtained for the studied samples were slightly higher compared with that of the commercial gum, with values recorded at 0.63 and 0.83 g/cm^3, respectively. The values obtained in this study were higher than the values found by Gayathri and Ganapathy (2018), with values reported at 0.53 and 0.57 g/cm^3 for bulk and tapped densities, respectively.

Particle size can be correlated with powder compressibility. However, it is not a direct measure of flowability; instead, it provides a useful indication of the flow properties. Carr (1965) reported that the compressibility of powder refers to its capability of affecting the flow properties through micro-scale adhesion forces between the particles. The findings of this study showed that the compressibility index and angle of repose of the gum powder ranged from 11.25 to 19.11% and 20.44 to 26.28°, respectively. Based on the standard compressibility index values, 11 to 15% indicate good flow characteristics (USP30 NF 25). Meanwhile, angle of repose values of less than 25° indicates excellent flow; whereby a reading between 25 and 30° indicates good flow characteristics without the addition of flow promoters. The measurements indicated that the very coarse (790 μm) particles had lower compressibility index and angle of repose, with values reported at 11.89% and 20.44°, respectively. This could be due to the decrease in cohesive force between the larger granules, resulting in an increase in the binding level of the granules (Onunkwo, 2010). For smaller particles, the flowability characteristic worsens due to the particle shrinking in size, resulting in an increase in particle surface area per unit mass. Therefore, an enlarged surface area would result in surface cohesive force, leading to greater cohesive effects (Fitzpatrick *et al.,* 2004). The results obtained were in the agreement with previous work by Ogunjimi and Alebiowu (2013), where the values obtained were 1.21 and 22.69° for Hausner ratio and angle of repose, respectively. Besides that, similar flowability behaviour was observed for tea and salt powders (Teunou and Fitzpatrick, 2000; Fitzpatrick *et al.,* 2004). They indicated that tea and milk powders with particle size of less than 25 μm exhibited poor flowability; whereas, the particle size of more than 200 μm exhibited better flowability.

3.3 Physicochemical properties

Table 4 represents the physicochemical properties of gum arabic at various particle sizes. In the current study, the water activity of gum arabic ranged between 0.52 and 0.56, which was slightly higher compared to that of the commercial gum (0.45). These values indicate that the gum arabic is microbiologically safe, as low water activity limits microbial growth. Overall, the water activity was not significantly affected by the particle size. Meanwhile, the hygroscopicity of the gum ranged from 26 to 40%, whereby the very fine (37 µm) particles with the highest value of 40% presented a great capacity to retain and adsorb water. This study shows that the hygroscopicity increased with decreasing particle size, indicating gum with smaller size has a higher tendency to absorb moisture from the surrounding environment. This phenomenon can be explained due to the smaller particle size exhibits higher surface area, which will in turn promote moisture absorption. On the other hand, the swelling index (*SI*) of the gum ranged from 1.56 to 4.00. It was observed that the *SI* value had increased with increasing particle size, indicating higher retention of water-swollen granules for larger particle size. It was found that the very coarse (790 µm) particles had obtained the highest *SI* (4.00), which is slightly higher compared to that of the commercial gum arabic (2.00).

The emulsion capacity (*EC*) and emulsion stability (*ES*) of gum dispersions had ranged from 83.33 to 93.33% and 60.71 to 88.80%, respectively. The very coarse (790 µm) particles tested in this study recorded the highest *EC* value of 93%, revealing that its large particle size had a higher ability to form emulsion with oil. Apart from that, the above-mentioned *EC* value was found to be higher than that of the commercial gum (87%). On the other hand, the finest (37 µm) particles demonstrated the highest *ES* value (89%) compared to the commercial gum (75%). The difference in *ES* could be due to the presence of high percentage of residual lipids and lower protein content in the commercial gum powder, which led to the poor emulsifying properties. These properties are commonly affected by the surface-active molecules, such as proteins, due to their amphiphilic nature and capability of lowering the surface tension. Moreover, the low hydrophobicity of the gum would prevent the interaction between the proteins and the oils, thus restricting the emulsifying properties (Hailing, 1981; Philips *et al*., 1994).

