Quality attributes and anthocyanin content of rice coated by purple corn cob extract as affected by coating conditions

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Abstract

We investigated the optimal conditions for coating rice with the water extract of purple corn cob (PCC) using a top-spray fluidized bed coating method with variations of inlet air temperature of 50, 60 and 70 °C and spaying time of 5 10 and 15 min. The results showed that the inlet air temperature significantly influenced in reducing final MC with higher temperature. Fissured coated rice was higher with increasing temperature and spraying time. Percentage of head rice yield was not affected by inlet temperature, while it tended to decrease with longer spraying time except at 15 min. In addition, longer spraying time resulted in higher values of chroma implying a larger amount of coating solution. In addition, we found that increasing temperature decreased values of total phenolic, total flavonoids and total anthocyanins contents as well as their antioxidant activities as determined by DPPH and FRAP assays. In contrast, those values were increased when the spraying time increased. The same trend was found for anthocyanin composition. Based on the optimization criteria with the highest desirability of 0.702, we recommend the inlet air temperature of 50°C and spraying time of 14.87 min to obtain the minimum fissure and maximum coating material.

Key words: top-spray fluidized bed; chroma; fissure; flavonoid; antioxidants

1. Introduction

Rice is a staple food consumed worldwide, particularly in Asia. Even though brown rice contains higher nutritional values and phytochemicals content, including antioxidants, white rice or milled rice has been preferred for consumers due to its flavor and texture. In order to maintain such values, adding the natural extract containing antioxidants to the white rice is taken into considered as an improvement of its health benefits.

Anthocyanins are flavonoid pigments providing colors that vary from orange, red, violet, blue and dark purple in vegetables and fruits such as grapes, blueberry, blackberry, raspberry, purple carrot etc. (Wang et al., 1997; He and Guisti, 2010). They have been widely used as natural colorants due to their low toxicity. Anthocyanins have been reported to have high antioxidant properties which are correlated with prevention of chronic diseases in humans (Yang and Zhai, 2010; Flanigan and Niemeyer, 2014) such as cancers, cardiovascular disease and others. For example, consumption of dietary containing anthocyanins associated with neuroprotective effects decreases risk of Parkinson's disease (Flanigan and Niemeyer, 2014). However, anthocyanins are highly susceptible and unstable to processing especially thermal processing (Vegara et al. 2013). Furthermore, due to high cost of such vegetables and fruits, many attempts have been made in order to find other potential natural sources, as summarized in (Fu et al., 2011; Deng et al., 2013; Morales-Soto et al., 2014).

Purple corn originated from Peru is one of rich sources of anthocyanins. It contains not only higher anthocyanins than those of aforementioned vegetables and fruits, but its price-per-unit is also much lower (Cevallos-Casals and Cineros-Zevallos, 2003). Purple corn has now been gaining popularity for consumption in many regions including Thailand. It is consumed on the cob as fresh food after being cooked by boiling or steaming (Harakotr et al, 2014). The corn cob is normally thrown away as waste, even though it contains as much bioactive compounds especially anthocyanins as in the corn seed. Therefore, the purple corn cob could be a cheaply potential natural source of anthocyanins and other bioactive components.

Recently, rice coated with natural extracts containing antioxidants or other bioactive compounds has been considered as value-added product gaining more popularity in the market. Coating the solid particles can be made by means of rotating drum, rotating pan, fluid bed and other mixers (Teunou and Poncelet, 2002). Among them, the rotating pan and fluid bed associated with the coating spray are most appropriate in this application (Maronga, 1998). However, the former is still not suitable technique in food industries when compared with the fluidized bed coating process providing higher reproducibility and coating uniformity (Maronga, 1998; Palamanit et al., 2013). In this process, particles at the bottom are fluidized by a continuous air stream blown through an air distributor. Coating solution is pumped and subsequently atomized through a nozzle and sprayed onto the surface of particles, resulting in wet particles. The deposited solution is subsequently dried by the hot air, leading to formation of layered growth on the particle surface. Among bottom-spray, tangential-spray and top-spray configurations, the latter in which a nozzle may be positioned above or submerged inside the bed has been successfully employed in food industries due to its high flexibility and simplicity of high batch size (Duangkhamchan et al., 2015).

