Mathematical models of pretreatment processes to utilize purple-fleshed potato (*Solanum tuberosum* L.) peels for anthocyanin extraction

Hwabin Jung, Cheol-ho Pan¹, and Won Byong Yoon*

Department of Food Science and Biotechnology, College of Agricultural and Life Science, Kangwon National University, Chuncheon, Gangwon 24341, Korea

¹Functional Food Center, Korean Institute of Science and Technology (KIST), Gangneung, Gangwon 25451, Korea

Received March 14, 2016
Revised June 22, 2016
Accepted June 27, 2016
Published online October 31, 2016

*Corresponding Author
Tel: +82-33-250-6459
Fax: +82-33-241-0508
E-mail: wbyoon@kangwon.ac.kr

pISSN 1226-7708
eISSN 2092-6456

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Abstract The effect of particle size on the extraction rate of anthocyanin from *Solanum tuberosum* L. (purple-fleshed potato) peels (PFPPs) using the stagnant single-stage batch extraction system was investigated. Core pretreatment processes such as drying and grinding were quantitatively evaluated using mathematical models. The drying behavior of PFPP was successfully described using thin layer models (Page model and Midilli-Kucuk model). The effective diffusion coefficient of drying temperature at 40°C was determined to be $1.67 \times 10^{-12} \text{ m}^2/\text{s}$. The grinding time to obtain particles of a specific size was accurately estimated using the grinding kinetic model ($R^2=0.97$). The extraction rate of anthocyanin increased as the particle size decreased; however, when the particle size was 0.15 mm, the anthocyanin content decreased. Our study demonstrated that the grinding kinetic model is useful to estimate the grinding time to produce an optimum particle size for anthocyanin extraction from PFPP.

Keywords: anthocyanin, colored potatoes, drying, grinding, peel

Introduction

Potato is an important source of carbohydrates, protein, vitamins, and minerals (1). In addition, colored potato varieties include considerable amounts of phytonutrients such as polyphenols. Recently, the colorants and antioxidants isolated from purple- and red-fleshed potatoes have been applied in food and nutraceutical industries (2), with the research and commercialization of colored potatoes being very active. Most of the commercial products of colored potatoes require only the fleshy parts of the potato. The potato peels are currently underutilized and wasted.

Anthocyanins, i.e., a group of natural phenolic compounds, are major components for the attractive colors of many flowers, fruits, vegetables, and products (3). Purple-fleshed potato (PFP) contains petunidin, peonidin, delphinidin, and malvidin (4). Antioxidant levels in colored potatoes are more twice two times higher than the antioxidant levels in regular white-fleshed potatoes.

Powdering or flouring is an important process in the commercialization of natural resources as food ingredients. In particular, the “powdering after drying” is an inevitable process for the utilization of by-products or wastages because the raw material itself is not suitable to be processed. In addition, the powdered form of

ingredients has many benefits in food processing. Recently, the food industry widely uses dehydrated potato powder because of its convenience. Mixing processes in noodles, ready-to-cook mashed potatoes, and bakeries prefer to use powder forms of ingredients because of the convenience and the efficiency of handling and mixing. In addition, powders require less cooking and extraction times than raw materials.

The drying process, including a coupled heat and mass transfer, has to be applied before the grinding process because the grinding characteristics are highly dependent on the moisture content. Food industries commonly use conventional hot air drying for the dehydration of natural ingredients. The drying time and the degree of drying must be estimated quantitatively to control the moisture content of the sample before grinding. Thin layer models are well known to describe the drying kinetics of natural resources.

Grinding is a major unit operation for the size reduction process (5). The key variables for designing a grinder or a pulverizer are the time and the amount of energy consumed in obtaining suitably sized particles after grinding. Conventionally, empirical methods for measuring energy are used in industries (5-9). Semi-empirical or analytical approaches have recently been introduced in food grinding systems (1).

