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EFFECT OF MALTODEXTRIN, ARABIC GUM, AND BEETROOT JUICE CONCENTRATION ON THE POWDER PROPERTIES OF SPRAY-DRIED BEETROOT-SKIM MILK MIXTURES

– Research paper –

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Abstract: Milk products are widely consumed as a beverage and used as the main ingredient in many food applications. Beetroot is suitable as an ingredient for the natural red color in food products. Color stability of natural colorants is mainly affected by mixtures of materials and temperatures. The effect of beetroot juice concentration and types of carrier agents on the physical properties of the red-colored skim-milk powder and rehydrated powder at different temperatures were studied. Beet juice concentration significantly affects the redness (a*) and lightness (L*) of skim milk in both powders and reconstituted forms. Powder with mixtures of maltodextrin and Arabic gum showed better retention of redness, high solubility, low moisture content, water activity, and less hygroscopic. The finding from this study may benefit food product development, beverage, and confectionery in the food industry.

Keywords: Spray Drying, Maltodextrin, Arabic Gum, Natural Colorant, Rehydration, Beetroot, Skim Milk

INTRODUCTION

Colour serves as an important marketing strategy that affects the purchasing decision of consumers due to the eye-catching effect. Carmoisine (E122), Ponceau 4R (E124), Erythrosine (E127), and Allura red (E129), are some examples of artificial red food colors that are permitted by the European Union (Amchova et al., 2015). However, research proved that excessive intake of synthetic colorants adversely affects the health of human beings. Some studies reported that Allura red (E 129) and Carmoisine (E122) tend to bind to human serum albumin (Wu et al., 2015) and caused hyperactivity in children (McCann et al., 2007). Scientific Opinion of the European Food Safety Authority Panel stated that a mixture of Allura Red and other synthetic colorants in food products may cause allergic reactions and asthma (Rovina et al., 2016; European Food Safety Authority, 2009). Therefore, natural red food colors primarily obtained from anthocyanins or betalains start to become a choice for replacing synthetic colorants. Beetroot is the edible taproot portion of the beet plant and has a high concentration of betalain which acts as the natural color pigment. It contains 12 to 20% of dry matter which includes 4 to 12% of sugars, 1.5% protein, 0.1% fat, 0.8% fiber, and other micronutrients such as minerals and vitamins (Janiszewska, 2014). Beetroot has a high antioxidant capacity, vitamin B complex, folic acid, and a significant amount of phenolic acids (Ochoa-Martinez et al., 2015; Kujala et al., 2000). Consumption of red beet helps to prevent age-related diseases (Ravichandran et al., 2013), and lowers cholesterol levels and arterial pressure (Ochoa-Martinez, 2015). Many researchers are using beetroot as one of the experimental materials either for health purposes or food coloring. Beetroot red has been recognized by European Union as a food colorant and is denoted with an E number of 162 (Ravichandran et al., 2013; Janiszewska, 2014). Introducing natural colorants into foods is a great challenge for the industry due to their low stability. Spray drying technology is common in the food industry. It is a single continuous process that is

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preferable for thermally sensitive materials such as natural color pigments. It turns the feed solution into powder in an extremely short time which minimizes the thermal degradation process and reduces nutrient loss. The feed solution is atomized through the nozzle into fine droplets in the drying chamber. The introduction of hot air at elevated temperatures evaporates the moisture from the droplets instantaneously and turns the droplets into powder. Spray drying conditions such as inlet temperature (Bazaria & Kumar, 2016; Ochoa-Martinez et al., 2015), feed flow rate (Bazaria & Kumar, 2016; Ochoa-Martinez et al., 2015), feed temperature (SunWaterhouse and Waterhouse, 2015), feed concentration (Balasubramani et al., 2015), types of agents (Carneiro et al., 2013) and amounts of encapsulating agent (Ng et al., 2012) could affect the properties of the powder produced. Encapsulation provides a barrier to protect the core material from direct contact with the environment and improves the color stability of pigments (Janiszewska, 2014; Antigo et al., 2018). Carbohydrates such as maltodextrin, Arabic gum, modified starch (Krishnan et al., 2005), proteins such as whey protein, milk protein (Baranauskiene´ et al., 2006), and lipids such as are some examples that had been used as carrier agents for the spray drying process.

Maltodextrin is a hydrolyzed starch that is classified by dextrose equivalent (DE) ranging from DE 5-19 depending on the amount of reducing sugar that is present in it. A low DE maltodextrin possesses a higher average molecular weight. For those with a DE value of more than 20, it is commonly referred to as glucose syrup or syrup solids and is suitable to be used as a drying carrier for sugar-containing juices (Bazaria & Kumar, 2016). It is commonly used in the spray drying process as encapsulating agent due to its high solubility in cold water (Tonon et al., 2008), low viscosity in high solids ratio (Balasubramani et al., 2015), bland flavor, and low cost. Maltodextrin has a low emulsifying capacity and its combination with other surface active biopolymers such as Arabic gum, modified starch or whey protein contributes to the production of better-quality microcapsules (Carneiro et al., 2013; Costa et al., 2015). Kishimoto et al. (2013) tested the tolerance of a maximum single dose of resistant maltodextrin in the human diet. The study found that the experimental subjects suffered from gastrointestinal symptoms such as gurgling sound flatus with no association with the dose level of maltodextrin. This proved that the consumption of maltodextrin might cause bloating effect.

Arabic gum is also known as acacia gum which is obtained from the hardened sap of the acacia tree either Acacia Senegal or Acacia Seyal (Montenegro et al., 2012). Both of the gums consist of the same sugar residue with only a slight difference in terms of content. Compared to Acacia Senegal gum, Acacia Seyal gum has lower rhamnose and glucuronic acid content but higher arabinose and 4-O-methyl glucuronic acid content. At the same time, it also contains a lower proportion of nitrogen (Montenegro et al., 2012). It is compatible with most gums, starches, carbohydrates, and proteins with high soluble fiber content, prebiotic effect, high digestive tolerance, and low caloric value (Badreldin et al., 2009). In folk medicine, Arabic gum has been reported to be used internally for the treatment of inflammation of the intestinal mucosa, and externally to cover inflamed surfaces (Gamal el-din et al., 2003). However, Arabic gum is restricted for encapsulation due to its high cost and limited supply because it is only produced in unpredictable climate regions (Krishnan et al., 2005; Costa et al., 2015).

Ravichandran et al. (2014) reported that encapsulation of betalains with the combination of maltodextrin and other gums as carrier agents increased the stability of betalains. Beetroot has higher stability to temperature and pH variation from pH 3 to 7 (Ravichandran et al., 2013). Many types of research had done on the processing and stability of red beet extract. Ng and Sulaiman (2018) developed a foam mat-dried beetroot powder using different foaming agents (egg albumin and fish gelatine). Varner (2014) compared the physical properties of beetroot powder produced using different drying methods including drum drying, freeze drying, and spray drying.