Due to a unique operation providing simultaneous processes (coating and drying) taking place in only one apparatus, Palamanit et al. (2013) applied the fluidized bed coating process to improve functional properties of white rice. They improved the antioxidant property of white rice by coating turmeric extract solution by means of fluidized bed coating technique with top-spray configuration. That work revealed high potential to increase total phenolic content and total antioxidant capacity of white rice. In addition, the experimental results showed the influence of operating parameters including spraying rate and inlet air temperature on physic-chemical properties of coated rice. In order to reduce attrition promoted in the conventional rotating-pan equipment, Solís-Morales et al. (2009) applied a top-spray fluidised bed reactor to coat puffed wheat with sweet chocolate. It can be proven from two aforementioned publications that the top-spray fluidized bed technique can be potentially applied in the food industry. However, the occurrence of side effects including the premature spray-drying of the droplets containing the dissolved coating material and agglomeration (i.e. sticking or clumping together of wetted particles) could result in poor product quality and product losses (Dewettinck and Huyghebaert, 1999; Werner et al., 2007). To solve these problems, all phenomena in the coating process including air suspension, particle dynamics, coating solution droplet trajectories and their interactions have to be clearly understood so that appropriate selection of process input variables can be achieved (Teunou and Poncelet, 2002).

As a result of various operating variables i.e. process conditions, material properties, affecting the coating process dynamics and quality of the resulting product, many attempts have been made to optimize the coating system, improving the reactor design and increasing material efficiency, as reviewed by Teunou and Poncelet (2002). For instance, Atarés et al. (2012) investigated the effects of core materials on the layer growth mechanism as well as coating quality. In addition to core material properties, the effects of process variables on quality attributes were studied by Palamanit et al. (2013). Process optimization has not only been carried out experimentally, but has also been studied by means of mathematical models (Perfetti et al., 2012). Since the quality of coated products is greatly affected by operating variables, the multivariate analysis such as response surface method widely applied to food process optimization could be potential means to investigate the relationships between process and end-product quality. Therefore, in this work, the effects of inlet air temperature, spraying time on physical attributes of rice coated with purple-corn cob (PCC) in terms of percentage of fissured kernel, head rice yield and chroma were investigated by means of the response surface methodology. Subsequently, it was applied to optimize the top-spray fluidized bed coating condition for white rice coated with purple-corn cob extract. Also anthocyanin and phenolic contents along with their antioxidant activities were included. We expect to obtain an appropriate coating condition for preserving both physical and antioxidant properties of rice coated with PCC.

2. Materials and methods

2.1 Materials

2.1.1 Rice sample

Milled rice variety Khao Dawk Mali 105 (KDML 105) harvested from Mahasarakham province, Northeastern Thailand, was used in this work. Prior to testing, its moisture content,

% head rice yield and % fissure were analyzed, and the rice sample was kept in a dark room at temperature of 4±1 °C.

2.1.2 Purple-corn cob extract solution preparation

Purple-corn cobs (Zea mays L. var. ceratina) supported by Assistant Professor Sakulkarn Simma, the Department of Agriculture Technology, Faculty of Technology, Mahasarakham Univerisity, Thailand, were sliced into small pieces. One hundred and fifty grams of sliced cob were boiled (85-95 °C) in 100-ml distilled water for 10 mins. The extract was subsequently filtered through multi layers of white cloth. Finally, the purple-corn cob extract was mixed with maltodextrin in order to obtain 15°Brix of solution used as a coating material, and was then stored in a dark room at 4±1 °C until a test and analysis.

2.2 Experimental setup

A laboratory scale top-spray fluidized bed coater consisted of a conical stainless steel vessel with inclination of 8.1° (a top diameter of 0.30 m, a base diameter of 0.14 m and a height of 0.56 m.). A stainless perforated plate with a hole size of 1 mm was used as an air distributor at the bottom of the vessel. Fig.1 shows a schematic diagram of the apparatus. The fluidizing air was supplied using an 1-hp blower associated with a frequency inverter to adjust its velocity. The fluidizing air heated by an electric heater enters the bed through the air distributor, and its temperature was controlled by a temperature controller. In order to spread on the rice grain surface, small droplets containing the coating material were continuously sprayed towards the fluidizing bed by means of a two-fluid nozzle with a droplet size ranging from 10 to 40 μm (Duangkhamchan et al., 2012). In this work, the nozzle was positioned at 0.12 m above the air distributor. The coating solution was fed into the two-fluid nozzle by a peristaltic pump, and it was subsequently atomized associated with the compressed air supplied by an air compressor.

2.3 Experimental procedure

2.3.1 Coating procedure

Milled rice of 500 g, corresponding to approximately 2 cm of initial bed height, was used in this work. Before loading rice sample, the desired inlet temperature and velocity of fluidizing air were set. As soon as the desired conditions reached steady-state behavior, the rice sample was loaded at the top of a reactor. The onset of coating process was provided once the coating solution was subsequently sprayed into a fluidized bed of rice. The experimental conditions carried out in this work included the variations of inlet air temperature (50, 60 and 70°C) and spraying time ranging from 5 to 15 min, while coating solution feed rate, fluidizing air velocity and atomization air pressure were kept constant as 10 ml/min, 4.7 m/s (three times of minimum fluidization velocity) and 1.5 bar, respectively. Due to simultaneously coating and drying in this technique, the coated rice was not further dried. Prior to quality analyses, it was kept in an aluminium-foil bag under cold storage (4±1°C). Each condition was carried out in triplicate.

