J Food Sci Technol (September 2021) 58(9):3379–3387
https://doi.org/10.1007/s13197-020-04910-8

ORIGINAL ARTICLE

Microencapsulation of betacyanin from red dragon fruit (*Hylocereus polyrhizus*) peels using pectin by simple coacervation to enhance stability

Edia Rahayuningsih[1] · Felix Arie Setiawan[2] · Ahmad Badawi Kasyfur Rahman[1] · Tomimoto Siahaan[1] · Himawan Tri Bayu Murti Petrus[1]

Revised: 6 November 2020 / Accepted: 13 November 2020 / Published online: 20 November 2020

Abstract Betacyanin is a red natural dye pigment widely used in food products. However, the pigment is also unstable and easily degraded by temperature during storage and food processing. This research aims to increase the stability of betacyanin obtained from dragon fruit peels using pectin as a wall medium via the coacervation method. Due to the efficiency and shell integrity, the coacervation method was selected instead of spray drying to enhance betacyanin's stability. Coacervation was conducted in a three-necked round-bottomed flask fitted with a mercury-sealed stirrer and reflux condenser. An accelerated stability test was conducted at 80 °C and 100 °C for 30 min and considered completed after obtaining a stable absorbance. Two full factorials, three-level design, for 80 °C and 100 °C, were analyzed by Response Surface Methodology using Minitab® 19. The core/wall ratio, agitation speed, and pH were the continuous variables, with temperature as the categorical variables. The models were yielded high R-square and low coefficient of variance on the validation process. Simple coacervation is selected because of a superior method such as simplicity, low-cost, high efficiency, and high shell integrity.

Keywords Betacyanin · Coacervation · Natural dye · Microencapsulation · Pectin

✉ Edia Rahayuningsih
edia_rahayu@ugm.ac.id

[1] Department of Chemical Engineering, Universitas Gadjah Mada, Jalan Grafika No. 2 Kampus UGM, Yogyakarta 55281, Indonesia

[2] Department of Chemical Engineering, Universitas Jember, Jalan Kalimantan No. 37 Kampus Tegalboto, East Java 68121, Indonesia

Introduction

As a natural dye, betacyanin can be derived from red dragon fruit (*Hylocereus polyrhizus*) peels. Dragon fruit peels as agro-industry waste are abundantly available in Indonesia, with around 150,000 tons/year of dragon fruit (Muas et al. 2019) and can support natural dye production requirements. Betalain consists of two components, namely, betacyanin and betaxanthin. Betacyanin is responsible for the reddish to the peels' violet color, while betaxanthin produces a yellow to orange color. However, compared with synthetic dyes, betacyanin is much easier to degrade by light exposure, temperature, pH, water activity, soluble metals, and enzymatic reactions. During food processing, heating causes betacyanin to break down into betalamic acid and cyclo-DOPA-5-O-β-glucoside (Gengatharan et al. 2015). Degradation is one of the key issues encountered in the use of food colorants. As natural dyes' potential and drawback, some innovation is necessary to minimize natural dyes' disadvantages as food colorants (Rahayuningsih et al. 2019).

Improving the stability of betacyanin could greatly expand its applications, although many schemes of degradation reactions exist, as seen in Fig. 1. The stability of betacyanin may be improved by adding a stabilizer. A stabilizer commonly used in the food industry and betacyanin extraction is ascorbic acid (Esquivel 2016). The addition of 0.01% (w/v) ascorbic acid increases betacyanin's stability and protects the pigment from degradation (Skopińska et al. 2015). However, Woo et al. (2011) revealed that ascorbic acid is only effective under dark storage conditions.

Other methods should be developed to optimize the utilization of betacyanin as a natural dye. The encapsulation method has recently gained increased interest on

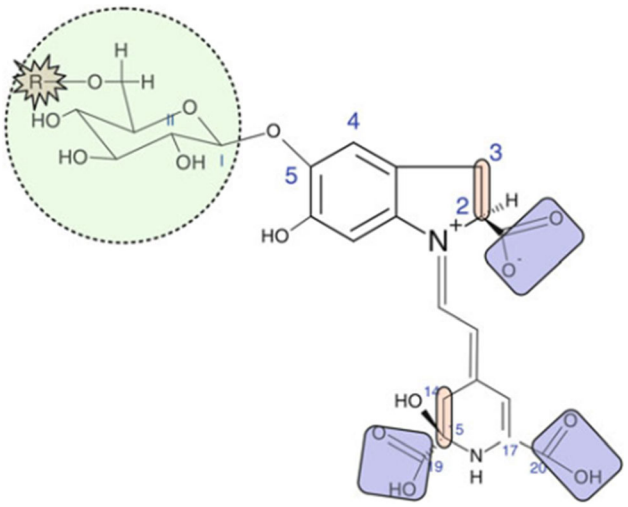

Fig. 1 Structure of betacyanin with easily degraded groups. Here green, blue, and roseate groups/bonds can be modified by deglycosylation, decarboxylation, and dehydrogenation, respectively (Stintzing and Carle 2007)

account of its ability to enhance betacyanin's stability. Several encapsulation methods, including emulsification, fluid bed coating, coacervation, extrusion, and coextrusion (Zuidam and Nedovic 2010; da Silva et al. 2016), have been proposed. Coacervation is a microencapsulation method in which the active compound is continuously coated by an encapsulation medium (Wong and Siow 2015). In recent work by Castro-Enríquez et al. (2019), the coacervation method has not been applied in increasing betacyanin stability; with spray drying, and freeze-drying dominated the findings. Although spray-drying technology is commonly applied to achieve microencapsulation because of its low cost, flexibility, good quality, and high yield (Ileana et al. 2019; Gómez et al. 2018), coacervation has some advantages such as more applicable, high encapsulation efficiency, and high shell integrity (Gaonkar et al. 2014).

