Spray-drying microencapsulation of polyphenols by polysaccharide from yeast cell walls

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ABSTRACT

This study used polysaccharide (PS) from yeast cell walls to encapsulate polyphenols (PP) extracted from green tea (a good antioxidant substance) to avoid the effects of sensitive factors such as temperature, light, and oxygen and to preserve its stability and bioactivities. The objective of this study was to investigate the effects of four types of wall material (PS-MD (maltodextrin), PS-whey, whey, and MD). After selecting the most appropriate wall material, the study continued to investigate the effects of the ratios of the core to the wall material (1:1, 1:2, 1:3 and 1:4, w/w); the inlet air temperatures of spray-drying (130, 140, 150, and 160°C); and the feed flow rates (04, 05, 06 and 07mL/min) on the microencapsulation yield (MEY) and the microencapsulation efficiency (MEE). The results showed the best settings as follows the wall material being PS-MD, the ratio of PP to the wall material as 1:3 (w/w), the inlet air temperatures at 140°C, and the feed flow rate at 05mL/min. Under those conditions, the MEY and the MEE were found to be highest at 31.118mg/g and 86.73%, respectively. When examined by Scanning Electron Microscopy (SEM), they had various sizes, and spherical shapes, and some of them had smooth or concave surfaces. As a result, it could be concluded that polyphenols were successfully encapsulated in the PS-MD matrix by spray-drying, and the application to some food products could be further studied.

1. Introduction

Wasted brewer's yeasts are a by-product of the beer industry, but they are not exploited efficiently. Most of them are used as a source of proteins, vitamin B, and minerals in animal feed production. The remaining is wasted, causing water pollution. However, there are many yeast cells left in wasted brewer's yeasts, whose cell walls contain some valuable polysaccharides (PS) such as mannoproteins, β-glucan, and chitin (Podpora, Świderski, Sadowska, Rakowska, & Zys, 2016), which are widely used in food and medicine industry.

Microencapsulation is a technique of encapsulating bioactive substances by using different materials such as gum, protein, polysaccharides, lipids, etc., to avoid disadvantaged effects of environmental factors such as light, humidity, oxygen, temperature, etc. (Nazzaro, Orlando, Fratianni, & Coppola, 2012). There are many technical methods used for microencapsulation including emulsification, spray-drying, sublimation drying, crystallization, and nano-scaled

granulation (Fang & Bhandari, 2010). This is a potential research direction currently applied in medicine and functional foods. Yeast cell walls have been proved to be stable at temperatures as high as 250^{o}C (Bishop, Nelson, & Lamb, 1998). Microencapsulated flavors in hollow yeast cells have been denatured only at temperatures higher than 243^{o}C (Bishop et al., 1998). Paramera, Konteles, and Karathanos (2011) used *Saccharomyces cerevisiae* to microencapsulate curcumin compounds. Pham, Guido, Phan, and Waché (2018) used *Yarrowialipolytica*'s cell walls to microencapsulate β-carotene. Kha, Do, and Huynh (2019) used PS and MD as wall material to encapsulate β-carotene by spray-drying at the inlet temperature of 150^{o}C. The encapsulated β-carotene powder was found to be stable under exposure to light and oxygen due to low moisture content and free of cracks and pores as compared to the commercial one β-carotene was successfully encapsulated in the PS and MD matrix. The compounds after microencapsulating are more stable and better resistant to the impacts of sensitive factors of the environment.

Polyphenols are a group of antioxidants that are used in food, cosmetics, and medicine with the aim of preventing aging, treating inflammatory diseases, and cancer (Conesa & Larrosa, 2020). However, the solubility of polyphenols in water is weak, and their biological activity is easily affected by light and temperature. To restrict these, microencapsulation of polyphenols is a potential solution.