Cow skim milk is a highly nutritious food for direct consumption and the main ingredient for food products such as chocolate, yogurt, ice cream, cake, and biscuits. According to Poirieux et al. (2017), researchers showed interest in the development of dairy products containing more health benefits. Limited studies focused on the stability of natural red colorants in dairy applications. Güneşer (2016) reported on the effect of heat treatment on the pigment and color stability of beetroot betalains in cow milk. Yadav et al. (2016) and Mohammad Sayadi et al. (2013) developed yogurt incorporated with beetroot extract and evaluated the products' qualities in terms of physicochemical, microbiological, and sensory characteristics. Studies had been conducted on beetroot betanin in dairy products by High-Performance Liquid Chromatography (HPLC) (Gandia-Herrero et al., 2012). Thermal degradation of beetroot betalain applied in milk follows the first-order kinetics (Guneser, 2016). According to Neelwarne (2013),

compared to purified pigment, whole beet extract has been quite successful as a commercial product. However, beetroot contains geosmin and pyrazines which might contribute to the undesirable earthy flavor and aroma that affect the sensory characteristics of food when added as a natural colorant (Bach et al., 2015).

This research aims to produce natural red color skim milk powder by incorporating beetroot juice extract during spray drying with different types of encapsulating agents. The effect of rehydration temperature on the natural red colorant of beetroot-skim milk mixtures is determined.

MATERIALS AND METHODS

Raw materials

Beetroot (Beta vulgaris) was purchased from the local store NSK Trade City in Klang, Selangor. Fresh and unpasteurized cow's milk was purchased from Ladang 16, Universiti Putra Malaysia, Serdang, Selangor, and stored in a cold room at 6˚C one day before the experiment. The encapsulating agents used are Maltodextrin DE 15-20 and Gum Arabic Seyal. The Arabic gum was purchased from the distributor Markaid (M) Sdn. Bhd. was manufactured in France by Nexira SAS Company.

Beetroot extract

Beetroot was extracted based on the method presented by Poornima and Sinthiya (2017) and Omae et al. (2017) with slight modifications. Fresh red beets were washed under running water, peeled, and cut into slices about 3mm thick and steam blanched for 3 minutes to inactivate the enzymatic reaction. Red beet slices were then quickly cooled down to room temperature and blended with distilled water (60˚C) using a blender (MX-898M, Panasonic, Osaka, Japan) in the ratio of 1:0.15 (mass of beetroot: mass of distilled water) until it turned into puree. The puree was filtered through a muslin cloth and collected as the first extraction. The pomace left was further extracted another 3 times at the ratio of 1:1 of pomace and distilled water (60˚C) until the red color of the pomace faded. All the filtrate collected was mixed and filtered through muslin cloth before being poured into small plastic containers. Some headspace was provided in the container for the expansion of the solution during freezing. Aluminum foil was used to wrap around the container to prevent light exposure. The extract was stored in the freezer at -18˚C and thawed in the chiller at 4˚C one or two days before being used.

Skim milk

Fresh milk was slightly preheated until warm to facilitate the separation process using a disc bowl centrifuge (Armfield Ltd, England) to obtain the skim milk. The skim milk obtained was pasteurized at 63˚C to 65˚C for 30 minutes using a jacketed electric kettle (Groen, Sul Supplies Sdn. Bhd., Malaysia). Pasteurized milk was immersed in a basin of tap water to facilitate the cooling process. Tap water was changed intermittently until the temperature of pasteurized milk was reduced to warm. The pasteurized milk was then kept to cool in the cold room at 6˚C overnight. The cooled pasteurized milk was bottled and kept in the freezer (Kelvinator, Fisher & Paykel Ltd, New Zealand) at -18˚C and thawed in the chiller at 10 ± 2˚C one to three days before use.

Spray drying of beetroot and skim milk mixtures

A fixed amount of pasteurized skim milk (SM) was mixed with 15% and 30% beetroot extract (15B and 30B), respectively based on the amount of skim milk. The mixture was further blended with 5% of different encapsulating agents on a total weight basis for 2 minutes. The encapsulating agents involved are Maltodextrin DE 10-15 (MD), Arabic gum (AG), and a mixture of Maltodextrin and Arabic gum in a ratio of 1:1. Spray drying process was conducted using a spray dryer (Niro, GEA, Germany) at inlet temperature 165˚C, outlet temperature range of 75-90˚C ± 2˚C, feed rate at 14rpm or 18mL/min, and atomizing pressure of 3-4 bar. The powder collected in the cyclone was kept in a zip log polyethylene bag, covered with aluminum foil, and kept in a storage box in the chiller until further analysis.

Composition of skim milk

Protein content

The nitrogen content of cow's skim milk followed the Micro Kjeldahl method (Yoganandi et al., 2014) and it was calculated based on equation 1 while the crude protein content of milk was calculated using equation 2.

$$\text{Nitrogen content (\%)} = [(ls - lb) \times N \times 1.4]/W \quad (1)$$

where ls refers to the volume of NaOH to titrate sample (ml), lb is the volume of NaOH to titrate blank (g), N is the normality of NaOH and W refers to the weight of sample milk used.

$$\text{Protein content (\%)} = \text{nitrogen content (\%)} \times 6.38 \quad (2)$$

$$\text{Protein content (g/kg)} = \text{protein content (\%)} \times 10 \quad (3)$$

Fat content

The fat content of cow's skim milk was determined using the Gerber method (AOAC, 2005; Method No. 2000.18). Fat content was calculated using equations (4) and (5):

Fat content (%) = Upper meniscus reading − lower meniscus reading (4)

Fat content (g/kg) = Fat content (%) × 10 (5)

Ash content

The ash content of liquid skim milk was determined by the gravimetric method (AOAC, 2005; Method No. 945.46). Ash content was calculated using the formula (6):

Ash content (g/kg) = weight of ash (g)/weight of the fresh sample (kg) (6)

Total solids

The total solids of skim milk were determined using the oven drying method by referring to the procedure by Lingathurai et al. (2009) with slight modification. 3g of skim milk was dried in a pre-weighed crucible at 105˚C overnight and total solids were calculated as follows:

Total solids (g/kg) = weight of the dried sample (g)/weight of the fresh sample (kg) (7)

pH

The pH of skim milk was determined by using a pH meter. Before measuring pH, the pH meter was first calibrated with buffer pH 7 followed by buffer pH 4.