The physicochemical properties of powder are highly dependent on the particle size because the surface area per unit volume of particle increases as the particle size reduces. Particle size is an important factor in biochemical reactions. In general, when powder forms of ingredients are used in biochemical reactions, the even particle size distribution (i.e., homogeneity) and smaller size of particles can accelerate the biochemical reactions. However, a critical particle size at which the reaction rate could not increase was recently reported (10). The extraction rate of anthocyanins from the powder form of purple-fleshed potato peels (PFPPs) might be improved by regulating the size of particles during the grinding process, which is a pretreatment process applied prior to extracting the anthocyanins from PFPPs.

Several studies on utilizing colored potatoes are available (4,11,12); however, there are no studies on the properties of colored potato peels. In particular, the pretreatment processes such as drying and grinding of the potato peels that are generally conducted before the extraction have never been investigated. The objectives of this study were to evaluate the drying characteristics such as the effective diffusion coefficient of PFPPs at a low drying temperature, estimate the grinding kinetics of PFPPs, and investigate the effect of particle size on the extraction rate of anthocyanin in PFPPs using a stagnant single-stage extraction system.

Materials and Methods

Sample preparation Purple-fleshed potato (PFP) was provided by the Korean Institute of Science and Technology (KIST), Gangneung, Gangwon, Korea. The PFPs were carefully stored in a storage room maintained at 4°C and 80% relative humidity. Samples were used for one month. The potatoes were washed and peeled. The PFPPs were collected and used for experiments. The thickness of the peels was controlled at approximately 2 mm.

Drying studies Drying with hot air was performed at a temperature of 40°C in a tray dryer stacked horizontally (NB-901M; N-Biotek, Bucheon, Korea). To avoid the thermal degradation of the anthocyanin during drying, a relatively lower drying temperature (40°C) was selected. The dimension of the drying chamber was 55x52x60 cm³. The temperature deviation in the dryer (NB-901M; N-Biotek) was regulated within ±2.0°C from the target drying temperature, and the velocity of air flow was adjusted to 300.0 cm/s. The weight of the samples was manually measured every 30 min using an analytical balance (HS410A; Hansung Ace, Seoul, Korea) with an accuracy of ±0.01 g to monitor the moisture loss of samples during drying.

Mathematical modeling of drying curves The moisture content (M , a dry basis, d.b.) and the moisture ratio (MR) were determined based on the dry weight of the PFPPs using the following formula:

$$\text{Moisture content } (M) = \frac{W_w}{W_d} \quad (1)$$

$$\text{Moisture ratio } (MR) = \frac{M - M_e}{M_i - M_e} \quad (2)$$

where W_w and W_d are the mass of water and the dry matter, M_e is the equilibrium moisture content, and M_i is the initial moisture content, respectively.

Drying curves were fitted to 11 thin-layer drying models given in Table 1, which are commonly used in most food materials. The criteria to determine the best model expressing the drying curves of the PFPP are the correlation coefficient (R^2), root mean square error (RMSE), and sum of squared error (SSE).

Grinding characteristics Batch grinding was conducted on 30 g of PFPP for 10.0, 20.0, 30.0, 60.0, and 90.0 s using a dry grinder (FM-909T-350 W; Hanil Electric, Seoul, Korea). The dried samples were cut into small patches (3x3 mm) before grinding. Sieves with standard screen mesh (1.00, 0.60, 0.43, 0.25, and 0.15 mm) were used to measure the particle size of each sample. The sieves with different mesh sizes were stacked. The powdered samples after each grinding period were placed on the top screen and mechanically shaken for 10.0 min using a motor-powered sieve shaker (CG-211-8; Chunggye, Gunpo, Korea). The retained particles on each sieve were collected and weighed. The mass fraction of the samples was converted from the individual screen increments (5).

$$L_2 = \sum_{i=1}^n \Phi_i d_i \quad (3)$$

L_2 is the final volume surface mean diameter (mm) of the sample after grinding, Φ_i represents the differential weight fraction of the particles passing through the aperture of size d_i . The parameter d_i (mm) indicates the average size of the aperture in the mesh (7).