This research aims to boost the stability of betacyanin from dragon fruit peels using pectin as a wall medium via the coacervation method. Pectin as the wall medium is proposed to achieve the microencapsulation of betacyanin by adsorbing the water formed during coacervation to form a gel. Pectin, guar gum, and locust bean gum are reported to be promising matrices that can enhance betacyanin's stability (Esquivel 2016). Accelerated conditions to test the stability of betacyanin after microencapsulation was also proposed in this study (Aguilar-Tuesta et al. 2018; Gómez et al. 2018; Ileana et al. 2019; Otálora et al. 2015; Vergara et al. 2014).

Materials and Method

Materials

The material used in this study was the dragon fruit peels. Dragon fruits were purchased from a market in Yogyakarta City, Indonesia. The flesh and peels were separated using a knife. The acetic acid (glacial) and reagent grade methanol were purchased from Merck. Pectin (food grade) with a high methoxyl content was purchased from a grocery store in Yogyakarta, Indonesia.

Preparation of dragon fruit peel

Dragon fruit peels were washed with water at room temperature to remove adherent dirt. The peels were cut into small pieces using a knife, dried in an oven at 70 °C until the moisture was reduced by 30%. The drying process was occurred for around 2 h. The dried peels were blended into 0.50 mm accordingly.

Control solution preparation

The treated dragon fruit peel was weighed out into samples of 1.5, 2.0, and 2.25 g and mixed with 300, 400, and 450 mL of distilled water, respectively. Separately, each mixture was blended for 10 min with the blender rotation indicator on a scale of 3. The mixture was then filtered with filter paper. The resulting filtrate is a solution of betacyanin dye. The mixture has measured the pH using a pH meter, and the absorbance using Vernier—SpectroVis plus SVIS-PL spectrophotometer at 540.2 nm assisted with the Logger Lite program. These three solutions are then used as control solutions. The control sample was used to compare with or without a simple coacervation method on the accelerated test as a preliminary study.

Sample solution preparation

Betacyanin dye solution was prepared in the same way as the control solution. The variation of the core/wall ratio was determined to be 1:1; 2:1 and 3:1, made by mixing pectin as much as 1.5 g, 1.0 g, and 0.75 g, respectively dissolved into 300 mL, 200 mL, and 150 mL of distilled water in a three-neck flask equipped with a stirrer. To this pectin solution, each of the previously prepared betacyanin solutions was added (1.5 g, 2.0 g, and 2.25 g dragon fruit peel powder in 300 mL, 400 mL, and 450 mL aquadest). Thus, the core/wall ratio variation was 1:1; 2:1 and 3:1 can be obtained. The stirrer rotation speed was varied by 400 rpm, 600 rpm, and 800 rpm in the same methods. Moreover, the betacyanin solution was also added by

prepared acetic acid solution (5 mL 96% acetic acid plus 40 mL distilled water) to get a variation of pH 4, pH 5, pH 6.

Encapsulation efficiency

The encapsulation efficiency test was conducted by the dissolution method because betacyanin is soluble in methanol. Betacyanin solution was dissolved in methanol with a 1:1 ratio for 10 min. The solution was centrifuged to separate insoluble pectin. The solution, then, was analyzed using a Vernier—SpectroVis plus SVIS-PL spectrophotometer at 540.2 nm assisted with the Logger Lite program. The encapsulation efficiency was calculated using the following equation:

$$\%EE = \frac{A_{final}}{A_{initial}} \times 100\% \quad (1)$$

where $\%EE$ is encapsulation efficiency, A_{final} is the absorbance of the sample after dissolution, and $A_{initial}$ is the initial absorbance of the sample.

Preliminary study of accelerated stability

Prior to the main research, screening research was conducted to determine the betacyanin solution's behavior on heating time. The control and sample solutions were treated at 70 °C to determine the effective time of the accelerated stability. The sample solutions used in the preliminary study was varied at 400, 600, and 800 rpm with a 1:1 core/wall ratio and neutral pH. The samples' absorbance value was analyzed using a Vernier—SpectroVis plus SVIS-PL spectrophotometer at 540.2 nm assisted with the Logger Lite program every 5 min for 60 min. The effective time was obtained by stable absorbance value within time. The effective time would be used as the duration of stability test on a simple coacervation method. Moreover, the effectiveness of simple coacervation was observed accordingly to compare control and sample solutions.

Acceleration of betacyanin stability

The sample solutions were treated at 80 °C and 100 °C to accelerate betacyanin degradation. The samples' absorbance was measured at the initial condition and final condition at an effective time from the preliminary study. The analysis was conducted by a Vernier—SpectroVis plus SVIS-PL spectrophotometer at 540.2 nm, assisted with the Logger Lite program. The retention percentage was calculated using the following equation:

$$\%retention = \frac{A_t}{A_0} \times 100\% \quad (2)$$

where % retention is the ability to deal with temperature in betacyanin stability, A_t is the absorbance of the sample at the effective time, and A_0 is the initial absorbance of the sample. This formula, which relates the absorbance to the concentration of betacyanin in solution, was described by Cai and Corke (1999).

$$BC = \frac{A \times DF \times MW \times 1000}{\varepsilon \times L} \quad (3)$$

where BC is the amount of betacyanin equivalents in mg/L, A is the absorption at 540.2 nm, DF is the dilution factor, MW is the molecular weight of betacyanin (550 g/mol), ε is the molar extinction coefficient (60,000 $Lmol^{-1}$ cm^{-1}), and L is the length of the cuvette (1.0 cm).