Powder analysis

Feed total solids

The feed total solids were determined using the method proposed by Zhang et al. (2013) with some slight modifications. About 3g of feed was weighed precisely and dried in an oven at 105°C until a constant weight was obtained. The total solid percentage on a wet basis was calculated as follows:

Total solids % (wb) = (weight of dried sample/ weight of feed) × 100 (8)

Powder total solids

The spray-dried sample total solids were determined using the method proposed by Al-Asheh et al. (2013) with some slight modifications. 3g of powder was dried in the oven at 105°C overnight. The total solid percentage on a wet basis was calculated as indicated in eq. (9):

Powder total solids % (wb) = (weight of dried powder/weight of powder) × 100 (9)

Powder yield

It was determined by the ratio of the mass of total solids in the powder and the mass of total solids in the feed solution (Santana et al., 2013).

Powder yield (%) =(mass of total solids in powder (g)/mass of total solids in feed solution (g))×100 (10)

Moisture content

The moisture content of the powder was determined using the standard AOAC method. 3g of powder was dried in the oven (Binder, Model ED115) at 105°C overnight. The crucible with the dried sample was cooled in the desiccator for 20 minutes. The moisture content of spray-dried powder on a wet basis was calculated using the formula (11):

Moisture content % (wb) = [(weight of sample − weight of dried sample)/weight of sample]×100 (11)

Water activity

The water activity of powder was measured at 25˚C using AquaLab Water Activity Meter Series 3TE (Decagon Devices, Inc., Pullman, WA, USA).

Bulk density

The bulk density of powder was determined using the method described by Reddy et al. (2014) and Ng and Sulaiman (2018) with slight modification. 5g of powder was freely poured into a 25ml glass graduated cylinder using a gateway spatula without tapping and disturbance. The volume occupied was recorded and calculated as loose bulk density. Tapped bulk density was determined by lifting the container to a height of 20mm ± 2 mm and allowing the container to drop under its weight until a constant volume reading was obtained. The loose and tapped bulk density powder was calculated using the equation (12):

Loose bulk density (g/mL) = mass of powder (g)/bulk powder volume (mL) (12)

Tapped bulk density (g/mL) = mass of powder (g)/tapped powder volume (mL) (13)

Flowability

The flowability of spray-dried red skim milk powder was evaluated through Carr's index and Hausner ratio as described by Reddy et al. (2014) and Lebrun et al. (2012).

Carr's index (CI)

Carr's index was determined by using the loose and tapped bulk density of spray-dried red skim milk powder obtained from different treatments.

Carr's index (%) = [(tapped bulk density−loose bulk density)/tapped bulk density]×100% (14)

Hausner ratio (HR)

Hausner ratio spray-dried red skim milk powder was calculated from the loose and tapped bulk density obtained.

Hausner ratio = tapped bulk density/loose bulk density (15)

Particle size

The particle size of the red skim milk powder was determined with slight modification (Chever et al., 2017) by laser diffraction using Mastersizer Scirocco 2000 (Malvern Instrument Ltd., Malvern, United Kingdom) with a powder feeder unit. Vibration feed rate, dispersive air pressure, and the refractive index were fixed at 30%, 1.5 bar, and 1.52 respectively. Particle size was expressed in volume-weighted mean $D_{[4,\ 3]}$, surface area-weighted mean $D_{[2,\ 3]}$, span index, and diameters d(0.1), d(0.5), and d(0.9) which represents the size of the sample with 10, 50 and 90% lying below the diameter. Measurements were performed in triplicate.

Solubility

The solubility of spray-dried red skim milk powder was determined with slight modification (GEA, 2006; Chia & Chong, 2015). 1g of powder was mixed with 10 mL of distilled water for 30 minutes using a magnetic stirrer and magnetic bar. The mixture was transferred into a 15mL centrifuge tube and further vortex for 1 minute to ensure complete dissolution. The reconstituted milk was centrifuged for 5 minutes at 3000rpm (EBA 20, Hettich, Germany). The supernatant was discarded by using a dropper. The precipitate was re-suspended in distilled water and centrifuged for another 5 minutes at 3000 rpm. The supernatant was discarded. The sediment was transferred to the crucible and dried in the oven at 105˚C overnight. Solubility was calculated based on the difference in weight between fresh powder and dried sediment.

Solubility (%) = [(Weight of fresh powder−weight of dried sediment)/weight of fresh powder]× 100 (16)

Hygroscopicity

The hygroscopicity of skim milk powder was determined by the following methods proposed by Cai and Corke (2000) with some modifications. 1g of powder was spread evenly on pre-weighed crucibles and inserted in an airtight desiccator filled with saturated sodium chloride, and NaCl solution with a relative humidity of 78% at 28 ± 2°C for one week. After one week, the weight of the powder was recorded. The difference in weight was used to calculate hygroscopicity in grams of adsorbed moisture per 100g of dry matter as below:

Hygroscopicity (g / 100g) = [$\Delta m/(m$+m1)]/ [1+($\Delta m/m$)] (17)

where Δm refers to the increase of powder's weight after reaching equilibrium (g), m is the initial mass of powder (g) and m_1 is the free water content (moisture content) of powder before being exposed to air's humidity (g/ 100 g).

Total soluble solids

Determination of total soluble solids was done by using a hand refractometer at a readable Brix of 0 – 33.0% (Atago, Japan). 1g of powder was reconstituted with 10mL of distilled water at 25˚C using a magnetic stirrer and magnetic bar for 30 minutes. A drop of solution was placed on the surface of the prism. The reading was recorded and expressed as degree Brix (˚Brix).

pH

1g of powder was reconstituted with 10mL of distilled water at 25˚C using a magnetic stirrer and magnetic bar for 30 minutes. The pH of reconstituted red skim milk powder was determined by using a pH meter until getting a constant pH value.

Color of powder

The color of red skim milk powder was determined using HunterLab UltraScan Pro Spectrocolorimeter (Hunter Associates Laboratory Inc, United States) on the CIELAB scale (Abdalla et al., 2017; Chia & Chong, 2015; Hunterlab, 2012). The final result was presented in L* (lightness: 0 = black, 100 = white) and a* (-a* = greenness, +a* = redness). Before color measurement, the Hunter colorimeter was standardized for RSIN mode with light trap and white tile. D65/10˚ was used as the reference illuminant. Skim milk powder was filled into the plastic cell and placed against the reflectance port. The sample cell was covered with a black metal cover to prevent light interference.

Color stability of rehydrated red skim milk

Red skim milk powder was reconstituted with distilled water at 25 ± 1˚C to 10˚Brix using a magnetic stirrer for 30 minutes. Color changes in milk were studied at 25˚C, 40˚C, 60˚C, and 80˚C which were within the range provided by Güneşer (2016) to study the effect of heat treatment on the stability of pigment in the milk system. About 18mL of reconstituted milk was filled into a screw cap glass tube of 15mm diameter and the tubes were capped well to prevent evaporation during heat treatment. All the tubes were inserted into a water bath pre-heated at the temperature and the recording

time was started (t = 0) when the milk reached the targeted temperature which took approximately 2 to 3 minutes right after placing it in the water bath. After 30 minutes, heated milk was immediately cooled in an ice water bath to prevent further denaturation and color change. Each sample was heated in triplicate.