The initial size, i.e., the size before grinding, of the PFPPs was measured using a vernier caliper (530-101; Mitutoyo America Corporation, Aurora, IL, USA) with a precision of ±0.02 mm. The parameters to characterize the grinding process, such as Rittinger's, Kick's, and Bond's constants and the Bond work index were estimated based on the initial and final particle sizes using the following equations:

Rittinger's law

$$E = K_r \left[\frac{1}{L_2} - \frac{1}{L_1} \right] \quad (4)$$

Kick's law

$$E = K_k \ln \left[\frac{L_1}{L_2} \right] \quad (5)$$

Bond's law

$$E = K_b \left[\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}} \right] \quad (6)$$

Table 1. Thin-layer drying models and results tested for modeling

Model No.	Model name	Model equation	References	R^2	RMSE	SSE
1	Newton	$MR = e^{-kt}$	Lewis (13)	0.9829	0.04582	0.02309
2	Page	$MR = ae^{-kt^n}$	Page (14)	0.9851	0.04496	0.02021
3	Modified Page	$MR = ae^{(-kt)^n}$	White <i>et al.</i> (15)	0.9829	0.04805	0.02309
4	Henderson and Pabis	$MR = ae^{-kt}$	Henderson and Pabis (16)	0.9843	0.04614	0.02129
5	Logarithmic	$MR = ae^{-kt} + c$	Yaldiz <i>et al.</i> (17)	0.9843	0.04860	0.02125
6	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (18)	0.9393	0.09064	0.08215
7	Diffusion approach	$MR = ae^{-kt} + (1-a)e^{-kbt}$	Togrul and Pehlivan (19)	0.9837	0.04985	0.02212
8	Verma	$MR = ae^{-kt} + (1-a)e^{-gt}$	Verma <i>et al.</i> (20)	0.9836	0.04969	0.02222
9	Two-term exponential	$MR = ae^{-kt} + (1-a)e^{-kat}$	Sharaf-Elden <i>et al.</i> (21)	0.9837	0.04957	0.02212
10	Simplified Fick's diffusion equation	$MR = ae^{\frac{-ct}{l^2}}$	Togrul and Pehlivan (19)	0.9843	0.04863	0.02129
11	Midilli–Kucuk equation	$MR = ae^{-kt^n} + bt$	Midilli <i>et al.</i> (22)	0.9856	0.04943	0.01954

Work index

$$W_{ind} = \frac{K_b}{0.3162} \quad (7)$$

where L_1 is the volume surface mean diameter estimated before grinding. Characteristic parameters in the equations, such as K_r , K_k , and K_b , indicate the Rittinger's, Kick's, and Bond's constants, respectively. The energy consumed for grinding (E) is the grinding power per unit weight of the sample during grinding, and can be calculated by

$$E = \frac{Pt}{W_s} \quad (8)$$

where P is the power consumption, t is a given grinding time, and W_s is the weight of the sample.

The work index (W_{ind}) is defined as the amount of energy consumed for grinding the material with a large initial size of particles to a size that can pass through a 100 μm sieve. These constants and parameters represent the amount of energy consumed in a grinding process.

Grinding kinetic model In general, the grinding yield is proportional to the grinding time. The increase in yield can be expressed by a prototypical sigmoid model. To develop the kinetic model governing the grinding process, the yield was manually measured for each time interval while the grinding operation was performed. Typically, a sigmoid curve fits the time function of the grinding yield well (9). The kinetic equation describing the amount of ground particles of size i at an arbitrary processing time, $S_i(t)$ was estimated according to Lee *et al.* (9):

$$S_i(t) = \frac{S_{\max}}{1 + e^{\frac{1}{a}(t-b)}} \quad (9)$$

where $S_{\max}$ is the maximum amount of sample passing through a sieve of mesh size i , parameter a indicates the grinding ability constant, and parameter b represents the time required for grinding 50% of the initially loaded sample. To determine the model parameters, the samples at a specific diameter were weighed at a particular grinding time. Eventually, the time function of the weight of PFPPs with a specific size was empirically monitored, and the data could be used to develop the grinding kinetics equation, Eq. 9, for PFPPs.