Robert et al. (2010) encapsulated polyphenol and anthocyanin compounds from pomegranates by a spray-drying method in which using maltodextrin (MD) at temperatures ranging from 140^{o}C to 160^{o}C and applying the feed flow rate at 10mL/min, and the pressure of 20psi. The results showed that maltodextrin microcapsules protected the antioxidant activity of these compounds from the thermal effect of 60°C for 56 days. Podpora et al. (2016) microencapsulated polyphenol compounds from pea flower with alginate sodium and calcium chloride. The results showed that the encapsulated polyphenol particles reached a maximum antioxidant degree of 11.76 ± 0.07mg gallic acid/g and the microencapsulation efficiency reached 84.83 ± 0.40%. Polyphenols from pea flower after microencapsulating have the ability to stabilize antioxidant activity under the influence of temperature at 188°C. Shi et al. (2008) used the cell walls of *Saccharomyces cerevisiae* to encapsulate resveratrol (a natural polyphenol). Resveratrol was absorbed into yeast cell walls under the pressure of 25MPa, at 40°C for 04 hours. After absorption, the solubility in water was improved, the chemical structure was kept stable and the biological activity was ensured (Nguyen, Nguyen, Nguyen, Tran, & Tran, 2017) investigated the factors affecting the spray drying process of green tea powder, which were inlet temperature and dry matter content. The research results showed that when the dry matter content reached 25% and the inlet temperature was 160^{o}C (for cyclodextrin carrier) or 170^{o}C (for maltodextrin carrier), the highest total polyphenol content was 203.08mg GAE/g inoculant and the recovery efficiency was 65.81% respectively.

In order to take advantage of a by-product of the brewery, the research used PS from wasted brewer's yeasts as the wall material to encapsulate polyphenols from green tea. The purpose of microencapsulation was to increase the ability to withstand the impact of light, oxygen, and temperature as well as to retain the biological activity of green tea polyphenols. Microencapsulated polyphenols could be then added to some foods as a natural antioxidant.

2. Materials and methods

2.1. Materials

Green tea (from Lam Ha District, Lam Dong Province) was dried at a temperature of 60°C until the moisture reached 05%, and then it was ground into powder. Based on the experiments of

(Friedman, Levin, Choi, Kozukue, & Kozukue, 2006) with some improvements, polyphenols were extracted from green tea powder by soaking with 80% ethanol solvent, of which the ratio of raw material to solvent was 1:10 at 80°C for 30min. Afterward, they were centrifuged at 4,500rpm for 10min, and finally, vacuum evaporated to obtain extracts used for experiments. Folin-Ciocalteu reagents and DPPH (2,2-diphenyl-1-picrylhydrazyl) were purchased from Sigma-Aldrich Pty. Ltd. All solvents used in this study were of analytical grade.

PS was obtained from a by-product of a brewery (Saigon Brewery, Vietnam) by combining ultrasonic and enzyme methods (Kha et al., 2019). Briefly, yeast by-product gelatinous form was mixed with distilled water at the ratio of 1:3 (w/w), respectively. The mixture was allowed to settle for 1h, and then the remained residues of beer, water, and malt were decanted from the upper layer. These steps were performed in triplicate. The collected yeast residue (about 10g) was added 3% (v/w) of protease and incubated at 45°C for 06 hours. Afterward, 40mL of water was added, and ultrasound was treated for 10min and centrifuged at 4,500rpm for 15min. The collected residue was washed with water three times and centrifuged at 4,500rpm for 15min to collect PS.

2.2. Microencapsulation of polyphenols

Investigated factors concluded the type of wall material, the ratio of core material and wall material, the inlet temperature, and the feed flow rate.