2.3.2 Moisture content determination

Moisture content (MC) of both milled rice and coated rice was determined according to the standard method of AOAC. Five grams of rice sample was dried at 103°C in a hot air oven for 72 h. The average value obtained from five replicates for each experiment was presented.

2.3.3 Head rice yield (HRY) determination

Coated rice of 2.5 g, corresponding to approximately 100 rice kernels, was randomly sampled from each experiment. Broken rice defined as the kernel length less than 75% of its original length (Palamanit et al., 2013) was visually examined associated with a high resolution digital camera. The ratio of a number of broken kernels and total kernels was calculated as head rice yield. The measurement was carried out with ten replications, and the average result was presented.

2.3.4 Fissure determination

Similarly, fissure of coated rice was determined by randomly sampling 100 kernels (approximately 2.5 g). The kernels were placed on a glass above fluorescent bulb to which cracking of coated rice could be inspected clearly. Visual inspection associated with the high resolution digital camera was carried out. The magnified images were taken and visually inspected. Ten replicates were performed for each measurement and the average value was presented.

2.3.5 Chroma measurement

The chroma of coated rice was examined by the colorimeter (model ColorFlex, HunterLab Reston, VA, USA) with a D65 illuminant and observer angle of 10°. The chroma was calculated from Chroma = $(a^{*2}+b^{*2})^{1/2}$ using the CIE L*a*b* color scale, a* (redness-greenness) and b* (yellowness-blueness). The colorimeter was first calibrated with a standard white plate obtaining L* of 93.19, a* of -1.12 and b* of 1.33. The color was measured in ten individual replicates of each experiment and the average value was presented.

2.3.6 Total phenolics content determination

Total phenolic content in PCC was determined using the Folin-Ciocalteu reagent as following the methods of Zhou and Yu (2006), and Kubola and Siriamornpun (2008). Briefly, 30 μL of extract was mixed with 2.25 ml of Folin-Ciocalteu reagent (previously diluted 10-fold with distilled water) and allowed to stand at room temperature for 5 min; 2.25 ml of sodium carbonate (60 g/ml) solution was added to the mixture. After 90 min at room temperature, the absorbance was measured at 725 nm using a spectrophotometer. The standard curve of the absorbance of gallic acid was made. The total phenolic content of the tested compound was determined and reported as milligram gallic acid equivalents per gram dry weight (mg GAE/g DW).

2.3.7 Total flavonoid content determination

Total flavonoid content was determined using the method of Abu Bakar et al. (2009). Briefly, 0.5 ml of the mixture was mixed with 2.25 ml of distilled water in a test tube followed by addition of 0.15 ml of 5% $NaNO_2$ solution. After 6 min, 0.3 ml of a 10% $AlCl_3{\bullet}6H_2O$ solution was added and followed to stand for another 5 min before 1.0 ml of 1M NaOH was added. The mixture was taken to measure for the absorbance at 510 nm using a spectrophotometer. The total flavonoid content was represented as milligrams of rutin equivalents per gram dry weight (mg RE/g DW).

2.3.8 Total anthocyanin content

Total anthocyanin content was determined using the spectrophotometric method (Cinquanta et al., 2002). Approximately 10 mg of powder were extracted twice with 10 ml of water (1:1 w/v). The extract was centrifuged for 10 min at 10,000 g and recorded in a Beckman Du-640 spectrophotometer (Beckman Coulter, Fullerton, USA). Total anthocyanin content was expressed as cyaniding -3 rutioside. The absorbance was measured at 534 nm. Analyses were performed in triplicate and the results expressed as mg/100 g of dried extract.

2.3.9 Identification of anthocyanins by HPLC

Reversed-phase HPLC analysis of anthocyanins was performed using a method of Kim et al. (2007). RP-HPLC instrument consists of Shimadzu LC-20AC pumps, diode array detector (SPD-M20A) and chromatographic separations were performed on a C-18 column (4.6 x 250 mm., i.d. 5 μm) (Waters USA). The mobile phase used were 0.1% hydrochloric acid in methanol (15:85 v/v) (phase A) and 8% formic acid (phase B), at a flow rate of 1 mL/min. The gradient elution conditions used were described previously by Kim et al. (2007). Operating conditions were as follows: column temperature 30 °C, injection volume 20 μL, and a detection wavelength at 520 nm. Solutions were injected after being filtered through a 0.45 μm nylon membrane filter. Anthocyanins in samples were identified by comparing their relative retention times and UV spectra with those of standards and were detected using an external standard method. The results for the anthocyanins were expressed as μg per mg dry weight (μg /g DW)