Anthocyanin extraction A low-temperature stagnant single-stage batch extraction method was applied. To minimize the degradation of anthocyanin in the PFPPs, the extraction temperature was set to 25°C. A stagnant single-stage batch system was applied because this type of system provides more information on the influence of particle size and more useful data to design either a batch extraction or a multi-stage extraction system. The samples were classified with each standard sieve size (0.15, 0.25, 0.43, 0.60, and 1.00 mm) to control the particle size for extraction. The anthocyanin was extracted using distilled water in a conical tube (50 mL). During the extraction process, the tube was controlled at room temperature (25°C) and placed in a dark room to avoid light-induced oxidation. The experimental conditions were determined based on the results of the preliminary tests performed in our lab. The solvent/sample ratio was 15/1 (w/w). The extraction time was 5, 10, 15, 20, and 30 min.

Evaluation of anthocyanin content The anthocyanin level in PFPP extracts was determined using a spectrophotometer (SpectraMax® i3; Molecular Devices, Sunnyvale, CA, USA). The level was estimated by the pH differential method used in Lee *et al.* (23). The maximum wavelength ($A_{\lambda_{\max}}$) is 535 nm for PFPPs.

$$\text{Total anthocyanins } \left(\frac{\text{mg}}{\text{L}} \right) = \frac{A \times MW \times DF \times 1000}{\varepsilon \times l} \quad (10)$$

where $A = (A_{\lambda_{\max}} - A_{700})_{\text{pH } 1.0} - (A_{\lambda_{\max}} - A_{700})_{\text{pH } 4.5}$; molecular weight (MW) = 718.5 g/mol for malvidin-3-glucoside; DF = a dilution factor defined as the ratio of final volume to initial volume; l = a path length of the 96-well plate; ε (molar extinction coefficient) = 30,200 L/mol/cm for malvidin-3-glucoside; and 1,000 = a unit conversion factor to convert g to mg. Twice-distilled water was used to control absorbance readings.

Statistical analysis Three different samples were used for each experimental treatment. All the measurements were triplicated. The average values were applied to develop kinetic models. Mathematical software, MATLAB (R2011b; Mathworks, Natick, MA, USA), was used to perform regression analysis to estimate the parameters in the kinetic models. Both a linear and a non-linear regression procedure were applied to determine the best fit models. The determination coefficients were used as criteria to evaluate the good fitness of models. Significant difference was evaluated by a one-way analysis of variance with Microsoft Excel (ver. 2014; Microsoft, Redmond, WA, USA) at 95% of significant level.

Results and Discussion

Changes in moisture content and drying rate Changes in the MR of PFPPs during hot air drying at 40°C were evaluated (Fig. 1). The moisture level of PFPP was initially 5.02 (g/g d.b.), and hot air drying was continuously conducted until the moisture level reached the target value, 0.02 (g/g d.b.). The drying time was estimated as 240 min to achieve the target moisture content at 40°C. With increased drying time, the major mechanism for the moisture movement in PFPPs may be a diffusion-controlled mass transfer, and the resistance at the interface between the sample and hot air might be ignored compared to the internal resistance (24). The drying curve was fitted to experimental data using 11 semi-empirical models, as shown in Table 1. All the models showed high R^2 values (>0.939), and low RMSE (<0.0906) and SSE (<0.0822). The highest R^2 values were observed for the Page and Midilli-Kucuk models (>0.985), and the corresponding RMSE and SSE were lower than 0.0494 and 0.0202, respectively. The Page and Midilli-Kucuk models are the most suitable models to describe the drying characteristics of PFPP. In Fig. 1, both the Page and Midilli-Kucuk models described the drying kinetics of PFPPs well. However, the Midilli-Kucuk model seems to be more suitable after 150 min, which might be because of the linear term of the Midilli-Kucuk model. Several researchers reported that