For core material, 05g of polyphenol extract (total polyphenol content: 327.974mg GAE/g dry matter) was dissolved in 50mL of 0.37% trehalose solution. For wall material, there were 04 types prepared as follows: 10g of PS combined with 01g of MD; 10g of PS combined with 01g of whey protein; 4.5g of whey protein; and 4.5g of MD. After mixing the core and the wall material together, they were homogenized by a homogenizer (IKA RW 20 digital, Germany) at 4,200rpm for 15min to allow full incorporation. The stable solutions were spray-dried in a LabPlant SD-06 spray dryer (LabPlant UK Ltd., North Yorkshire, UK). The dryer was equipped with a two-fluid nozzle atomizer whose diameter was 0.5mm. The operating conditions of the spray-drying were the inlet temperature at 140ºC, the outlet temperatures at 73 - 80ºC, and the feed flow rate at roughly 05mL/min under the pressure of 01 bar. The spray-dried powders were stored at 04ºC in vacuum bags within 24 hours until the analysis was carried out to compare the Microencapsulation Yields (MEY), the Microencapsulation Efficiency (MEE), and the antioxidant activity to choose the best among 04 different types of wall material.

After selecting the most suitable wall material, the investigation was conducted under specific conditions as follows: the ratios of core material to wall material were 1:1, 1:2, 1:3, and 1:4 (w/w) with 01g of maltodextrin added to each; the inlet temperatures were 130, 140, 150 and 160ºC, and the feed flow rates were 04, 05, 06 and 07mL/min, respectively.

2.3. Analytical methods

All subsequent measurements were carried out in triplicate.

2.3.1. Determining the Total Polyphenol Content (TPC) by Folin-Ciocalteu method

TPC is determined based on the oxidation reaction of polyphenol compounds with Folin-Ciocalteu (F-C) reagent and gallic acid as titer agents. These compounds are oxidized in an alkaline environment leading to the formation of superoxide ions, which react with molybdate to form molybdenum oxide (MoO^{4+}), which is a blue complex whose absorption at 765nm. The color intensity of the reaction mixture is proportional to the polyphenol concentration. Based on the measured color intensity and the standard graph of gallic acid with the reagent, it is possible to determine the Total Polyphenol Content (TPC) of the samples (Ainsworth & Gillespie, 2007).

Dissolving 0.004g of sample with 01mL distilled water, a stock concentration of 4000µg/mL was obtained. Aspirating 0.5mL of a diluted sample whose concentration was 100µg/mL into the mixture, and then 0.5mL of Folin-Ciocalteau reagent was added, vortexed, and incubated for 05min. After that, 04mL of Na_2CO_3 2% was added, vortexed, and incubated at room temperature for 20min, and then measured the OD at 765nm. Distilled water was used as the reference when comparing colors.

$$\text{Total polyphenol content (mg GAE/g dry matter)} = \frac{X \times V \times f}{m} \quad (1)$$

Where:

X: value derived from the gallic acid calibration curve (µg/mL);

V: extracted volume (mL);

f: dilution factor;

m: mass of extract in volume V (g).

2.3.2. Determining the antioxidant capacity by the DPPH method

Antioxidant capacity was assessed by its ability to neutralize free radicals (by shifting the color of the DPPH reagent from purple to yellow). Firstly, 0.2g of spray-dried powder sample was dissolved in 04mL of buffer solution. Secondly, 02mL of the 1,000-times diluted extracted solution was aspirated into the mixture, and 02mL of DPPH was added as well. Then, the mixture was incubated in the dark at ambient temperature for 30min and finally measured OD at the wavelength of 517nm. DPPH was diluted at a concentration of 40µg/mL by methanol (Lu & Chen, 2008).

The percentage of free radical reduction of the sample was calculated as follows (Lu & Chen, 2008):

$$I\ (\%) = 100 \times \frac{(A_0 - A_1)}{A_0} \quad (2)$$

Where:

I (%) is the percentage of free radical reduction of the sample at 517nm;

A_o: Absorbance of DPPH;

A_1: Absorbance of the tested sample;

The blank sample is a methanol solution.