Data analysis

In this work, the independent variables were core/wall ratio (1:1, 2:1, and 3:1), agitation speed (400, 600, and 800 rpm), and pH (4, 5, and 6). The dependent variable was betacyanin retention of the sample solution. Meanwhile, the temperature, 80 °C and 100 °C, became the categorical variable in this study. All samples were conducted three times to ensure data repeatability. All variables, three continuous and two categorical variables, were analyzed using Minitab® 19 optimization software via the response surface methodology (RSM). Thus, a three-level full factorial design was used to analyze the correlation of variables for each categorical variable. RSM provides a means to explain the effect of each parameter studied on the retention percentage. Indeed, this method has been used in many previous research studies (Rahayuningsih et al. 2018, 2019, 2020). The validation was also conducted using specified independent variables to generate the response at 80 °C and 100 °C. The retention value was compared with the model, and the Coefficient of Variance (CV) was calculated accordingly. The morphology analysis was also conducted to strengthen the coacervation process using Transmission Electron Microscopy (TEM).

Results and discussion

In preliminary research, the results demonstrated that the solutions' absorbance shows a relatively constant value after 30 min. Moreover, the trend is typical at various agitation speeds, while the microencapsulation process yielded good results compared with the control. The control had a 23% retention value, while the sample had a

66 ± 5% retention value. The retention percentage was calculated using Eq. (2).

The color degradation could be analyzed by colorimeter and UV–Visible spectrophotometry. In general, a colorimeter can be used to describe the color degradation, but the calculation should be conducted further with a specified formula. In addition, UV–Visible spectrophotometry offers more advantages such as higher sensitivity, flexibility, and versatility compared with colorimeters (Lee et al. 2020). Thus the color difference could be calculated easily and precisely, and the retention value would represent the phenomena. To give a perspective of color degradation, Fig. 2 represents the color difference of the study. The encapsulation process was evaluated by encapsulation efficiency using the dissolution method. The encapsulation efficiency showed a significant result as much as 93.2 ± 3.1%. The absorbance value of the encapsulation efficiency is presented in Table 1. The simple coacervation process was also confirmed by morphology analysis, as seen in Fig. 3. The morphology image showed that the betacyanin size was increased with a simple coacervation process, from Fig. 3a to Fig. 3b. In other words, pectin as the wall media has successfully encapsulated betacyanin. Pectin has a large molecule, which eventually enlarges the betacyanin particle size.

Prior to RSM, a residual analysis was carried out to check the data distributions. The residual data versus percentage are close to the reference line. These results

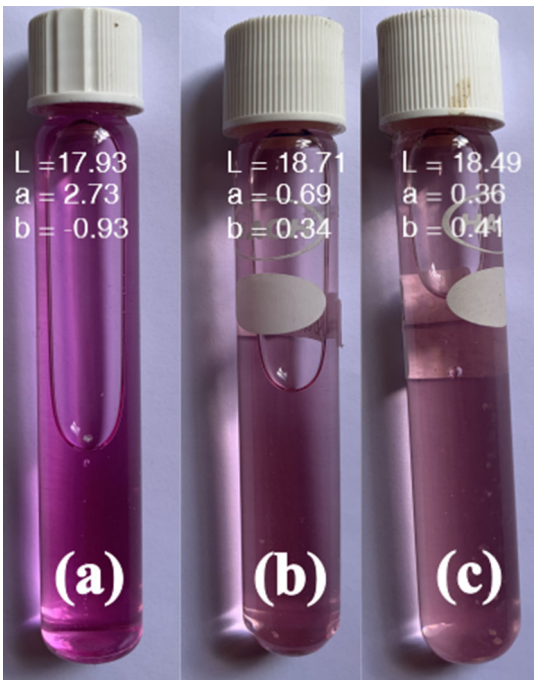

Fig. 2 Visual perception of the samples at **a** initial condition, **b** 30 min at 80 °C, and **c** 30 min at 100 °C with Hunter lab colorimeter result

Table 1 Encapsulation efficiency test result

No	Sample	Absorbance	%EE
1	EE1	0.0766	87.8
2	EE2	0.0793	90.9
3	EE3	0.0791	90.7
4	EE4	0.0811	93.0
5	EE5	0.0827	94.8
6	EE6	0.0840	96.3
7	EE7	0.0825	94.6
8	EE8	0.0852	97.7
9	EE9	0.0807	92.6
10	Initial condition	0.0872	

confirmed that the data obtained in this research could be used to determine correlations among the independent and dependent variables. The data were analyzed using RSM for both temperatures, which are shown in Table 2. The *F*-value and *P*-value describe the fitness and significance of the RSM models. The F-values should be greater than the *F*-statistic values, 25.025 and 28.771 for experiments conducted at 80 °C and 100 °C, respectively. A comparison of *F*-values indicated that the model fit the data well. Moreover, the *P*-value of the models obtained at 80 °C and 100 °C revealed statistical significance. R^2 results also gave high values of 95.74% and 96.72% for both models.