2.4 Response surface methodology

Physical properties of PCC coated rice as affected by coating variables were evaluated by means of response surface method (RSM) due to its suitability for multivariate problems. In this work, a full factorial experimental design was employed with two factors (inlet air temperature and spraying time) and three levels for each factor. Fissure and chroma were used as responses in order to provide the consistency with the factors. A second-order polynomial equation applied to describe the effects of factors on responses is expressed as follow (Singh et al., 2006):

$$Y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i}^{n} a_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} a_{ij} x_i x_j \quad (1)$$

In equation (1), the coefficients a_0 is the constant; a_i and a_{ii} are the linear and quadratic effects, respectively, while the interaction effect between them is denoted by a_{ij}. x_i (n = 2) is the actual value of the ith factor, x_1 defined as inlet air temperature (°C) and x_2 spraying time (min). In order to optimize the coating condition, the models obtained from equation (1) were applied associated with the desirability criteria, minimum % fissure and maximum value of chroma (implying the amount of coating material on rice surface). The suitable condition was chosen based on the highest desirability value, ranging from 0 to 1.

3. Results and discussion

We divided the experimental data into two parts. Firstly, the coating condition was optimized for the physical attributes. The second part is investigation of bioactive compounds affected by spraying time and temperature. The results and discussion are as follows:

3.1 Physical properties of rice coated with purple-corn cob extract and optimized coating condition

3.1.1 Moisture content

The MCs of rice coated with PCC extract using a lab-scale top-spray fluidized bed coater at different conditions are presented in Table 1. It can be found from this table that the final MCs were varied in a range of 10.18 – 12.81% (wet basis), depending on coating conditions being used in this work. The MCs of coated rice tended to increase, comparing with the initial MC ranging from 11.37 – 11.74%, except that obtained under temperature of 70°C and 10 min for spraying time, decreasing from 11.74 to 10.18%. Considering the effect of spraying time at constant temperature of 50°C, the MCs increased after coating at various spraying times was not significantly different. It could be explained that the variation of spraying time used in this work did not affect the change in evaporation rate. To investigate the effect of temperature on the final MC of coated rice, variation of inlet air temperature was employed, while spraying time was kept constant at 10 min. It was found from Table 1 that the inlet air temperature strongly affected the final MC, decreasing with higher temperature. Especially when operated under inlet air temperature of 70°C, the final MC was lower than the initial one (1.56% decrease). It could be explained that evaporation rate of moisture from the rice kernels provided by this condition was higher than the amount of coating solution deposited on the surface of rice kernels. The existing moisture of white rice kernels was therefore evaporated to compensate the required amount of moisture evaporation rate of drying air, resulting in a decrease in MC after coating. This effect was consistent with the results presented by Palamanit et al. (2013).

3.1.2 % Fissure and % HRY

Various inlet air temperatures and spraying times were used in order to study the effects of these operating parameters on % fissure and % HRY of rice coated with PCC extract, as shown in Table 1. It was revealed that the percentage of fissured coated rice kernels, ranging from 20.08 to 96.66%, was found higher with increasing inlet air temperature and spraying time. The possible explanation of rice fissure could be the fact that the stress formation takes place when the moisture on rice surface evaporates quicker than the diffusion rate of moisture from inside kernels to their surface (Iguaz et al., 2006). The fissure subsequently occurs if the stress formed inside rice kernels reaches a limit of failure strength (Kunze and Choudhury, 1972, Palamanit et al., 2013). At constant temperature of 50°C, a number of fissured coated rice kernels tended to increase when spraying time was higher. This is due to the longer resident time for which the rice kernels absorbed heat from the fluidizing air. When operated under constant spraying time of 10 min, inlet air temperature affected strongly the percentage of fissure, as found to be up to 96.66% at the highest temperature of 70°C. Palamanit et al. (2013) stated that in the case of high % fissure up to 97%, a textural quality of cooked coated rice was poor, leading to unacceptability of consumers. Therefore, this condition is not suitable when acceptability of consumers is concerned.

In addition, Table 1 shows the percentage of head rice yield after coating by the lab-scale top-spray fluidized bed coater. At constant spraying time of 10 min, the inlet air temperature did not significantly affect % HRY of coated rice (~84%), but lower than that of uncoated rice samples (92.17±1.33%). The collision between fluidizing rice kernels and the reactor wall as well as inter-collision among kernels could be possible explanation of a decrease in % HRY after coating. However, when operated under various spraying times, tendency was found to be decrease with longer time, except at spraying time of 15 min. At this condition, % HRY turned out to be higher than that of rice coated for 10 min. It could be explained by agglomeration of coated rice when high amount of coating solution was supplied, while heat used for droplets evaporating remained constant as inlet air temperature was unchanged at 50°C. In this case, agglomerates could move slower, meaning that intense collisions resulting in kernel breakage may rarely occur during coating process.