2.3.3. Microencapsulation Encapsulation Efficiency – MEE

Approximate 200mg of spray-dried powder was dissolved with 02mL of a mixture of ethanol and methanol (1:1 v/v) and then vortexed for 01min and filtered. The total phenolic compound was quantified as described above (the surface polyphenols), and the SB and the MEE were calculated as follows (Robert et al., 2010).

$$SB\ (\%) = \frac{\text{surface polyphenols}}{\text{Initial polyphenols}} \text{ x } 100 \quad (3)$$

Microencapsulation Encapsulation Efficiency (MEE)

MEE (%) = 100 – SB(%)

2.3.4. Microencapsulation Yield (MEY)

About 200mg of spray-dried powder was dissolved in 02mL of solution of methanol, acetic acid, and water whose proportion of volume was 50:8:42 (v/v/v), vortexed for 01min and then ultrasound treated for 20min. The supernatant was collected by centrifuging at 5,000rpm for 05min. The total phenolic content was determined by the Folin-Ciocalteau method (total polyphenol content after spray drying)

The EY was calculated as the number of microencapsulated polyphenols in 01g of spray-dried powder (Robert et al., 2010):

$$\text{MEY} = \frac{\text{Amount of microencapsulated polyphenols}}{\text{Amount of spray-dried powder}} \ (\mu g/g) \quad (4)$$

The amount of microencapsulated polyphenols = total polyphenol content after spray-drying -surface polyphenol content.

2.4. Statistical analysis

The independent experiments and subsequent measurements were done in triplicate. The results were presented as mean values with standard deviations. A one-way analysis of variance (including the type and the proportion of wall material, the inlet temperature, and the feed flow rate) and LSD (least significant difference) were used to analyze the data using the Statgraphics Centurion XVI software.

3. Results and discussion

3.1. The effect of the types of wall material

The wall material has an important influence on the microencapsulation process. In this experiment, polyphenols were microencapsulated with different materials as follows: The mixture of the yeast cell wall and maltodextrin, the maltodextrin only, the mixture of the yeast cell wall and whey protein, and the whey protein only. The results are presented in Figure 1. When using PS-MD as the wall material, the MEE and the MEY were highest at 78.790 ± 0.394% and 28.722 ± 0.407mg/g, respectively. They appeared to be gradually declined in the case of using MD and whey. And the lowest MEE and MEY, 13.308 ± 2.4611% and 2.060 ± 0.439mg/g respectively, were found when using whey-PS.

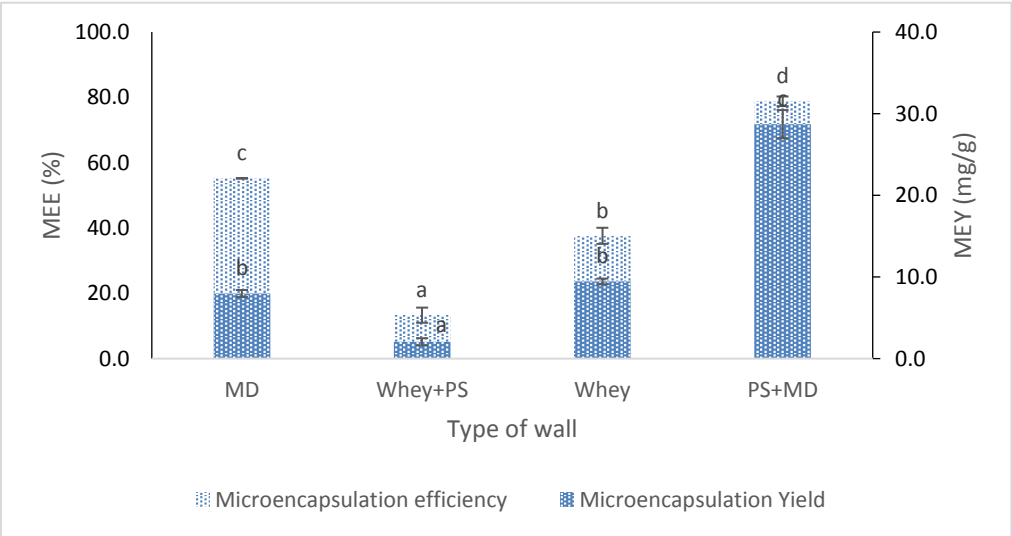

Figure 1. The effect of the types of wall material on the microencapsulation process (a, b, c are letters showing a statistically significant difference at 95% confidence level)