Fig. 1. Changes in the moisture ratio of colored potato peels during hot air drying.

the Midilli-Kucuk model was the most appropriate equation to predict the drying kinetics of sea cucumbers (25), pear peels (26), and rough rice (27). The model parameters k and n in the Page model and Midilli-Kucuk model indicate the reduction rate of moisture and the time dependence of the reduction parameter, respectively. In general, the Midilli-Kucuk model showed better fitting than the Page model because the first-order term of time dependence fits well to the deviation of the exponential model, i.e., the Page model. Thus, the k and n of the Page and Midilli-Kucuk models generally showed similar values. The parameter values were $k=0.0134$ and $n=1.1202$ for the Page model and $k=0.0135$, $n=1.1008$ for the Midilli-Kucuk model. The parameter a in the Midilli-Kucuk model indicates the contribution of initial value and becomes 1 once the experiment data are normalized. Thus, in the Page model, a showed the same value as the coefficient of exponential term, i.e., 1. This study also showed $a=1.012$, which is nearly 1. The coefficient b of the first-order time function term in the Midilli-Kucuk model was $b=7.18 \times 10^5$. The b value was relatively small compared to a . This indicates that the deviation from Page model is small.

The effective moisture diffusivity (D_{eff}) was estimated from the slope after converting the drying data to a semilog scale, i.e., $\ln(MR)$ versus drying time. The slope was determined by taking a linear regression from the semilog scale data. The D_{eff} value of the PFPPs of 2.00 mm thickness was $1.67 \times 10^{-12} \text{ m}^2/\text{s}$. Ortuño *et al.* (28) reported that the D_{eff} value of orange peel slabs (thickness 5.95 mm) was $4.04 \times 10^{-9} \text{ m}^2/\text{s}$ at 40°C. In the studies of Henríquez *et al.* (29) on the kinetic modeling of apple peel (thickness 2.00 mm) during drum drying, the value varied in the range from 0.28×10^{-9} to $7.34 \times 10^{-9} \text{ m}^2/\text{s}$ at 110–140°C. Garau *et al.* (30) reported the D_{eff} value to be from 8.10×10^{-9} to $5.11 \times 10^{-9} \text{ m}^2/\text{s}$ for orange skin (thickness 4.64 mm) at 30–90°C. Compared to previous studies, the D_{eff} value of PFPP is significantly low ($p < 0.05$), which might be because of the low drying temperature. In general, high drying temperatures induced a higher moisture diffusivity during hot air drying (31). However, our studies

Fig. 2. Grinding kinetics of PFPPs corresponding to Eq. 9. (▲) <1.00 mm, (△) <0.60 mm, (●) <0.43 mm, (○) <0.25 mm, and (■) <0.10 mm. The data are the mean $\pm$ standard deviation (SD) from three independent experiments in triplicate.

imply that hot air drying processing for PFPPs is practically applicable to dehydrate the PFPPs for producing a powder form of PFPPs and minimizing the degradation of anthocyanin.

Grinding characteristics and kinetics Grinding kinetics (Eq. 9) was fitted based on the average particle sizes measured for each sampling term during the grinding process (Fig. 2). The weight fraction of each mesh size on the sieve horizontally stacked was measured to determine the grinding yield at a specific particle size (Fig. 2). The grinding characteristics generally represented the work index and the energy consumed for grinding described in Eq. 4, 5, 6, and 7 (Table 2). As the grinding time increased, the particle size decreased from the average initial particle size (3.00 ± 0.20 mm) for all samples. The grinding kinetic model and the work index parameters evaluated in this study successfully estimated the amount of energy consumed to produce a powder form of PFPPs. More energy was required for the smaller particles. The amount of energy consumed to generate each average particle size ranged from 20.37 to 183.33 Wh/kg. As grinding is a highly energy-intensive process, a method to save energy is required but this has not been investigated deeply. The major difficulty in finding a systematic approach to lower the energy consumption in grinding is owing to the paucity of estimating the energy consumed for a specific size-reduction process. The grinding