3.1.3 Color

The effect of operating variables on the color values of PCC coated rice are presented in Table 2. From this table, the hue angle of coated rice was in a range of 21.56 – 33.53, indicating a shade of reddish-purple. This range of hue angle corresponded to the redness value (a^*) of 10.17-16.35, yellowness value (b^*) of 6.15-6.74, and lightness value (L^*) of 42.31-54.64. In addition, Table 2 presents chroma values used to evaluate the intensity of color of coated rice. Considering the effect of spraying time, increasing spraying time ranging from 5 to 15 min under constant inlet air temperature of 50 °C resulted in higher values of chroma, meaning more intense color of coated rice. This is due to the fact that for longer spraying time, a larger amount of coating solution was supplied to a bed, and subsequently adhered onto the rice surface. In contrast, the chroma values tended to decrease with increasing inlet air temperature at constant spraying time, as shown in Table 2. Higher premature droplet evaporation resulted from increasing inlet air temperature could be possible explanation of this observation. These results were also observed by Palamanit et al. (2013). This is so-called spray drying effect often encountered in the top-spray reactor (Dewettinck and Huyghebaert, 1998). Therefore, the distance the droplets travel before contacting the core particles should be optimized in order to minimize coating imperfections cause by premature droplet evaporation.

3.2 Optimized coating condition

Three levels of inlet air temperature and spraying time were applied to provide to the consistency with % fissure and chroma values as responses of each factor.

On the basic of response surface methodology, the correlations for % fissure and % chroma are expressed in equations (2) and (3), respectively;

$$\text{Fissure} = 73.27 + 33.66A + 7.40B - 8.39AB;\ R^2 = 0.81 \quad (2)$$

$$\text{Chroma} = 16.50 - 0.56A + 2.62B + 0.23AB;\ R^2 = 0.83 \quad (3)$$

where A denotes the inlet air temperature (°C) and B the spraying time (min). The statistical analysis of the above equations showed an acceptable coefficient ($R^2 > 0.8$), meaning that the models could explain approximately 80% of variability.

However, determination of an appropriate coating condition for PCC coated rice was dependent on all operating parameters tested. The simultaneous optimization of % fissure and chroma values was therefore investigated by defining a 2-dimension global desirability plot, as shown in Fig. 2. Based on the minimum % fissure and maximum chroma, the highest desirability value was 0.702 corresponding to the inlet air temperature and spraying time of 50°C and 14.87 min, respectively. This means that the combination of the different independent operating parameters was globally optimal.

Although chroma values could subjectively predict the amount of coating material, determinations of bioactive components by HPLC must be performed. Therefore, the bioactive compounds as affected by coating conditions were further evaluated experimentally in the following section.

3.3 Effects of operating parameters on bioactive compounds

We investigated the effect of coating temperature (50, 60 and 70 °C) on the contents of bioactive compounds along with antioxidant properties. The spraying time was then collectively studied with respect to the optimal coating temperature. As expected, all coated rice samples had significantly ($p<0.05$) higher values of TPC, TFC and TAC compared with the control (Table 3). However, those parameters were decreased with an increase of coating temperature, being highest at 50 °C and lowest at 70 °C (Table 3), hence 50 °C was selected as an optimal coating temperature. At constant temperature at 50 °C, different spraying times at 5, 10 and 15 min were studied. The longer time resulted in the higher TPC, TFC and TAC. These results were similar to those of antioxidant activities in Table 4. The increase of temperature led to a higher degradation of phenolics, flavonoids and anthocyanins because they are highly thermo-sensitive (Tonon et al., 2010). Thermal processing has been reported to have inconsistent effect on bioactive compounds and antioxidant properties of plant samples. It could cause losses, no change or even improvement of antioxidant properties (Nicoli et al., 1999). Food Processing can improve the properties of native antioxidants or induce the formation of new compounds with antioxidant properties so the overall antioxidant activity increases (Tomaino et al., 2005) in some products such as in dried mulberry leaves using far infrared drying (Wanyo et al, 2011). However, in our study the values of DPPH radical scavenging and FRAP were stepwise decreased when higher temperature applied (Table 4). The presence of sugars and proteins causing a non-enzymatic browning reaction, called Maillard reaction may have an effect on more rapid degradation of anthocyanin at higher temperature. Furthermore, as we mixed the PCC extract with maltodextrin (a polyscaccharideconsisting of D-glucose units connected in chains of variable length) as a coating media, the degradation of anthocyanin may be accelerated by the conversion of sugars to furfural which is a compound derived from the Maillard reaction, leading to the formation of brown color compounds. This reaction is susceptible to thermal process (Von Elbe and Schwartz 1996; Tonon et al., 2010)