Thus, the ability to create films and storing the microencapsulation material of PS-MD was found to be the best, whose MEE is twice higher than that of whey, eight times higher than whey-PS, and 1.5 times higher than MD. Because polysaccharides from brewer's yeast had a more particular structure than that of other wall materials because of containing 1.3-β glucan and phospholipid double layers, therefore, yeast polysaccharides can be combined with compounds that are both hydrophobic and hydrophilic groups like polyphenols (polycyclic and hydroxyl groups) (Liu, Wang, Cui, & Liu, 2008; Wang & Xu, 2018). There was a hydrophobic interaction between the polycyclic of polyphenol and the hydrophobic tail of the phospholipid double layers of the yeast polysaccharide. In addition, there was hydrogen bonding between the OH groups of polyphenols and the β-glucan of the yeast polysaccharides (Liu et al., 2008). Besides MD also created a membrane to encapsulate polyphenols, thus, the MEE and MEY increased. For the samples microencapsulated by whey and whey- PS, the humidity of powder after drying was high, so it was easy to stick to the drying chamber leading to weight loss. In addition, the supplied heat while preparing the sample might not be sufficient, so whey was not completely denatured, and the whey's structure was not opened thoroughly, leading to polyphenols could not being encapsulated. Thus, MEE and MEY were low.

Some research results are similar. According to Paramera et al. (2011), the MEE and the MEY of beta-cyclodextrin were lower than that of yeast. Specifically, using polysaccharides brought out the highest MEE and MEY (88.2% and 31.8%, respectively), while using beta-cyclodextrin only got the MEE and the MEY as 22.8% and 3.4%, respectively, which was much lower than that of PS. Robert et al. (2010) studied and concluded that the polyphenols encapsulating efficiency were significantly better in the SPI matrix, whereas for anthocyanins were in the MD matrix. Therefore, the yeast cell wall and MD were found to be better wall materials than the others.

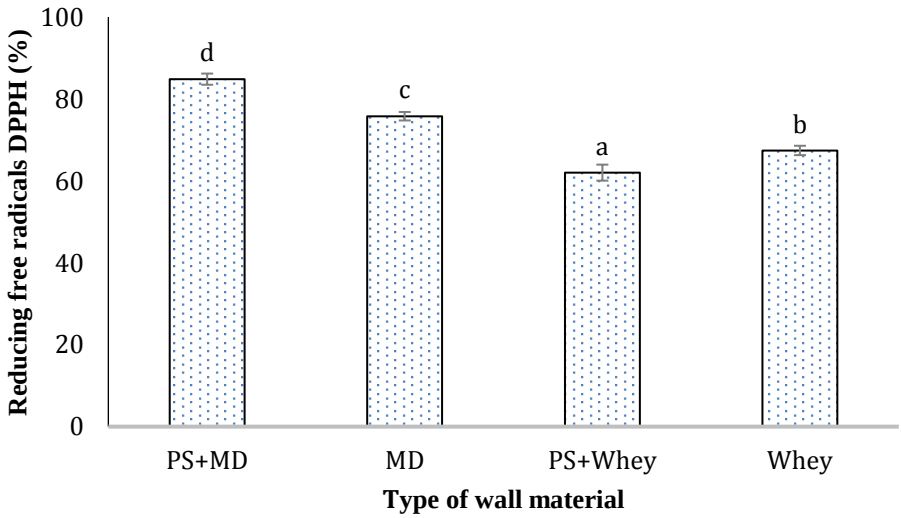

Figure 2. The effect of types of wall material on the antioxidant capacity of polyphenols (a, b, c are letters showing a statistically significant difference at 95% confidence level)

Antioxidant capacity was assessed by its ability to neutralize free radicals by shifting the color of the DPPH reagent from purple to yellow. The samples were dissolved in the buffer solution. After mixing DPPH, the mixture was incubated in the dark at ambient temperature and was finally measured OD at the wavelength of 517nm (Lu & Chen, 2008).