All of the parameters examined revealed good results; thus, the models could be used to analyze the relationships between the independent and dependent variables. The models obtained for the data collected at 80 °C and 100 °C are presented below:

$$\begin{aligned} \%Retention = & -76.6 - 16.19X_1 + 0.1803X_2 \\ & + 40.4X_3 + 2.60X_1^2 - 0.000112X_2^2 \\ & - 2.99X_3^2 - 0.00129X_1X_2 \\ & - 2.36X_1X_3 - 0.00549X_2X_3 \end{aligned} \quad (4)$$

$$\begin{aligned} \%Retention = & -10.4 - 15.05X_1 + 0.0229X_2 \\ & + 32.7X_3 + 1.07X_1^2 - 0.000021X_2^2 \\ & - 2.66X_3^2 + 0.00307X_1X_2 \\ & - 1.78X_1X_3 + 0.00101X_2X_3 \end{aligned} \quad (5)$$

where X_1 is the core/wall ratio (i.e., 1, 2, and 3), X_2 is the agitation speed (i.e., 400, 600, and 800 rpm), and X_3 is the pH (i.e., 4, 5, and 6). Linear plots of the retention models versus the experimental retentions obtained are provided in Fig. 4. Overall, the models showed high R^2 values (> 0.95) and good value of slopes (≈ 1).

Furthermore, the validation had been conducted accordingly with fixed X_1, X_2, and X_3. The resulted percent

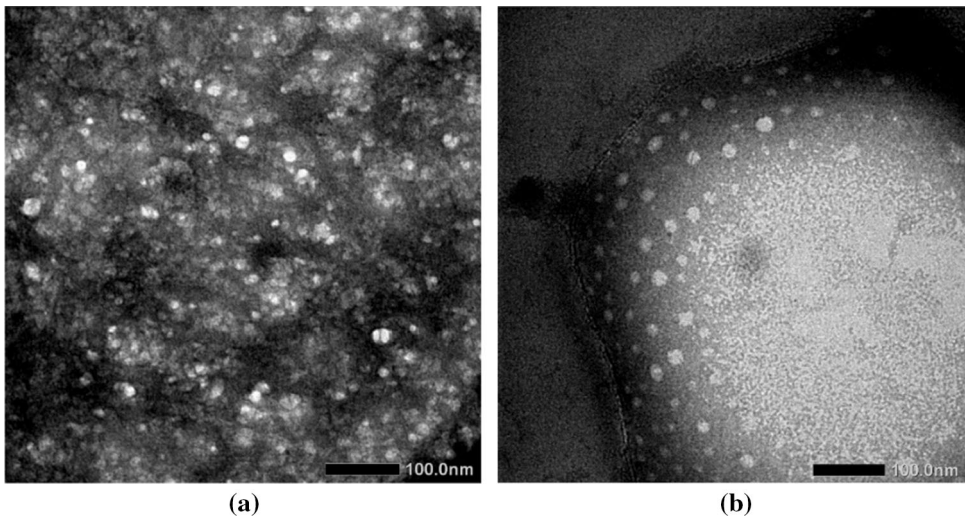

Fig. 3 TEM analysis result of betacyanin **a** before simple coacervation process and **b** after simple coacervation process

Table 2 Analysis of variance results

Source	80 °C		100 °C	
	F-value	*P* value	*F*-value	*P* value
Model	42.490	0.000	55.730	0.000
Linear	121.810	0.000	164.510	0.000
X_1	348.030	0.000	473.980	0.000
X_2	10.750	0.004	5.120	0.037
X_3	6.650	0.020	14.430	0.001
Square	4.100	0.023	1.480	0.256
X_1^2	2.330	0.145	0.570	0.459
X_2^2	6.900	0.018	0.340	0.568
X_3^2	3.080	0.097	3.520	0.078
2-Way Interaction	1.570	0.233	1.190	0.343
$X_1 \times X_2$	0.050	0.833	0.370	0.549
$X_1 \times X_3$	3.830	0.067	3.160	0.093
$X_2 \times X_3$	0.830	0.374	0.040	0.843
R^2	95.74%	96.72%		

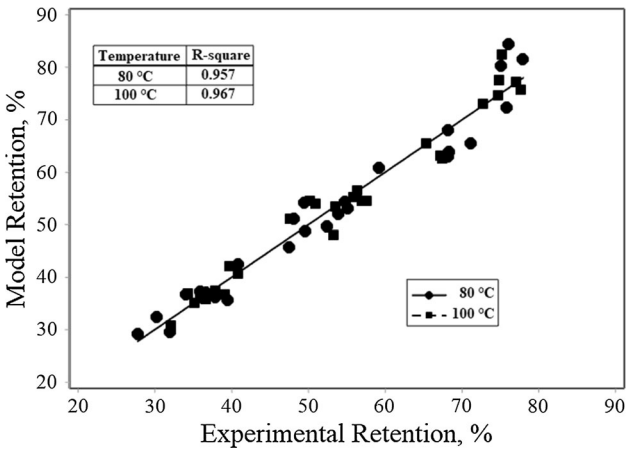

Fig. 4 Linear plot of experimental retentions versus the retention models

retention was compared with the model. The result showed that each model's Coefficient of Variance (CV) generates satisfied results with 0.7% and 1.6% for 80 °C and 100 °C, respectively. Thus, the models represent the phenomenon, correctly, of the simple coacervation method of betacyanin from the red dragon (*Hylocereus polyrhizus*) peels using pectin.