Table 3. Grinding kinetic model fitting constant

Particle size (mm)	Model constant			
	$S_{\max}$ (g/30 g)	a (s)	b (s)	R^2
<1.00	26.95	9.78	10.66	0.9918
<0.60	25.99	15.02	27.01	0.9975
<0.43	21.78	17.96	37.63	0.9950
<0.25	14.83	17.40	45.94	0.9929
<0.15	8.93	24.69	76.98	0.9927

characteristics are semi-empirically determined with the help of Bond's, Kick's, and Rittinger's laws (8). As shown in Table 2, three classical laws used for grinding PFPP generated fairly good results for each specific grinding. The energy (E) spent for grinding increases with a decrease in particle size, as is evident from the grinding constants and the work index that increased with a prolonged grinding time. Based on the grinding laws, previous studies suggested that Kick's law, Rittinger's law, and Bond's law are suitable for coarse grinding, fine grinding, and intermediate articles, respectively (8,32). In this study, the particle sizes of PFPP after different grinding times were suitable for all the three grinding laws. Compared with the grinding of rice, the grinding law constants and work index were relatively lower at similar particle size (10). These results may depend on the brittle character of the food material (9).

Our results demonstrated that the amount of energy required to produce particles with a particular size is quantitatively estimated, and the values might be useful for designing the grinding process of PFPP.

The kinetic behavior of the PFPP powder during grinding is represented in Fig. 2. A prototypical sigmoid shape was observed. The grinding kinetic model (Eq. 9) was developed from the grinding data, and the results of the model evaluation are summarized in Table 3. All the treatments were suitably fitted with the grinding kinetic model ($R^2 > 0.963$). The model parameters, such as $S_{\max}$, a , and b , indicate the maximum amount of ground PFPP passing through a specific mesh size of a sieve indicating the particle diameter i , the grinding ability, and the grinding time required to grind 50% of the initial amount of PFPP, respectively. The amount of powder for all samples increased as the grinding time increased. Saturation of the grinding yield was observed in most of the samples. In the early stage of grinding, the amount of 1.00 mm particles increased dramatically until 40 s, and after the initial increase, the grinding yield became saturated. The pattern of grinding yield upon the particle size,

Table 2. Grinding characteristics

Grinding time (s)	Average particle size, L_2 (mm)	Energy, E (Wh/kg)	K_r (Wh/kg)	K_k (Wh/kg)	K_b (Wh/kg)	W_{ind} (Wh/kg)
10	0.85	20.37	24.16	16.15	40.15	126.99
20	0.68	40.74	35.85	27.46	64.16	202.92
30	0.61	61.11	46.60	38.29	86.67	274.10
60	0.39	122.22	55.12	60.06	119.86	379.07
90	0.28	183.33	57.22	77.62	140.65	444.83

Fig. 3. Anthocyanin content during extraction of PFPPs for different particle sizes.