Seven authentic standards, namely kuromanin, keracyanidin, malvin, dephinidin, cyanidin, pelargonidin and malvidin were used to compare the retention time for identification of anthocyanin composition. In our present study, it was possible to identify all of those anthocyanins in the PCC extract, however only four components namely keracyanidin, malvin, dephinidin and cyaniding found in the coated rice samples. As can be seen from Table 5, the results were similar to those found for bioactive compounds (Table 3) and antioxidant activities (Table 4) that when the coating temperatures increased, the contents of anthocyanin were decreased (50°C >60°C >70°C). Therefore, we further investigated the coating temperature at 50 °C. It was found that the longer spraying time resulted in the higher content of anthocyanins present in all coated rice studied. Although most anthocyanins were coated by the top-spray fluidized bed coating method with suitable conditions, malvin, malvidin acid and pelargonidin were not attached to the rice materials as they were not detected in coated rice. It was observed that the difference of malvin and malvidin, compared with other anthocyanins is the presence of a methoxyl group in their molecules as indicated in Fig. 3. Malvin and malvidin contains one methoxyl groups while the others do not. The plausible explanation of how these two anthocyanins could not be attached to the rice kernels by coating processes may involve the linkages or bindings of the hydroxyl group of rice starch and the methoxyl groups or may be caused by hydrophobicity of methoxyl groups against water solubility. Whilst, pelargonidin contains unique structure of anthocyanin that there is no hydroxyl group at 3' position of B ring while others do. At this position, OH can donate electron better than that at other positions (Jing et al., 2014). The ability to link with other molecules such as starch, sugar in the coating media (maltodextrin) or the rice is strongly dependent on chemical structure, number and position of hydroxyl group especially OH at R_1 position of B ring. However, this must be studied further.

4. Conclusion

We have demonstrated that coating procedure affected the physical qualities and bioactive components of rice coated with PCC. High temperature applied caused undesirable physical qualities and lower amount of bioactive components as well as antioxidant activities. In addition, spraying time at constant temperature seemed to have less effect on those values than the former except for chroma value which was found greater with longer spraying time. This implies that more PCC added on the rice surface. Our findings have supported the previous information that anthocyanins were susceptible to thermal process. Therefore, to preserve the bioactive compounds and their biological activities of the PCC-coated rice, we recommend that the suitable coating conditions should be applied at low temperature for longer spraying time. However, besides coating parameters studied, concentration of coating materials, nature of core materials (rice variety) should be further investigated.

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Table

Table 1 Moisture content, %fissure and %HRY of purple-corn cob extract coated rice.

Conditions		Moisture content (%wet basis)			%Fissure	%HRY
Temperature (°C)	Spraying time (min)	Initial MC	Final MC	MC increased		
50	5	11.64 ± 0.08	12.81 ± 0.16	1.17 ± 0.18^{a}	20.08 ± 5.22^{b}	85.59 ± 0.76^{bc}
50	10	11.37 ± 0.08	12.68 ± 0.24	1.31 ± 0.25^{a}	27.21 ± 2.54^{b}	84.91 ± 1.19^{c}
50	15	11.44 ± 0.03	12.69 ± 0.19	1.25 ± 0.19^{a}	40.97 ± 1.50^{a}	87.30 ± 1.12^{b}
50	10	11.37 ± 0.08	12.68 ± 0.24	1.31 ± 0.25^{A}	27.21 ± 2.54^{C}	84.91 ± 1.19^{B}
60	10	11.43 ± 0.02	12.00 ± 0.49	0.57 ± 0.49^{B}	45.42 ± 2.17^{B}	83.98 ± 0.14^{B}
70	10	11.74 ± 0.22	10.18 ± 0.17	-1.56 ± 0.28^{C}	96.66 ± 0.40^{A}	83.72 ± 0.94^{B}
uncoated		-	-		5.12 ± 0.65^{cD}	92.17 ± 1.33^{aA}

Different superscripts in the same column denote significant difference at $p<0.05$.

Small superscripts are used for comparison at constant temperature, while capital ones are used when comparing under constant spraying time.

Table 2 Color values of rice coated with purple-corn cob extract.