The color of rehydrated milk was determined using HunterLab UltraScan Pro Spectrocolorimeter (Hunter Associates Laboratory Inc, United States) on the CIELAB scale (Abdalla et al., 2017; Chia & Chong, 2015; Hunterlab, 2012). The final result was presented in L* (lightness: 0 = black, 100 = white), a* (-a* = greenness, +a* = redness) and b* (-b* = blueness, +b* = yellowness). Before color measurement, the Hunter colorimeter was standardized for RSIN mode with light trap and white tile. D65/10˚ was used as the reference illuminant. Reconstituted milk was shaken, poured into the plastic cell, and placed against the reflectance port. The sample cell was covered with a black metal cover to prevent light interference.

Statistical analysis

The data were analyzed by one-way ANOVA using Minitab version 16.2.1 at a 95% confidence level. A value of $p < 0.05$ was considered statistically significant for comparison. Tukey's test was carried out and data which did not share a common letter on the column graph or table was significantly different from each other.

RESULTS AND DISCUSSION

Composition of skim milk

Based on Table 1, the composition of pasteurized skim milk used in this study was in the range of value reported by Biswas et al. (2017) where the skim milk contains 31.74 g/kg of protein, 2.67 g/kg of fat, 6.23 g/kg of ash, 80.70 g/kg of total solids and a pH value of 6.76. The fat content of skim milk in this study was slightly higher compared to the referred study. However, it was still within the range as stated in Food Regulations 1985 which is less than 0.5% or 5g/kg.

Physical properties of spray-dried red skim milk powder

Table 2 showed the highest yield of powder obtained from the skim milk sample without any additional beet juice and carrier agents. For samples containing beet juice, spray drying using carrier agents exhibited a higher yield compared to control samples SM-15B and SM-30B. Beet juice contains a high amount of low molecular weight components such as glucose, fructose, sucrose, and acids which contributed to low glass transition temperature (Janiszewska, 2014). Therefore, spray-dried red skim milk powder without carrier agents is hygroscopic and tends to adhere to the internal wall of the drying chamber and cyclone, leading to great losses (Bazaria & Kumar, 2016). Yousefi et al. (2011) obtained a similar result whereby the yield of spray-dried pomegranate juice without agents was the lowest compared to the sample encapsulated with agents.

The moisture content of all the skim milk powder obtained in this study was in the range of 2.16 to 4.74%, following Codex Alimentarius statement (requirements for all types of milk powder as a whole, partially skimmed, or skimmed, to a maximum of 5% water content. Findings by Ilari and Mekkaoui (2005) presented that the moisture content of skim milk powder was 4%.

Water activity measures the availability of free water contained in a food system. Food with a water activity of less than 0.6 is microbiologically stable and possesses longer shelf life. The water activity of all the spray-dried skim milk powder obtained was low, ranging from 0.232 to 0.309. The water activity range from 0.237 to 0.303 for skim milk powder produced by different European manufacturers (Pugliese et al., 2017). Low water activity below 0.40 is favorable for milk powder to prevent caking from the crystallization of lactose (Walstra et al., 2006). Additional beet juice and carrier agent to produce red color skim milk still showed moisture content and water activity within the range of acceptable range for common skim milk powder.

Table 1. Composition of pasteurised skim milk

Protein (g/kg)	34.90 ± 0.07
Fat (g/kg)	3.30 ± 0.04
Ash (g/kg)	7.30 ± 0.00
Total solids (g/kg)	81.60 ± 0.04
pH	6.68 ± 0.07

Table 2. Yield, moisture content, and water activity of spray-dried red skim milk powder.

Sample	Yield (%)	Moisture content (% wet basis)	Water activity, a_w
SM	85.48	3.04 ± 0.43^{bcd}	0.267 ± 0.012^{bc}
SM-15B	61.54	2.97 ± 0.37^{bcd}	0.262 ± 0.005^{bcd}
SM-15B (MD)	71.13	2.79 ± 0.48^{cd}	0.240 ± 0.017^{cd}
SM-15B (AG)	75.15	3.52 ± 0.23^{abc}	0.248 ± 0.015^{bcd}
SM-15B (MD + AG)	70.49	2.16 ± 0.11^{d}	0.232 ± 0.007^{d}
SM-30B	69.40	4.74 ± 0.24^{a}	0.258 ± 0.012^{bcd}
SM-30B (MD)	73.30	4.16 ± 0.36^{ab}	0.309 ± 0.004^{a}
SM-30B (AG)	67.77	2.79 ± 0.06^{cd}	0.274 ± 0.012^{b}
SM-30B (MD + AG)	81.20	2.55 ± 0.98^{cd}	0.270 ± 0.008^{bc}

Samples with different letters within the same column are statistically different from each other ($p<0.05$).

Powder with high bulk density is desirable due to easier transportation, less occluded air entrapped in the pore space, and a lower risk of powder oxidation (Tan et al., 2015). Based on Table 3, the addition of beetroot juice led to an increment in both loose and tapped bulk density. Red skim milk powder coated with encapsulating agent possessed higher loose and tapped bulk density than the control samples. According to Cai and Corke (2000), the bulk density of powder increased as the feed total solids increased. Before the spray drying process, the feed solution added with encapsulating agents had higher total soluble solids of 12.1˚Brix to 13.4˚Brix varying with different agents while the Brix value for SM-15B and SM-30B were lower which were 9˚Brix and 8.8˚Brix, respectively. Findings from Pugliese et al. (2017) showed the loose and tapped bulk density of commercial skim milk powder in the range of 0.396 – 0.666g/mL and 0.553 – 0.872g/mL, respectively. Both the loose and tapped bulk densities of SM-15B and SM-30B were greater than SM. Encapsulated powders were preferable over the control sample as they fall in the normal range of values. Red skim milk powder with Carr's index greater than 25% and a Hausner ratio of more than 1.34 is classified as cohesive or has poor flowability. Microencapsulation with carrier agents generally improved powder flowability when compared to the control samples. Samples with 15% beet juice regardless of the types of agents generally possessed slightly higher Carr's index than 30% beet juice however the difference was not significant to each other. The same trend was observed in the Hausner ratio. Among all the treatments, only powder-coated with maltodextrin, SM-30B (MD) falls into the category of passable. Overall results showed the types of encapsulating agents did not significantly affect both of these properties.