The effects of each parameter on the response variable were evaluated in turn, and the resulting surface plots are presented in Fig. 5. In general, the most significant effects for both temperature conditions were obtained by varying the core/wall ratio, followed by pH and agitation speed. The results revealed that higher core/wall ratios yield smaller retention percentages. The minimum and maximum retention percentages were approximately 40% and 75%, respectively, at 80 °C and 100 °C. These findings are in line with the hypothesis; the higher core/wall ratio gives lower retention because higher core/wall ratios provide smaller amounts of coacervation medium in the solution to maintain betacyanin stability. Dong et al. (2007) stated that increasing the core/wall ratio would increase particles' size and cause them to develop irregular forms. The stability of a particle is difficult to maintain when it is large and irregular in form. Thus, a low core/wall ratio provides a large amount of the wall medium to the solution and, in turn, a larger surface area for encapsulation. Consequently, cores with small particles have a larger surface area. The effects of the core/wall ratio on the encapsulation process show similar tendencies at 80 °C and 100 °C.

Agitation speed and pH did not have a significant effect on the retention percentage. Variations in agitation speed and pH resulted in only a 5% (from 50 to 55%) change in retention percentage. The pH curves in Fig. 4a and Fig. 4b

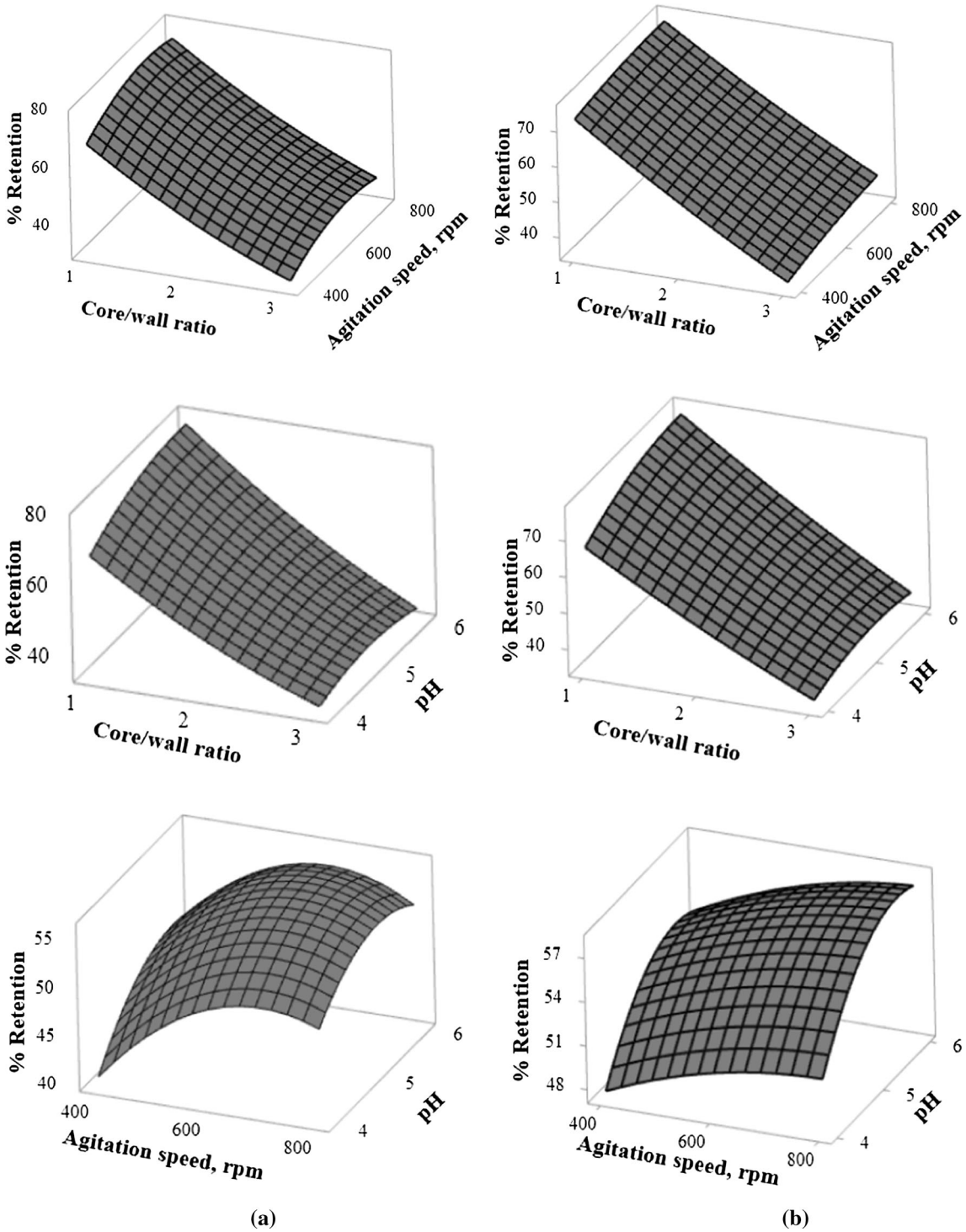

Fig. 5 Surface plot of the dependent variables at **a** 80 °C and **b** 100 °C

revealed the same tendency reported in previous works (Herbach et al. 2006). Betacyanin is mainly applied to food with low acidity (e.g., pH 3–7) on account of its weak stability (Herbach et al. 2006). While previous research reported different pH ranges of betacyanin stability, the range cited most often is between 4 and 7.