Conditions		L^*	a^*	b^*	Hue angle	Chroma
Temperature (°C)	Spraying time (min)					
50	5	54.64 ± 2.61^{a}	10.17 ± 0.77^{c}	6.73 ± 0.44^{a}	33.55 ± 2.75^{a}	12.21 ± 0.67^{c}
50	10	46.62 ± 1.67^{b}	15.17 ± 0.48^{b}	6.15 ± 0.35^{b}	22.08 ± 1.58^{b}	16.37 ± 0.39^{b}
50	15	42.31 ± 1.81^{c}	16.35 ± 0.62^{a}	6.31 ± 0.24^{b}	21.15 ± 1.46^{b}	17.53 ± 0.50^{a}
50	10	46.62 ± 1.67^{B}	15.17 ± 0.48^{A}	6.15 ± 0.35^{B}	22.08 ± 1.58^{B}	16.37 ± 0.39^{A}
60	10	47.26 ± 0.80^{B}	13.87 ± 0.10^{B}	6.67 ± 0.12^{A}	25.66 ± 0.46^{A}	15.39 ± 0.10^{B}
70	10	53.82 ± 0.89^{A}	13.98 ± 0.13^{B}	6.74 ± 0.18^{A}	25.73 ± 0.72^{A}	15.52 ± 0.11^{B}

Different superscripts in the same column denote significant difference at $p<0.05$.

Small superscripts are used for comparison at constant temperature, while capital ones are used when comparing under constant spraying time.

Table 3 Total phenolic, total flavonoids and anthocyanin content as affected by coating conditions.

Conditions		TPC	TFC	TAC
Temperature (°C)	Spraying time (min)	(mg GAE*/100 g of dry matter)	(mg RTE**/100 g dry matter)	(mg/100 g dry matter)
50	10	60.53 ± 1.37^{B}	5.02 ± 0.56^{B}	0.15 ± 0.02^{B}
60	10	56.88 ± 4.60^{BC}	5.01 ± 0.30^{B}	0.14 ± 0.02^{B}
70	10	55.65 ± 0.71^{C}	4.86 ± 0.31^{B}	0.15 ± 0.00^{B}
50	5	44.21 ± 1.07^{d}	1.30 ± 0.69^{d}	0.09 ± 0.02^{d}
50	10	56.88 ± 4.60^{c}	5.01 ± 0.30^{c}	0.14 ± 0.02^{c}
50	15	70.80 ± 4.03^{b}	7.30 ± 0.63^{b}	0.25 ± 0.04^{b}
Extract		132.97 ± 0.23^{aA}	31.10 ± 0.27^{aA}	0.39 ± 0.01^{aA}
Control		7.96 ± 0.54^{eD}	0.16 ± 0.05^{eC}	0.00^{eC}

Different superscripts in the same column denote significant difference at $p<0.05$.
Small superscripts are used for comparison at constant temperature, while capital ones are used when comparing under constant spraying time. *GAE: Gallic acid equivalent; **RTE: Rutin equivalent.

Table 4 Effect of coating conditions on antioxidant activities of coated rice with purple- corn cob extract.

Conditions		%inhibition DPPH radical	FRAP (μmol $FeSO_4$/g)
Temperature (°C)	Spraying time (min)		
50	10	24.14 ± 0.12^{B}	8.43 ± 0.72^{B}
60	10	22.90 ± 0.22^{C}	6.56 ± 0.03^{C}
70	10	23.08 ± 0.49^{C}	7.71 ± 0.27^{C}
50	5	22.09 ± 0.21^{c}	6.25 ± 0.02^{c}
50	10	22.90 ± 0.21^{c}	6.56 ± 0.02^{c}
50	15	24.28 ± 0.16^{b}	11.12 ± 0.09^{b}
Extract		71.96 ± 0.43^{aA}	50.22 ± 1.04^{aA}
Control		19.15 ± 0.58^{dD}	4.80 ± 0.15^{dD}

Different superscripts in the same column denote significant difference at $p<0.05$.
Small superscripts are used for comparison at constant temperature, while capital ones are used when comparing under constant spraying time.

Table 5 Anthocyanins composition in purple corn extract and coated rice (μg/g).