According to the differential scanning calorimeter readings, the glass transition temperature (T_G) of the gum arabic had ranged from 56.18 to 57.62°C, demonstrating that the gum was relatively stable at room temperature and had maintained in the glassy phase. It was observed that the fine (85 µm) particles had obtained the highest T_G, which was recorded at 57.62°C. Materials with higher T_G values signify greater crystallinity (Donovan, 1979; Hover, 2001). A higher degree of crystallinity is proven to yield greater structural stability, where granules become more heat resistant (Singh *et al.,* 2003; Ezekiel *et al.,* 2007; Mathew and Abraham, 2007). This implies that the gum arabic is structurally stable and highly resistant to heat. It was also learnt that the particle size did not exhibit any significant effect on the glass transition temperature of the gum.

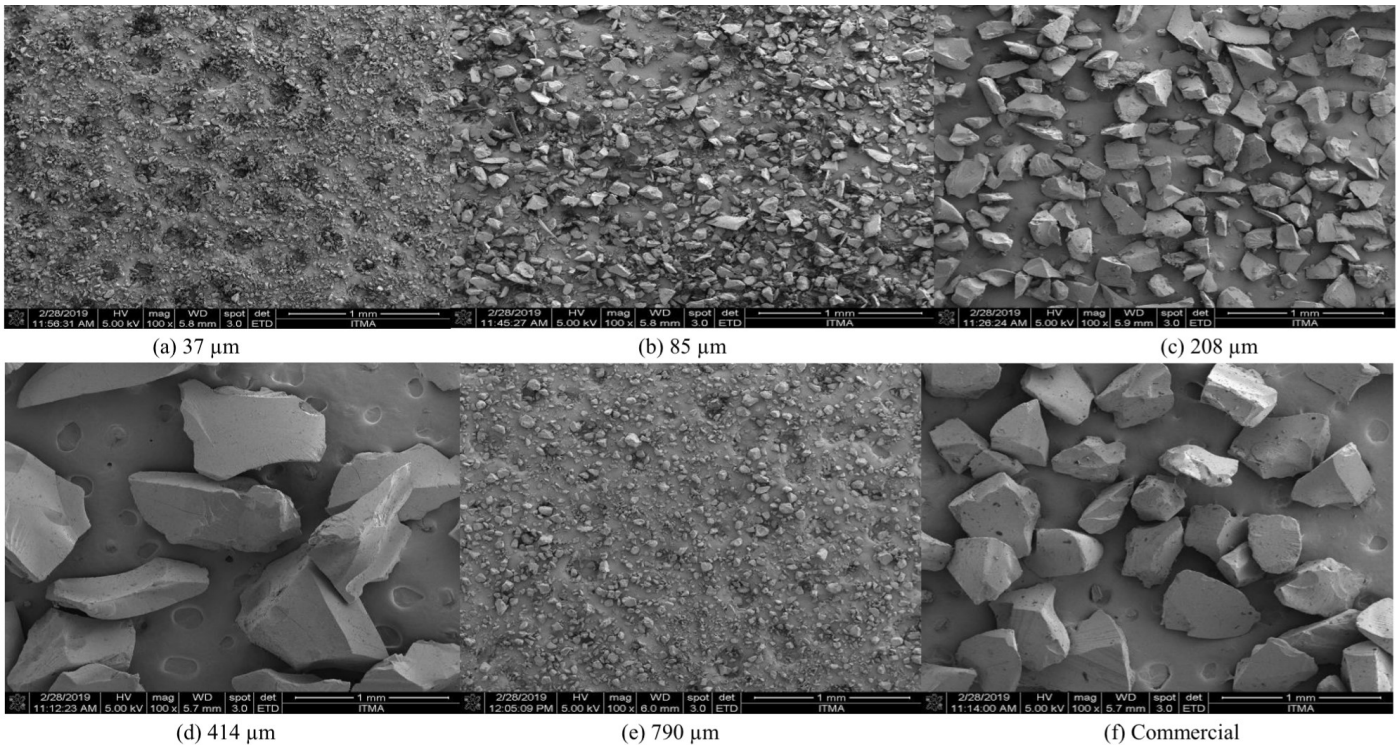
3.4 Colour analysis

Table 5 represents the colour analysis of gum arabic at various particle sizes. The results were expressed in terms of *L** (lightness), *a** (redness and greenness), and *b** (yellowness and blueness). The *L**, a*, and *b** values had ranged between 60.3 and 69.1, 3.7 and 4.2, and 20.9 to 24.6, respectively. The colour values varied greatly with different particle sizes. It was observed that the *L** value was found to have decreased with increasing particle size; this resulted in a darker powder. Meanwhile, the *a** value was found to have increased with an increase in particle size; therefore, powder with bigger particle size has a more intense yellow colour. According to Table 5, the fine (85 µm) particles had the lowest *b** values, which can be explained due to the increased specific surface area of the particles, hence, resulting in the material to emit intense colour values. The commercial gum had a lighter colour (*L**=71.4) compared with those of other particle sizes. In the meantime, the *a** value for very fine (37 µm) and fine