Comparison of Fig. 5a (curved plot) and Fig. 5b (plain plot) indicated that temperature increases would gradually affect the agitation speed. In general, the higher the operating temperature, the lower the solution's viscosity, and the smaller and more stable the resulting particle sizes (Lokhande et al. 2013). Moreover, variations in agitation

speed affect particle collision probability, and higher agitation speeds are observed at higher temperatures.

After evaluating the effect of the independent variables in the dependent variable, optimization was conducted to obtain the best values for each variable. Here, maximum retention is the target of the optimization process. The optimum parameters for both temperature conditions are presented in Fig. 6. Moreover, Fig. 6a reveals that the optimum core/wall ratio, agitation speed, and pH at 80 °C were 1:1, 660 rpm, and 5.76, respectively. By comparison, Fig. 5b illustrates that the optimum core/wall ratio, agitation speed, and pH at 100 °C were 1:1, 770 rpm, and 5.96, respectively. Encapsulation under the optimum conditions at 80 °C and 100 °C resulted in response values of as high as 78.47% and 77.68%, respectively. Thus, encapsulation at 80 °C is more effective than encapsulation at 100 °C. Nemzer et al. (2011) and Wybraniec (2005) reported that high temperatures could produce new compounds from betacyanin that may cause bathochromic and hypochromic shifts. The changes cause a bathochromic shift and hypochromic shift, which are the shifts of an absorbance peak.

As mentioned briefly, the application of the coacervation method for microencapsulation of betacyanin has not been developed. Thus, many researchers mostly applied spray dryer (Aguilar-Tuesta et al. 2018; Antigo et al. 2018; do Carmo et al. 2018; García-Lucas et al. 2017; Kumar and Giridhar 2016; Shaaruddin et al. 2017; Vargas-Campos et al. 2018) and freeze dryer (Antigo et al. 2018; Mohamed et al. 2018; Rodriguez et al. 2016; Tumbas Šaponjac et al. 2016) with different variables of their works. In general, spray and freeze dryer applied physical phenomena (temperature) to conduct microencapsulation, but coacervation preserves the chemical process to enhance the protection. The coacervation method's main advantages are a simple method and low-cost method due to the energy and solvent used. Hence, microencapsulation can still be applied in the industrial sector for up-scaling processes. Moreover, the coacervation method can be kept in ready used phase, a liquid form, rather than the solid phase.

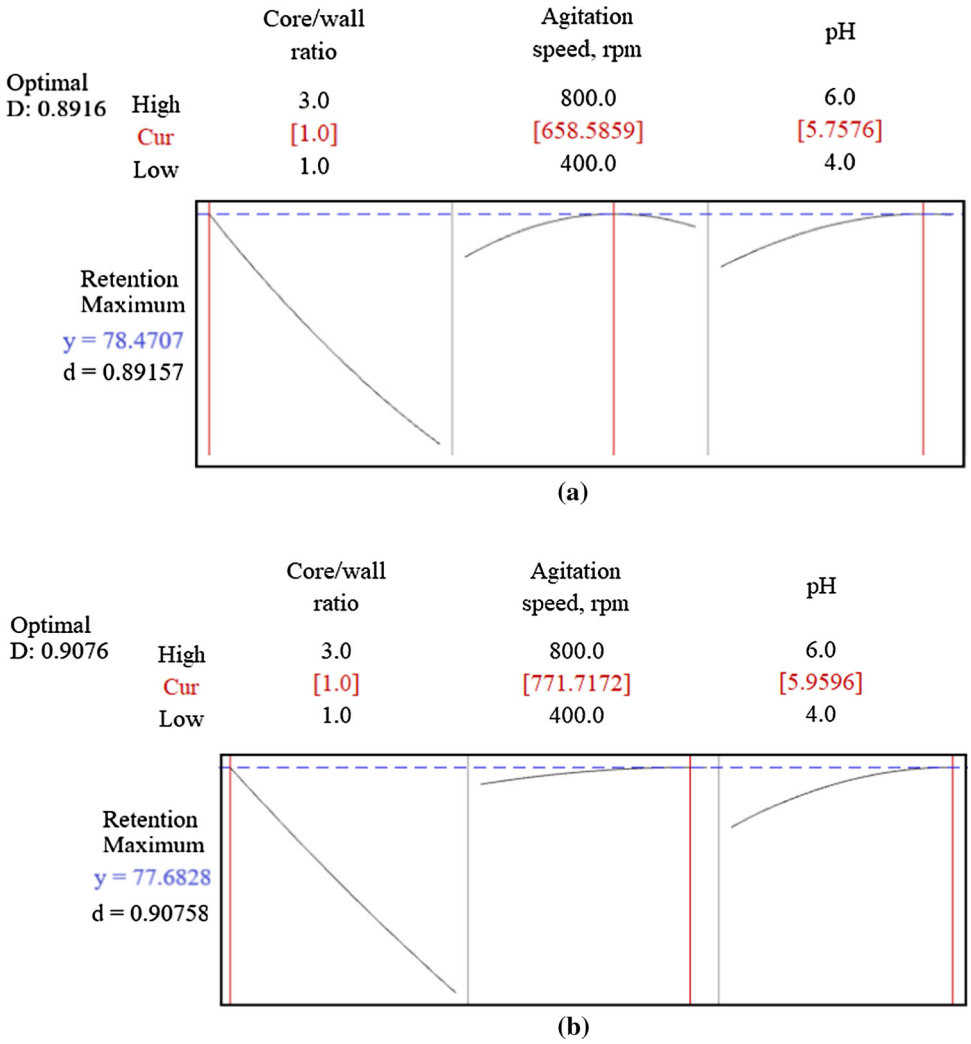

Fig. 6 Optimal values of the dependent variables at **a** 80 °C and **b** 100 °C

Conclusion

In summary, the coacervation method of betacyanin microencapsulation was successfully conducted to improve the stability of red dragon fruit peels using pectin (*Hylocereus polyrhizus*). The result showed that a simple coacervation method enhances the betacyanin stability around 78% for 80 °C and 100 °C. The models generated by Response Surface Methodology (RSM) represent the coacervation phenomena due to the high R-square value of the models and low Coefficient of Variance (CV) value of the validation process. The simple coacervation process, in this study, offered 93.2 ± 3.1% encapsulation efficiency. Simple coacervation is a superior method because of simplicity, low-cost, high efficiency, and high shell integrity.