From Table 4, the span value of SM is significantly greater than other samples which indicated that the powder was highly inhomogeneous (Pugliese et al., 2017). The range of surface weighted mean, $D_{[3,2]}$ for commercial spray-dried skim milk powder was between 25.86μm to 60.79μm (Pugliese et al., 2017). Most of the samples obtained in this experiment fall in the stated range except SM-15B and SM-15B (AG). A large standard deviation was observed in certain samples for value $D_{[4,3]}$. Generally, the addition of beetroot juice decreased the average particle size of the powder which can be seen from the control sample where both SM-15B and SM-30B were significantly smaller in size than SM. Researchers reported that particle size is correlated to the bulk density of powder whereby a smaller particle size possessed a larger bulk density (Bicudo et al., 2015). This statement was particularly true in this condition. However, in the case of different encapsulating agents, the bulk density and particle size did not correlate with each other.

Tamime (2009) presented that the solubility of spray-dried skimmed milk powder is usually more than 99%. Based on Table 5, most of the samples exhibited solubility greater than 99% except SM-15B (AG) and SM-30B (AG). It showed that microencapsulation using AG reduced the dissolution ability of beet juice skim milk powder. Arabic gum contains more hydrophobic sites than maltodextrin (Nurhadi et al., 2012) and thus making SM-15B (AG) significantly less soluble than others. However, overall, all the samples were considered highly soluble in water with a solubility of more than 95%. Researchers had stated maltodextrin and Arabic gum as highly soluble carrier agents. Maltodextrin showed solubility of 99% in water at room temperature (Shogren & Biresaw, 2007). According to Dauqan and Abdullah (2013), Arabic gum dissolves quickly in both hot and cold water up to 50% concentration.

Table 3. Bulk density and flowability of spray-dried red skim milk powder.

Sample	Loose bulk density (g/mL)	Tapped bulk density (g/mL)	Carr's Index (%)	Hausner ratio	Flow character
SM	0.24 ± 0.02^{e}	0.38 ± 0.01^{e}	35.55 ± 3.94^{abc}	1.56 ± 0.10^{ab}	Very poor
SM-15B	0.26 ± 0.01^{de}	0.45 ± 0.01^{d}	41.83 ± 2.23^{a}	1.72 ± 0.07^{a}	Very, very poor
SM-15B (MD)	0.40 ± 0.02^{c}	0.57 ± 0.00^{abc}	29.78 ± 3.08^{bcd}	1.43 ± 0.06^{b}	Poor
SM-15B (AG)	0.41 ± 0.01^{bc}	0.58 ± 0.02^{abc}	29.31 ± 1.39^{cd}	1.42 ± 0.03^{b}	Poor
SM-15B (MD + AG)	0.42 ± 0.01^{abc}	0.61 ± 0.02^{ab}	32.00 ± 4.00^{abcd}	1.47 ± 0.09^{ab}	Very poor
SM-30B	0.30 ± 0.01^{d}	0.52 ± 0.05^{c}	40.97 ± 6.65^{ab}	1.71 ± 0.18^{a}	Very, very poor
SM-30B (MD)	0.45 ± 0.02^{ab}	0.59 ± 0.02^{ab}	23.36 ± 5.52^{d}	1.31 ± 0.10^{b}	Passable
SM-30B (AG)	0.46 ± 0.02^{a}	0.63 ± 0.01^{a}	27.33 ± 4.64^{cd}	1.38 ± 0.09^{b}	Poor
SM-30B (MD + AG)	0.39 ± 0.01^{c}	0.55 ± 0.02^{bc}	30.39 ± 0.66^{abcd}	1.44 ± 0.01^{b}	Poor

Samples with different letters within the same column are statistically different from each other ($p<0.05$).

Table 4. The particle size of spray-dried red skim milk powder.

Sample	$D_{[3,2]}$	d(0.1)	d(0.5)	d(0.9)	$D_{[4,3]}$	Span
SM	31.08 ± 0.41^{a}	17.67 ± 0.30^{a}	39.42 ± 1.82^{a}	193.95 ± 18.75^{a}	71.74 ± 5.31^{a}	4.46 ± 0.28^{a}
SM-15B	24.06 ± 0.54^{d}	15.40 ± 0.18^{b}	31.02 ± 0.60^{de}	59.87 ± 4.08^{b}	53.68 ± 21.10^{a}	1.43 ± 0.11^{b}
SM-15B (MD)	27.53 ± 0.22^{bc}	19.03 ± 0.30^{a}	34.90 ± 0.06^{bc}	60.21 ± 0.97^{b}	40.66 ± 5.72^{a}	1.18 ± 0.04^{b}
SM-15B (AG)	24.86 ± 2.33^{cd}	15.79 ± 0.22^{b}	28.31 ± 0.53^{e}	52.27 ± 4.01^{b}	42.12 ± 19.09^{a}	1.18 ± 0.04^{b}
SM-15B (MD + AG)	26.44 ± 1.04^{cd}	17.85 ± 0.53^{a}	31.97 ± 0.93^{cd}	56.28 ± 5.79^{b}	54.83 ± 36.48^{a}	1.29 ± 0.12^{b}
SM-30B	26.19 ± 0.85^{cd}	15.76 ± 0.34^{b}	29.28 ± 0.23^{de}	57.98 ± 0.94^{b}	35.99 ± 0.50^{a}	1.44 ± 0.05^{b}
SM-30B (MD)	26.30 ± 0.96^{cd}	15.91 ± 0.54^{b}	29.34 ± 0.27^{de}	57.76 ± 1.68^{b}	35.79 ± 1.26^{a}	1.43 ± 0.09^{b}
SM-30B (AG)	30.55 ± 1.08^{ab}	19.19 ± 1.34^{a}	35.69 ± 1.50^{b}	78.31 ± 18.88^{b}	101.99 ± 56.19^{a}	1.64 ± 0.51^{b}
SM-30B (MD + AG)	25.99 ± 1.50^{cd}	15.72 ± 0.48^{b}	28.34 ± 1.69^{e}	55.39 ± 10.37^{b}	41.48 ± 16.05^{a}	1.39 ± 0.29^{b}

Samples with different letters within the same column are statistically different from each other ($p<0.05$).

Table 5. Solubility, hygroscopicity, TSS, and pH of spray-dried red skim milk powder.