The antioxidant capacity varied significantly with different materials (Figure 2), and the percentage of free radicals scavenging of microencapsulated samples using PS from yeast cell

walls combined with MD was the highest (84.817 ± 1.364) and lowest for sample PS and whey (62.010 ± 1.955). The reason is different types of wall material show different microencapsulation efficiencies and affect differently on protecting polyphenols from agents during spray-drying. Besides, PS from the yeast cell wall is also resistant to oxidation because of beta-glucan. As such, using the combination of PS and MD gives higher MEE, MEY, and antioxidant capacity than that of other wall materials like MD, whey, and PS-whey.

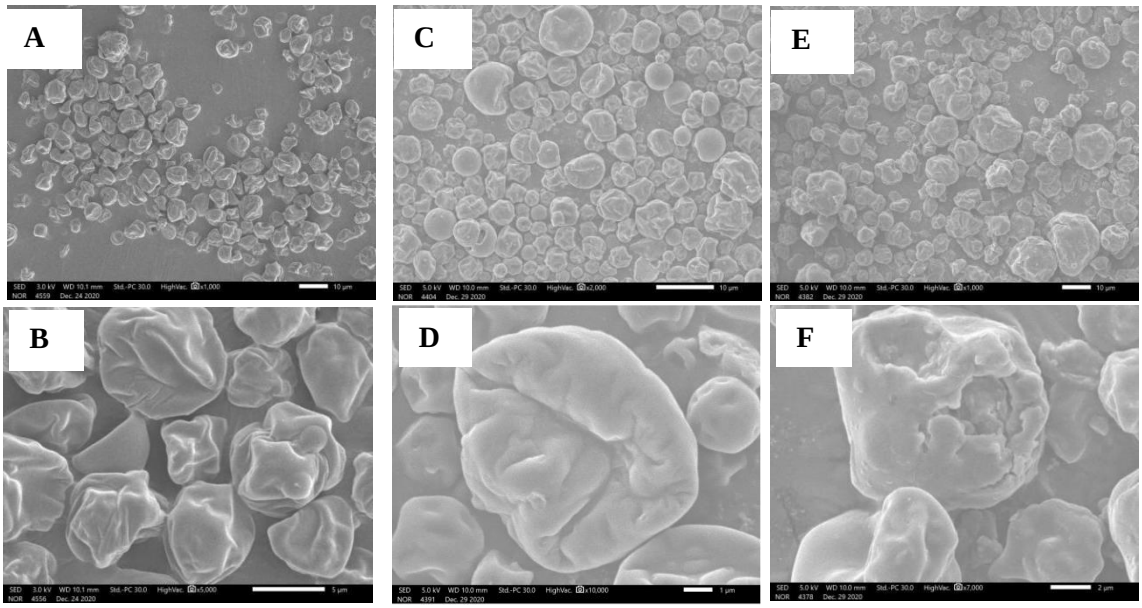

Figure 3. SEM microstructure of spray-dried encapsulated powders
(A, B: PS + MD; C, D: MD; E, F: Whey protein + PS)

The SEM results showed many different surfaces of PS-MD, MD and Whey-PS powders (Figure 3**)**. The surface of PS-MD powder was various in shapes (Figure 3A, B), while that of MD powder was spherical, and some particles were dented (Figure 3C, D), and Whey-PS was not intact and partly damaged. Especially, Whey-PS was also clumped, forming large blocks and non-discrete particles (Figure 3E, F). The shape of the particles depends not only on the micro-encapsulation material but also on the spray drying conditions and the homogenization process.

3.2. The effect of the ratios of core material and wall material

The ratio of core material and wall material has a significant effect on MEE and MEY. In this experiment, different proportions of core material to wall materials were investigated and presented in Table 1.