Acknowledgements This paper was supported by the Chemical Engineering Department, Engineering Faculty, Gadjah Mada University.

References

Aguilar-Tuesta S, Mamani-Navarro W, Espinoza-Silva C, Basilio-Atencio J, Condezo-Hoyos L (2018) Microencapsulated betacyanin from colored organic quinoa (*Chenopodium quinoa Willd.*): optimization, physicochemical characterization and accelerated storage stability. J Sci Food Agric 98:5873–5883. https://doi.org/10.1002/jsfa.9152

Antigo JLD, Bergamasco R, d. C. & Madrona, G. S. (2018) Effect of pH on the stability of red beet extract (*Beta vulgaris* L.) microcapsules produced by spray drying or freeze drying. Food Sci Technol 38:72–77. https://doi.org/10.1590/1678-457x.34316

Cai Y, Corke H (1999) *Amaranthus* betacyanin pigments applied in model food systems. J Food Sci 64:869–873. https://doi.org/10.1111/j.1365-2621.1999.tb15930.x

Castro-Enríquez D, Montaño-Leyva B, Del Toro-Sánchez C, Juaréz-Onofre J, Carvajal-Millan E, Burruel-Ibarra S, Tapia-Hernández J, Barreras-Urbina C, Rodríguez-Félix F (2019) Stabilization of betalains by encapsulation—a review. J Food Sci Technol. https://doi.org/10.1007/s13197-019-04120-x

da Silva BV, Barreira JC, Oliveira MBP (2016) Natural phytochemicals and probiotics as bioactive ingredients for functional foods: extraction, biochemistry and protected-delivery technologies. Trends Food Sci Technol 50:144–158. https://doi.org/10.1016/j.tifs.2015.12.007

do Carmo EL, Teodoro RAR, Félix PHC, de Fernandes RVB, de Oliveira ÉR, Veiga TRLA, Borges SV, Botrel DA (2018) Stability of spray-dried beetroot extract using oligosaccharides and whey proteins. Food Chem 249:51–59. https://doi.org/10.1016/j.foodchem.2017.12.076

Dong Z, Toure A, Jia C, Zhang X, Xu S (2007) Effect of processing parameters on the formation of spherical multinuclear microcapsules encapsulating peppermint oil by coacervation. J Microencapsul 24:634–646. https://doi.org/10.1080/02652040701500632

Esquivel P (2016) Betalains. Handbook on Natural Pigments in Food and Beverages. Elsevier, Amsterdam, pp 81–99

Gaonkar AG, Vasisht N, Khare AR, Sobel R (2014) Microencapsulation in the food industry: a practical implementation guide. Elsevier, Amsterdam

García-Lucas KA, Méndez-Lagunas LL, Rodríguez-Ramírez J, Campanella OH, Patel BK, Barriada-Bernal LG (2017) Physical properties of spray dryed *Stenocereus griseus* pitaya juice powder. J Food Process Eng 40:e12470. https://doi.org/10.1111/jfpe.12470

Gengatharan A, Dykes GA, Choo WS (2015) Betalains: natural plant pigments with potential application in functional foods. LWT Food Sci Technol 64:645–649. https://doi.org/10.1016/j.lwt.2015.06.052

Gómez B, Barba FJ, Domínguez R, Putnik P, Kovačević DB, Pateiro M, Toldrá F, Lorenzo JM (2018) Microencapsulation of antioxidant compounds through innovative technologies and its specific application in meat processing. Trends Food Sci Technol 82:135–147. https://doi.org/10.1016/j.tifs.2018.10.006

Herbach KM, Rohe M, Stintzing FC, Carle R (2006) Structural and chromatic stability of purple pitaya (*Hylocereus polyrhizus* [Weber] Britton and Rose) betacyanins as affected by the juice matrix and selected additives. Food Res Int 39:667–677. https://doi.org/10.1016/j.foodres.2006.01.004

Ileana TMK, Guadalupe GVT, Francisco TV, Ismael ORG (2019) Spray drying microencapsulation of purple cactus pear (*Opuntia ficus indica*) peel extract and storage stability of bioactive compounds. Emir J Food Agric. https://doi.org/10.9755/ejfa.2019.v31.i12.2046

Kumar SS, Giridhar P (2016) Stabilization of bioactive betalain pigment from fruits of *Basella rubra* L. through maltodextrin encapsulation. Madridge J Food Tech 1:66–70. https://doi.org/10.18689/mjft-1000111

Lee CC, Tomas M, Jafari SM (2020) Chapter fourteen—optical analysis of nanoencapsulated food ingredients by color measurement. In: Jafari SM (ed) Characterization of nanoencapsulated food ingredients. Academic Press, Cambridge, pp 505–528