Sample	Solubility (%)	Hygroscopicity (g/100g)	TSS (°Brix)	pH
SM	99.20 ± 0.12^{a}	12.28 ± 0.06^{d}	10.0 ± 0.0^{a}	6.50 ± 0.02^{b}
SM-15B	99.64 ± 0.18^{a}	13.77 ± 0.28^{bc}	9.9 ± 0.1^{ab}	6.51 ± 0.01^{b}
SM-15B (MD)	99.62 ± 0.06^{a}	12.54 ± 0.03^{d}	9.7 ± 0.1^{bcd}	6.57 ± 0.01^{a}
SM-15B (AG)	95.58 ± 1.62^{b}	14.80 ± 0.99^{ab}	9.5 ± 0.1^{d}	6.26 ± 0.01^{d}
SM-15B (MD + AG)	99.41 ± 0.07^{a}	12.43 ± 0.29^{d}	9.5 ± 0.1^{cd}	6.30 ± 0.02^{c}
SM-30B	99.82 ± 0.03^{a}	15.28 ± 0.07^{a}	9.8 ± 0.0^{abc}	6.52 ± 0.01^{b}
SM-30B (MD)	99.60 ± 0.05^{a}	13.70 ± 0.12^{c}	9.5 ± 0.1^{d}	6.59 ± 0.01^{a}
SM-30B (AG)	98.23 ± 0.44^{a}	15.21 ± 0.36^{a}	9.4 ± 0.0^{d}	6.20 ± 0.01^{e}
SM-30B (MD + AG)	99.49 ± 0.08^{a}	14.35 ± 0.05^{abc}	9.5 ± 0.1^{d}	6.33 ± 0.01^{c}

Samples with different letters within the same column are statistically different from each other ($p<0.05$).

The hygroscopicity of powder affects its lumping and caking properties. From this study, the addition of beet juice significantly increased the hygroscopicity of skim milk powder. It was clearly shown in Table 5 that SM was the least hygroscopic powder, followed by SM-15B and SM-30B. This was due to the high amount of hydrophilic group present in the betacyanin molecules which was found abundant in the beetroot extract (Sánchez et al., 2006), thus making the powder absorb water easily. Compared to the control sample, microencapsulation with MD and the combination of MD+AG improved the hygroscopicity of the powder. However, coated solely with AG resulted in highly hygroscopic powder. Bicudo et al. (2015) reported a similar finding where spray-dried jucara pulp encapsulated with Arabic gum was significantly more hygroscopic than the sample coated with maltodextrin. Some research reported that powder moisture content was inversely related to its hygroscopicity due to a higher water concentration gradient between the product and surrounding air (Ferrari et al., 2011). However, this statement was not always applied to all the spray-dried powder. In this experiment, SM-30B contained the highest moisture content and exhibited the most hygroscopic properties among all the samples. Research by Ahmed et al. (2010) showed that there was no direct relationship between these two properties of spray-dried sweet potato powder and the hygroscopicity was found to be affected by the carrier agents.

By referring to Table 5, generally, the total soluble solids of all the skim milk powder exhibited in the range of 9.4 – 10˚Brix. Increasing beet juice concentration slightly reduced the total soluble solids of skim milk powder. Before the spray drying process, the Brix value of pasteurized skim milk and beet juice extract was 9˚Brix and 6˚Brix respectively. The addition of beet juice diluted the skim milk and resulted in powder with lower total soluble solids. Microencapsulation with carrier agents reduced the Brix value of samples when compared to the original skim milk powder, SM. The sample coated with Arabic gum possessed the lowest Brix value. This can be explained by the lower solubility of Arabic gum leads to less soluble compounds in the reconstituted solution.

The pH of the reconstituted sample was in the range of 6.20 to 6.59. From Table 5, the concentration of beet juice did not significantly affect the pH of reconstituted milk. The sample encapsulated with MD exhibited the highest pH value. This finding was following Ekpong et al. (2016) where the pH of foam mat tamarind pulp increased with the addition of maltodextrin which was regarded as the dilution effect of the original sample. The addition of Arabic gum as a carrier agent significantly reduced the pH of reconstituted milk due to its naturally occurring structure. Arabic gum contributes to the acidic properties where a low pH value was detected in Arabic gum solution with pH 4.5 (Montenegro et al., 2012) and pH 4.66 reported by the researchers (Mariod, 2018).

Based on Figures 1 and 2, the addition of beet juice significantly increased the redness of skim milk powder from negative (greenness) to positive (redness) and significantly reduced the powder's lightness. Beetroot contains a high amount of betacyanin in the form of betanin which is responsible for the red color (Nemzer et al., 2011). The more beet juice added, the greater the number of betalains in milk, thus appearing more reddish. The blend of MD + AG was better at retaining the redness in both 15% and 30% beet juice concentrations. A similar finding was reported by Ferrari *et al.* (2012) where there is about 85% which is the highest pigment retention among the spray-dried blackberry powder by the encapsulation of Maltodextrin and Arabic gum in a 1:1 ratio compared to maltodextrin or Arabic gum alone. According to *Bach et al.* (2015), beet juice contains geosmin and pyrazines which contributes to the undesirable earthy flavor that might affect the sensory characteristic if an extra high concentration had been added to the milk. Thus, SM-15B (MD+AG) was recommended instead of SM-30B (MD+AG) as there is only a small difference between the two samples in terms of redness value. Microencapsulated samples appeared significantly lighter in color compared to their respective control sample, SM-15B and SM-30B. The presence of carrier agents diluted the system and resulted in color loss which in turn increased the lightness value (Ferrari et al., 2011).

Color stability of reconstituted spray-dried red skim milk

The redness of reconstituted skim milk decreased with increased temperature except for SM-15B (MD+AG) and SM-30B (MD+AG) when heated at 40˚C. The color of reconstituted red skim milk changed from purplish red to light pink from 25˚C to 80˚C. According to Güneşer (2016), at temperatures 70-90˚C, thermal degradation of betalain in milk sample followed first-order reaction with a rate constant increased from 13.588×10^{-3} (70˚C) to 30.975×10^{-3} min^{-1} (90˚C) and half-life value falls between 22 (90˚C) and 51 minutes (70˚C). This indicated that the amount of betalain reduced with time and the degradation was more intense at a higher temperature which caused the red

color of the sample significantly faded. By referring to Figure 3, it showed that in the reconstituted state, carrier agents of Arabic gum (AG) and the combination of maltodextrin and Arabic gum (MD+AG) were better at retaining the redness of the sample. It might be due to the lower pH value of the samples as shown in Table 5. According to Ibraheem *et al.* (2015), beetroot betalain pigments displayed the most intense red coloration under acidic conditions. However, it was found that during heat treatment at 80˚C, SM-15B (AG) and SM-30B (AG) curdled and separation of milk occurred where a layer of whey was observed. Lower pH enhanced the redness of the sample, however, in the milk system, it might facilitate the coagulation process under heat treatment.