Table 1

The effect of ratios of core material and wall material

Ratio of core and wall material (w/w)	TPC	MEY (mg/g)	MEE (%)
1:1	114.627 ± 3.862^{a}	7.329 ± 0.516^{a}	50.995 ± 2.542^{a}
1:2	265.122 ± 5.439^{c}	27.824 ± 0.519^{c}	81.863 ± 0.464^{b}
1:3	284.132 ± 14.425^{d}	30.498 ± 1.663^{d}	85.967 ± 0.540^{c}
1:4	192.581 ± 3.679^{b}	17.913 ± 0.645^{b}	84.812 ± 1.451^{c}

The values in the same column followed by different superscripts (a-d) were significantly different ($P < 0.05$)
Source: Study results

TPC is determined based on the oxidation reaction of polyphenol compounds with Folin-Ciocalteu which is a blue complex whose absorption at 765nm. The color intensity of the reaction mixture is proportional to the polyphenol concentration (Ainsworth & Gillespie, 2007).

Experimental results show that at the ratio of 1:1, the TPC was found to be the lowest possible because this ratio is not enough to create protective films, which makes polyphenols destroyed by high drying temperature. At the ratios of 1:2 and 1:3, the total polyphenol content was almost the same and considered to be the highest. At the ratio of 1:4, the total polyphenol content decreased due to too many wall materials, which reduces the total polyphenol content in 01g of spray drying powder. When increasing the ratio from 1:1 to 1:4, the MEE increased significantly from 50.99% to 85.97%. The MEE was highest at the ratio of 1:3 and 1:4, approximately 85%. The MEY increased from 7.329 to 30.498mg/g when increasing the ratio from 1:1 to 1:3, but when it reached 1:4, the MEY decreased.

When applying the ratio of 1:1, the MEY was low because the wall material is not enough to cover polyphenols. Powders easily absorb water leading to high moisture content, which makes the product stick to the wall of the drying chamber, resulting in the low MEY. On the other hand, when the ratio reached 1:4, the MEY decreased owing to the large number of wall materials. In addition, the adding of MD not only increases the dry matter content for a favorable drying process but also increases the adhesion of the microcapsules and reduces the moisture content of the product for MD, which is considered good microencapsulating material as well. According to many studies, MD could alter the surface adhesion of low-molecular sugars such as glucose, sucrose, fructose, and organic acids; therefore, it was conditioned to a good drying process and reduce the moisture content of the product (Quek, Chok, & Swedlund, 2007). Thus, the ratios of core material and wall material at 1:3 should be carried.

3.3. The effect of the inlet temperatures

The inlet temperature affects the film formation, the moisture content, and the loss of bioactive compounds of the resultant powder to be encapsulated. According to Kha, Nguyen, and Roach (2010), a higher inlet temperature of spray drier resulted in rapid steam loss due to a higher heat transfer rate, causing water to evaporate faster. The rapid dehydration allows faster encapsulation film formation, which can increase the retention of the microencapsulated particles. However, too high a drying temperature can lead to the cracks of the coating, resulting in greater polyphenol loss. The reduced polyphenol content can be attributed to the effect of heat and oxidation. According to Quek et al. (2007), when spray-dried, powders produced at lower temperatures tended to agglutinate due to higher humidity. The agglutination process reduced the powder's contact with oxygen and protected the compound inside. In this study, the heat input was investigated at the range of 130 - 160ºC, and the content of TPC, the micro-encapsulation yield, and the micro-encapsulation efficiency are shown in Table 2.

Table 2

The effect of inlet temperatures on TPC, MEY, and MEE in spray-drying powder

Inlet temperature (ºC)	TPC	MEY (mg/g)	MEE (%)
130	264.198 ± 2.142^{c}	22.990 ± 0.396^{c}	82.942 ± 0.767^{bc}
140	284.792 ± 10.902^{d}	31.200 ± 0.605^{d}	85.496 ± 1.652^{c}
150	209.610 ± 7.413^{b}	21.552 ± 1.228^{b}	79.996 ± 2.892^{ab}
160	161.954 ± 2.809^{a}	16.849 ± 0.196^{a}	79.113 ± 0.449^{a}

The values in the same column followed by different superscripts (a-d) were significantly different ($P < 0.05$)
Source: Study results

The inlet drying air temperature has a great influence on the microencapsulated powder collection. The total polyphenol content did change significantly at the investigated range of temperatures. The MEE was 82.942%, and the MEY was 22.99mg/g at 130ºC. At 140ºC, the highest MEE and MEY were 85.496% and 31.200mg/g, respectively. After increasing the temperature to 150 and 160ºC, the microencapsulation efficiency decreased under 80% and the yield dropped sharply at 160ºC to about 17mg/g along with the deep decrease in total polyphenol content.