Lokhande AB, Mishra S, Kulkarni RD, Naik JB (2013) Influence of different viscosity grade ethylcellulose polymers on encapsulation and in vitro release study of drug loaded nanoparticles. J Pharm Res 7:414–420. https://doi.org/10.1016/j.jopr.2013.04.050

Mohamed EE, Iwamoto S, Yamauchi R (2018) Optimization of betalain extraction from *Salicornia fruticosa* and its encapsulation. J Agroaliment Process Technol 24:1–8

Muas I, Mansyah E, Yuliati S (2019) Dragon fruit production and marketing in Indonesia: standard quality in the global and regional levels. FFTC Agric Policy Platf. https://ap.fftc.org.tw/article/1601

Nemzer B, Pietrzkowski Z, Spórna A, Stalica P, Thresher W, Michałowski T, Wybraniec S (2011) Betalainic and nutritional profiles of pigment-enriched red beet root (*Beta vulgaris L.*) dried extracts. Food Chem 127:42–53. https://doi.org/10.1016/j.foodchem.2010.12.081

Otálora MC, Carriazo JG, Iturriaga L, Nazareno MA, Osorio C (2015) Microencapsulation of betalains obtained from cactus fruit (*Opuntia ficus-indica*) by spray drying using cactus cladode mucilage and maltodextrin as encapsulating agents. Food Chem 187:174–181. https://doi.org/10.1016/j.foodchem.2015.04.090

Rahayuningsih E, Pamungkas MS, Olvianas M, Putera ADP (2018) Chlorophyll extraction from suji leaf (*Pleomele angustifolia Roxb.*) with $ZnCl_2$ stabilizer. J Food Sci Technol 55:1028–1036. https://doi.org/10.1007/s13197-017-3016-7

Rahayuningsih E, Subagya IS, Setiawan FA, Petrus HTBM (2019) Fresh Neem Leaves (*Azadirachta indica A. Juss*) extraction and application: an optimization using response surface methodology. Asian J Chem 31:2567–2574. https://doi.org/10.14233/ajchem.2019.22207

Rahayuningsih E, Setiawan FA, Ayanie CJ, Antoko AA, Ayuningtyas YI, Petrus HB (2020) Optimization model on the effect of clove oil, formaldehyde, and chitosan added to batik fabric colored

with gambier (*Uncaria gambir Roxb*): antifungal properties and stability. Indones J Chem 20:210–222. https://doi.org/10.22146/ijc.46038

Rodriguez EB, Vidallon MLP, Mendoza DJR, Reyes CT (2016) Health-promoting bioactivities of betalains from red dragon fruit (*Hylocereus polyrhizus* (Weber) Britton and Rose) peels as affected by carbohydrate encapsulation. J Sci Food Agric 96:4679–4689. https://doi.org/10.1002/jsfa.7681

Shaaruddin S, Ghazali HM, Mirhosseini SH, Muhammad K (2017) Stability of betanin in pitaya powder and confection as affected by resistant maltodextrin. LWT 84:129–134. https://doi.org/10.1016/j.lwt.2017.05.031

Skopińska A, Szot D, Starzak K, Mizrahi Y, Wybraniec S (2015) The effect of ascorbic acid supplementation on betacyanin stability in purple pitaya (*Hylocereus polyrhizus*) juice. Chall Mod Technol 6:14–18

Stintzing FC, Carle R (2007) Betalains–emerging prospects for food scientists. Trends Food Sci Technol 18:514–525. https://doi.org/10.1016/j.tifs.2007.04.012

Šaponjac VT, Čanadanović-Brunet J, Ćetković G, Jakišić M, Djilas S, Vulić J, Stajčić S (2016) Encapsulation of beetroot pomace extract: RSM optimization, storage and gastrointestinal stability. Molecules 21:584. https://doi.org/10.3390/molecules21050584

Vargas-Campos L, Valle-Guadarrama S, Martínez-Bustos F, Salinas-Moreno Y, Lobato-Calleros C, Calvo-López AD (2018) Encapsulation and pigmenting potential of betalains of pitaya (*Stenocereus pruinosus*) fruit. J Food Sci Technol 55:2436–2445. https://doi.org/10.1007/s13197-018-3161-7

Vergara C, Saavedra J, Sáenz C, García P, Robert P (2014) Microencapsulation of pulp and ultrafiltered cactus pear (*Opuntia ficus-indica*) extracts and betanin stability during storage. Food Chem 157:246–251. https://doi.org/10.1016/j.foodchem.2014.02.037

Wong Y-M, Siow L-F (2015) Effects of heat, pH, antioxidant, agitation and light on betacyanin stability using red-fleshed dragon fruit (*Hylocereus polyrhizus*) juice and concentrate as models. J Food Sci Technol 52:3086–3092. https://doi.org/10.1007/s13197-014-1362-2

Woo KK, Ngou FH, Ngo LS, Soong WK, Tang PY (2011) Stability of betalain pigment from red dragon fruit (*Hylocereus polyrhizus*). Am J Food Technol 6:140–148. https://doi.org/10.3923/ajft.2011.140.148

Wybraniec S (2005) Formation of decarboxylated betacyanins in heated purified betacyanin fractions from red beet root (*Beta vulgaris L.*) monitored by LC−MS/MS. J Agric Food Chem 53:3483–3487. https://doi.org/10.1021/jf048088d

Zuidam NJ, Nedovic V (2010) Encapsulation technologies for active food ingredients and food processing. Springer, Dordrecht