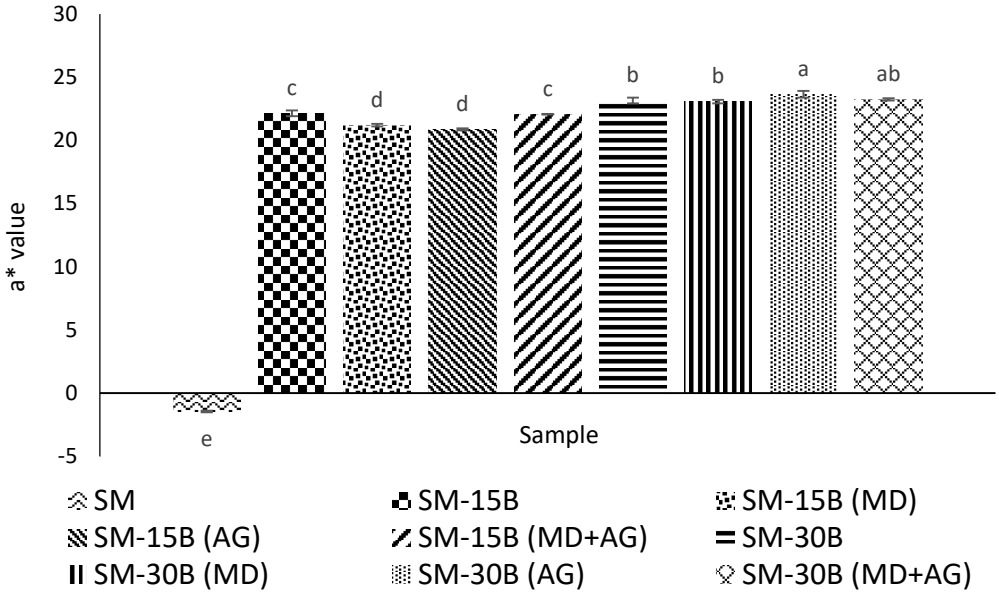

Figure 1. Redness value, a* of spray-dried red skim milk powder with different carrier agents. Means with different alphabets indicate significant differences among treatments ($p<0.05$).

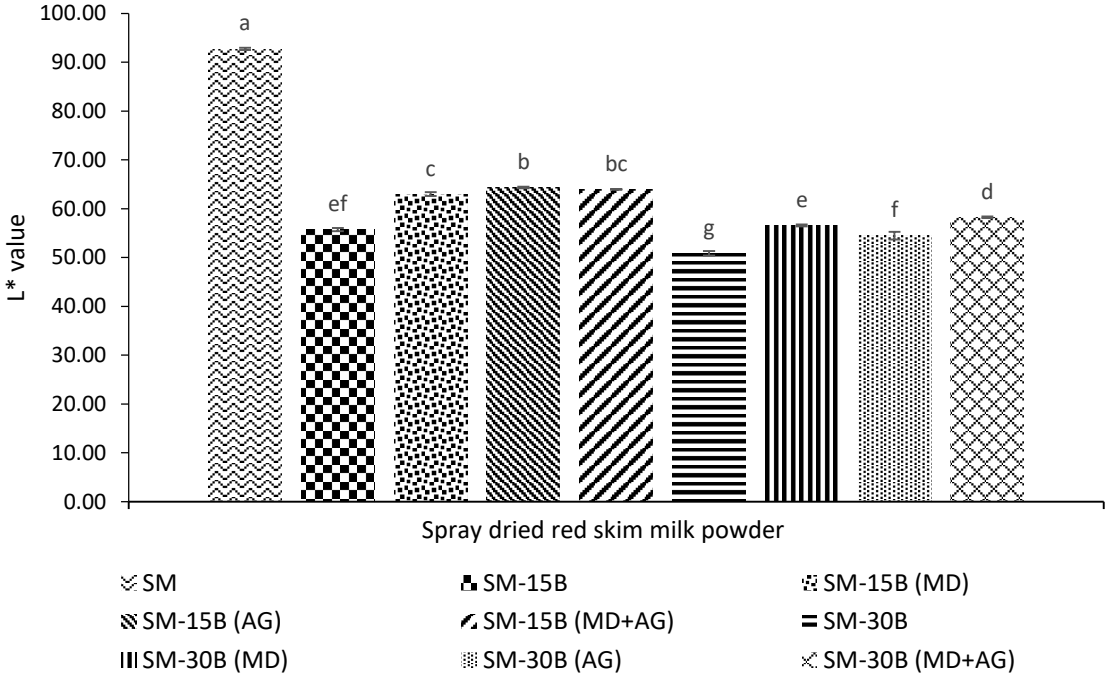

Figure 2. Lightness value, L* of spray-dried red skim milk powder with different carrier agents. Means with different alphabets indicate significant differences among treatments ($p < 0.05$).

The results shown in Figure 4 indicate that the lightness of rehydrated red skim milk significantly increased with temperature. The finding was in good agreement with Güneşer (2016) where the

research stated that an increment in temperature significantly increased the L* value. This can be explained by the thermal degradation of betalain which was following the result as shown in Figure 3 and lead to color loss. Generally, microencapsulation with the combination of Maltodextrin and Arabic gum (MD+AG) was able to impart a lighter sample in a reconstituted state for both 15% and 30% beet juice incorporation under the heat treatment temperature. The final red skim milk obtained from this study is shown in Figure 5.