Table 4. Physicochemical properties of gum arabic powder

	d_{50} (µm)					
Powder properties	37	85	208	414	790	Commercial
Water activity	0.52±0.00^{b}	0.56±0.00^{a}	0.56±0.00^{a}	0.56±0.00^{a}	0.56±0.00^{a}	0.45±0.00^{c}
Hygroscopicity, %	39.75±0.02^{a}	28.15±0.39^{b}	28.01±0.22^{b}	26.14±2.90^{b}	26.00±1.21^{b}	30.36±0.95^{b}
Swelling index	1.56±0.06^{d}	1.63±0.13^{d}	1.71±0.04^{c,d}	2.50±0.00^{b}	4.00±0.00^{a}	2.00±0.00^{c}
Emulsion capacity, %	83.33±0.00^{f}	86.67±0.00^{c}	86.67±0.00^{b}	83.33±0.00^{e}	93.33±0.00^{a}	86.67±0.00^{d}
Emulsion stability, %	88.80±0.80^{a}	69.62±0.38^{c}	78.85±1.93^{b}	82.00±2.00^{a,b}	60.71±0.00^{d}	75.00±1.92^{b,c}
Glass Transition temperature, °C	56.18±1.78^{a}	57.62±3.32^{a}	56.82±3.83^{a}	57.16±0.88^{a}	56.43±4.33^{a}	57.40±0.48^{a}

Different letters in the same row indicate significant differences ($P < 0.05$) between the samples



(a) 37 µm (b) 85 µm (c) 208 µm

(d) 414 µm (e) 790 µm (f) Commercial

Figure 1. Morphology characteristics of gum arabic powder

(85 µm) particles was similar to that of the commercial gum (a*=3.7). On the other hand, the coarse (414 µm) particles exhibited greater intensity of yellowness (b*=24.6) than that of the commercial gum (b*=21.4).

Table 5. Colour analysis of gum arabic powder

d_{50} (µm)	L* value	a* value	b* value
37	69.1±0.10^{b}	3.7±0.05^{b}	21.3±0.05^{c}
85	68.9±0.15^{b}	3.7±0.00^{b}	20.9±0.00^{c}
208	65.8±0.00^{c}	3.9±0.00^{a,b}	23.4±0.10^{b}
414	62.5±0.05^{d}	4.2±0.05^{a}	24.6±0.00^{a}
790	60.3±0.15^{e}	4.2±0.10^{a}	23.9±0.20^{b}
Commercial	71.4±0.10^{a}	3.7±0.05^{b}	21.4±0.05^{c}

Different letters in the same column indicate significant differences (P < 0.05) between the samples

3.5 Morphological characteristics

Figure 1 illustrates the morphology of gum arabic at various particle sizes. The powder was assessed via Field Emission Scanning Electron Microscope (FESEM). It was observed that the gum exhibited irregular shape with rough granule surfaces. The particles have a rough surface morphology that can help in attaining highly-viscous aqueous solution. This observation is consistent with Ohwoavworhua and Adelakun (2005), who stated that the intrinsic viscosity and molecular mass of exudate gums are significantly influenced by the particle size and specific surface area. Meanwhile, the particle shape of the powder can be irregular, although the average sizes are grouped uniformly through sieving technique. Such irregular shapes of the powder might also influence its flow properties. Therefore, understanding these properties could aid in the selection of application based on the surface characteristics of the material.

4. Conclusion

In this work, the effects of particle sizes on the physicochemical properties of the gum arabic powder were explored. Experimental results indicated that different particle sizes exhibited different physicochemical properties of the above-mentioned powder. This could be explained using experimental parameters that are capable of altering the physical structures of the particle, resulting in significant changes on the physicochemical properties. Apart from that, the present work also found that the coarse (208 to 414 µm) particles displayed better characteristics compared to the commercial gum that is available in the market. In conclusion, the characterisation of physicochemical properties of gum arabic powder provides important information for selecting a specific particle size prior to its potential applications in the food product development.

Conflict of Interest

The authors declare no conflict of interest.

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