If the inlet temperature is low, the product's moisture will be high. The spray drying powder will stick to the drying chamber wall, causing irreversible loss and affecting the collection performance and the product quality during storage time. Inlet temperature also affects the ability to create microcapsules. If the temperature is low, the microcapsules will be thick, and the moisture content will be high. If it is high, the formed films will be thin, and the protective ability of the network will be poor. It can be concluded that inlet temperature is an important factor that could affect the MEY and MEE. For this study, the inlet temperature of 140ºC should be chosen for better retention of polyphenols in the microencapsulated powder.

3.4. The effect of the feed flow rates

The feed flow rate has an influence on the equipment yield, the outlet temperature, and the microcapsules' size (Devakate, Patil, Waje, & Thorat, 2009). When the feed flow rate is low, the formed particle sizes will be small, the surface temperature of the particles will increase, and the long contact time will make the core to be denatured. In fact, too high feed flow rate and high humidity also affect the quality of the microencapsulated product (Samborska, Rajchert, & Gonçalves, 2005). In this experiment, the most suitable feed flow rates (04, 05, 06, and 07mL/min) were tested, and the results are shown in Table 3.

Table 3

The effect of the feed flow rates on TPC, MEY, and MEE in spray-drying powder

Feed flow rate (mL/min)	TPC	MEY (mg/g)	MEE (%)
4	261.954 ± 12.249^{bc}	29.780 ± 1.799^{b}	81.333 ± 1.522^{b}
5	284.462 ± 2.320^{c}	31.118 ± 0.229^{b}	86.733 ± 0.366^{c}
6	221.954 ± 29.013^{a}	22.971 ± 3.764^{a}	78.818 ± 2.351^{ab}
7	244.858 ± 11.384^{ab}	24.829 ± 0.702^{a}	77.958 ± 1.920^{a}

The values in the same column followed by different superscripts (a-d) were significantly different ($P < 0.05$)
Source: Study results

When the feed flow rate reached 5mL/min, the MEE and MEY were the highest (86.733% and 31.118mg/g). The MEE was the lowest (77.958%), if the feed flow rate increased at 07mL/min. At 06 - 07mL/min, the spray-dried powder had higher moisture content and was easy to stick to the drying chamber's wall.

The low feed flow rate was used, the retention time of material in the drying chamber increased. Therefore, the drying efficiency will be reduced due to longer resident time in a drying chamber; as such, the quality of the product was negatively affected, and a large micro-encapsulated particle was obtained. When the feed flow rate increases, the drying time will decrease, the drying efficiency increases, and the microencapsulated powder also becomes smoother.

Thus, it can be concluded that the best conditions for microencapsulated polyphenols are as follows the inlet temperature of spray-drying at 140°C, the ratio of core material to wall material at 1:3 (w/w), and feed flow rate at 05mL/min. Under those conditions, the MEE and MEY were the highest to be 86.733% and 31.118mg/g, respectively. As such, they should be chosen for better retention of polyphenols in the microencapsulated powder.

4. Conclusion

The study selected PS-MD as the wall material to microencapsulate polyphenols from green tea for the better MEE and MEY than that of MD, PS-whey, and whey. The microencapsulation process was done with PS-MD, in which the best setting was as follows the ratio of polyphenols and wall material was 1:3, the spray drying temperature at 140^{o}C, and the feed flow rate at 05mL/min. This promises the product's potential for food applications. It is recommended that the addition of microencapsulated polyphenols to several food products for health benefits should be tested.

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