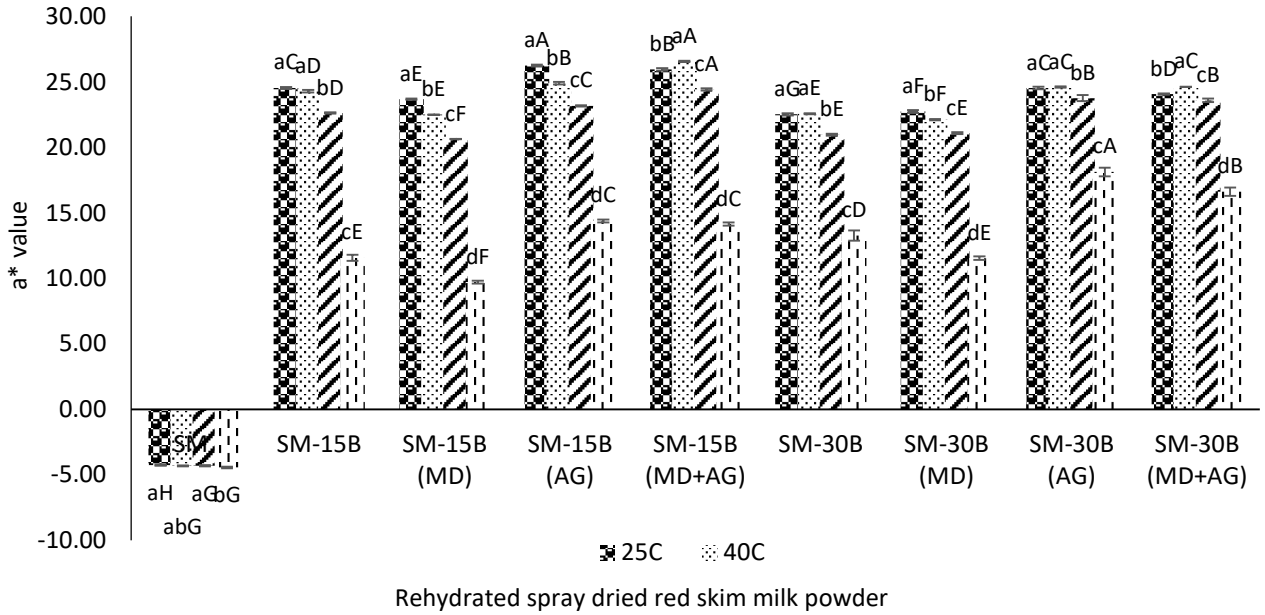

Figure 3. Effect of rehydration temperature on a* value of spray-dried red skim milk at 10˚Brix. Different alphabets in lowercase indicate significant differences between temperatures within the same sample while different alphabets in uppercase indicate significant differences between different samples within the same temperature ($p < 0.05$).

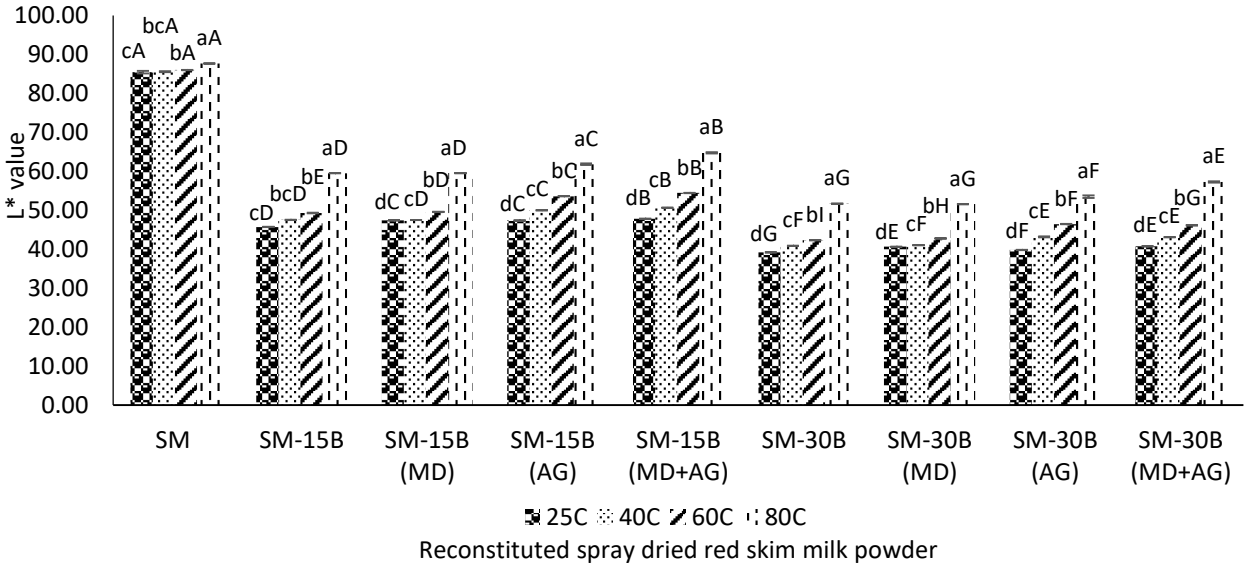

Figure 4. Effect of rehydration temperature on L* value of spray-dried red skim milk at 10˚Brix. Different alphabets in lowercase indicate significant differences between temperatures within the same sample while different alphabets in uppercase indicate significant differences between different samples within the same temperature ($p < 0.05$).

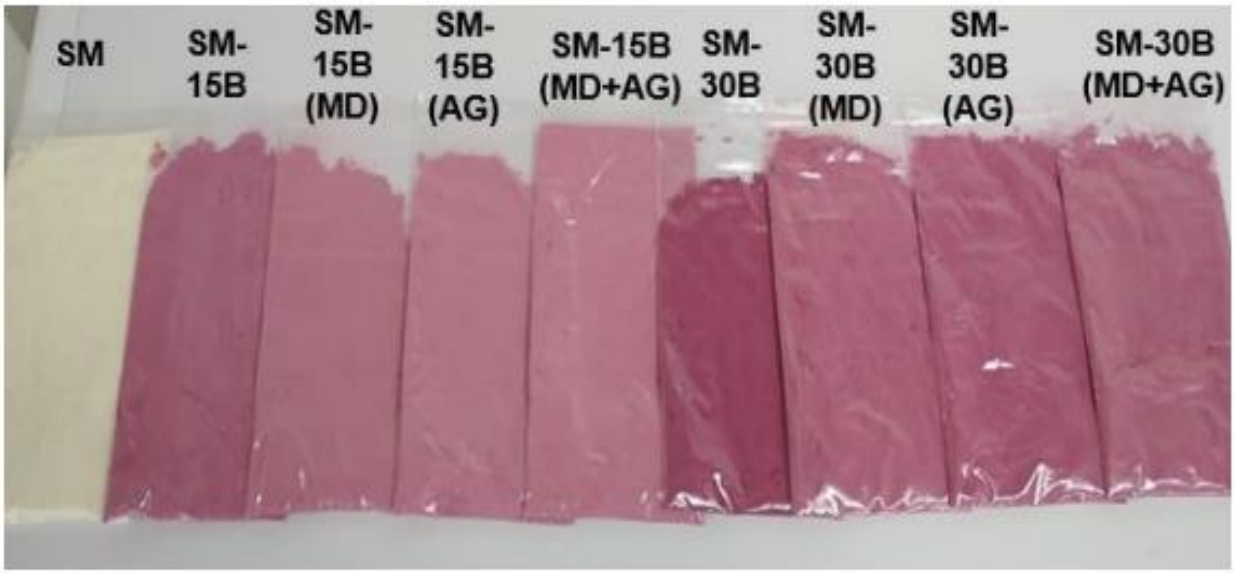

Figure 5. Spray-dried red skim milk powder from skim milk, beetroot juice, Arabic gum, Maltodextrin, and their mixtures.

CONCLUSION

Microencapsulation of beet juice in spray-dried red skim milk powder with a blend of Arabic gum and maltodextrin (1:1 ratio) possessed the best redness, and 15% beet juice concentration is recommended based on of the rehydrated powder properties. The sample coated with a combination of maltodextrin and Arabic gum exhibited high solubility, low moisture content, water activity, less hygroscopic, and moderate flowability. Increasing the rehydration temperature will increase the lightness and reduce the redness of reconstituted red skim milk powder. Spray-dried red skim milk may be used as an ingredient in many food applications due to its health benefits with its great natural red colorant.

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