however, showed a limit criteria. When the particle size is smaller than 0.43 mm, PFPP powders were not properly generated. The maximum grinding yields from the particle size of 0.25 and 0.15 mm PFPP powder were very small: 14.83 and 8.93 g/30 g, respectively. When grinding a piece of dried mango containing a high amount of sugar, the caking phenomenon due to the high concentration of sugar in the sample was observed as the grinding proceeded (5). Even a sample with low sugar content, such as soybeans, showed an exceptional kinetic behavior during grinding. Soybean powders with diameters smaller than 0.15 mm at 12% moisture content showed a large deviation from the prototypical kinetic behavior and the kinetic model was not suitable to describe the grinding behavior ($R^2=0.133$) (9). This result might be because of the agglomeration of particles associated with the high moisture content in the particles. The agglomerated particles having a weak bond between particles were not easily separated back to its original particle by applying a vibration from the sieve shaker. This causes an error to generate the raw data to develop a grinding kinetic model. When there is a biochemical reaction, such as caking or agglomeration, during grinding, the grinding kinetic model is not suitable to describe the grinding behavior. In our study, no caking or agglomeration was observed during the 90 s grinding time. This might be due to the low sugar and moisture content in the PFPPs. In addition, a lower energy consumption of dried soybeans and mangoes to produce a particular particle size was found at lower moisture levels (5,9). Therefore, the samples having lower moisture content produce more small particles for a given grinding time. This result demonstrated that the suitably designed drying process needs to be applied before grinding PFPPs to minimize the energy consumed while grinding and to maximize the grinding yield of small particles. In addition, the drying process may extend the shelf life of the PFPPs.

The kinetic model based on the sigmoidal pattern was widely applied to the biological systems, such as for predicting microbiological growth and estimating the degree of gelatinization (33,34). The

degree of gelatinization and deformation of wheat during thermal treatment was suitably estimated using the sigmoid model (34). In the case of the grinding process, the kinetic characteristics of grinding mango, rice, and soybeans were well described using the sigmoid based kinetics model (5,9,10). The grinding kinetics model is a practical way of predicting the grinding time required to produce a specific size of particles.

Anthocyanin content at varied particle sizes The anthocyanin content at different particle sizes during extraction is shown in Fig. 3. In general, the anthocyanin content in the extract increases as the particle size decreases. In the case of PFPP powders, the particle size of 0.43 mm showed the highest anthocyanin content at the beginning stage of extraction. The particle with the smallest size (0.15 mm) showed a very low anthocyanin content. The particles of size 0.15 mm showed slightly higher anthocyanin content than the extracts of 0.60 and 1.00 mm. Such a low anthocyanin content observed for the smallest particle size is called a “package phenomenon” (35). A small particle size can inhibit extraction because small particles have a very small gap between the particles, and the solvent thus has difficulty penetrating the particles. According to Pinelo *et al.* (35), the smaller particle size promoted a decrease in surface contact between grape skin solids and liquids, and thus, decreased the extraction efficiency. In addition, an agglomeration of particles could occur even in the early stages of extraction. Because of the agglomeration, the small particle size of rice flour showed lower glucose and alcohol yield compared to that of larger particles (10). As the extraction time increased, the 0.25 and 0.43 mm particles showed a similar anthocyanin content. Interestingly, the particle size could be adjusted depending on the extraction time in the stagnant stage extract process. For a single-stage process with a short extraction time, a 0.43 mm particle size is very efficient, even more efficient than a particle size of 0.25 mm. The size dependence of the extraction yield implies that the grinding time can be reduced to reduce the processing time and energy consumption. The stagnant extraction system has a benefit compared to the stirred extraction system in that the stagnant system requires less space and energy and has easy reuse of the raw material. However, because there are very limited studies on the effect of particle size on the extraction yield, many industries have difficulty in maximizing the efficiency of the stagnant extraction system.

The effect of the particle size of the powder from PFPPs on the yield of anthocyanin during extraction was investigated for different particle sizes (0.15, 0.25, 0.43, 0.60, and 1.00 mm). The highest anthocyanin content was observed for the 0.43 mm particles. The optimum particle size could reduce the extraction time as well as the grinding time, e.g., the smallest size of particles (0.15 mm) showed a very low amount of anthocyanin. The results of our study clearly demonstrated that PFPP could be utilized as a useful resource for producing anthocyanin by applying the drying and grinding processes.

Acknowledgment This work was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture, Forestry and Fisheries (IPET) through High Value-added Food Technology Development Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA) (314047-2).

Disclosure The authors declare no conflict of interest.

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