Temperature (°C)	Spraying Time (min)	Kuromanin	Keracyanidin	Malvin	Dephinidin	Cyanidin	Pelargonidin	Malvidin	Total
50	10	1.47 ± 0.18^{b}	6.37 ± 0.21^{b}	nd	3.14 ± 0.15^{b}	6.24 ± 0.02^{b}	nd	nd	17.21 ± 0.50^{b}
60	10	1.08 ± 0.13^{c}	5.93 ± 0.06^{b}	nd	3.05 ± 0.02^{bc}	6.09 ± 0.03^{bc}	nd	nd	16.14 ± 0.19^{c}
70	10	0.88 ± 0.02^{c}	5.74 ± 0.11^{d}	nd	2.85 ± 0.01^{d}	5.82 ± 0.12^{c}	nd	nd	15.28 ± 0.21^{d}
50	5	1.09 ± 0.16^{c}	5.72 ± 0.30^{c}	nd	2.93 ± 0.10^{cd}	6.10 ± 0.03^{bc}	nd	nd	15.85 ± 0.58^{cd}
50	10	1.47 ± 0.18^{b}	6.37 ± 0.21^{b}	nd	3.14 ± 0.15^{b}	6.24 ± 0.02^{b}	nd	nd	17.21 ± 0.50^{b}
50	15	1.75 ± 0.12^{a}	7.42 ± 0.27^{a}	nd	3.68 ± 0.18^{a}	6.80 ± 0.43^{a}	nd	nd	19.65 ± 0.70^{a}
Extract		13.48 ± 0.64	24.62 ± 0.93	6.34 ± 0.69	8.21 ± 0.25	44.70 ± 1.05	17.36 ± 1.08	0.39 ± 0.08	115.11 ± 4.16
Control		nd	nd	nd	nd	nd	nd	nd	nd

Kuromanin (cyanidin-3-O-glucoside chloride), keracyanidin (cyanidin-3-rutinoside), malvin (malvidin-3,5-diglucoside),dephinin, pelargonidin, malvidin.

Values are expressed as mean ± standard deviation (n=3). Means with different letters in the same column were significantly different at the level $p<0.05$.

Figure

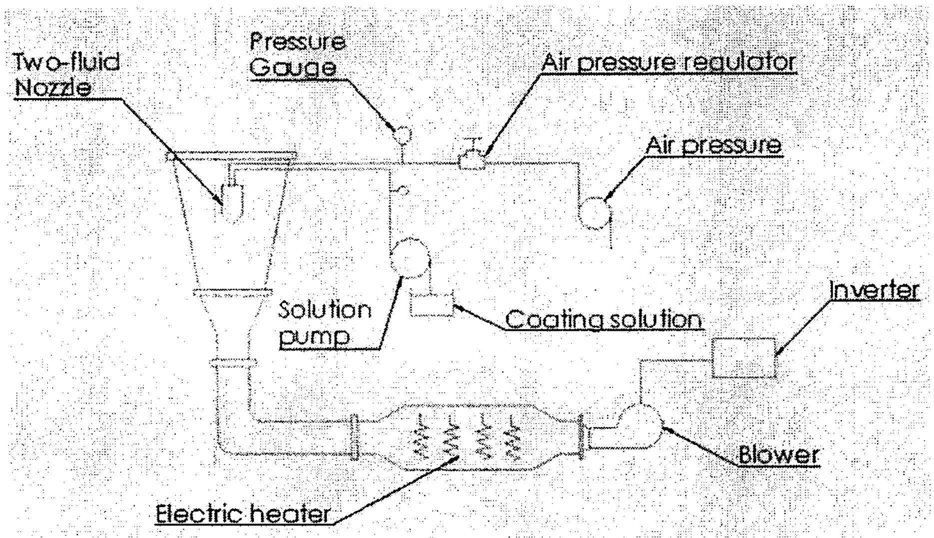

Figure 1 Schematic diagram of the top-spray fluidized bed coating unit.

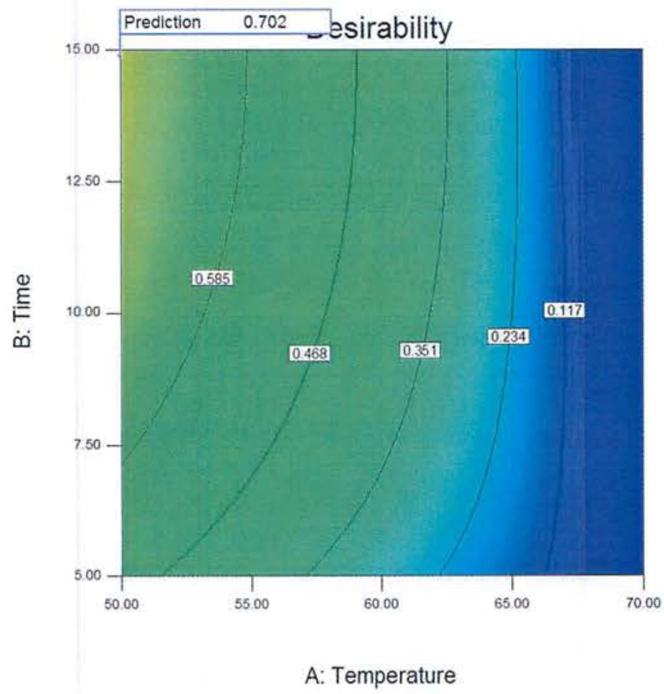

Figure 2 Desirability of the coating conditions.

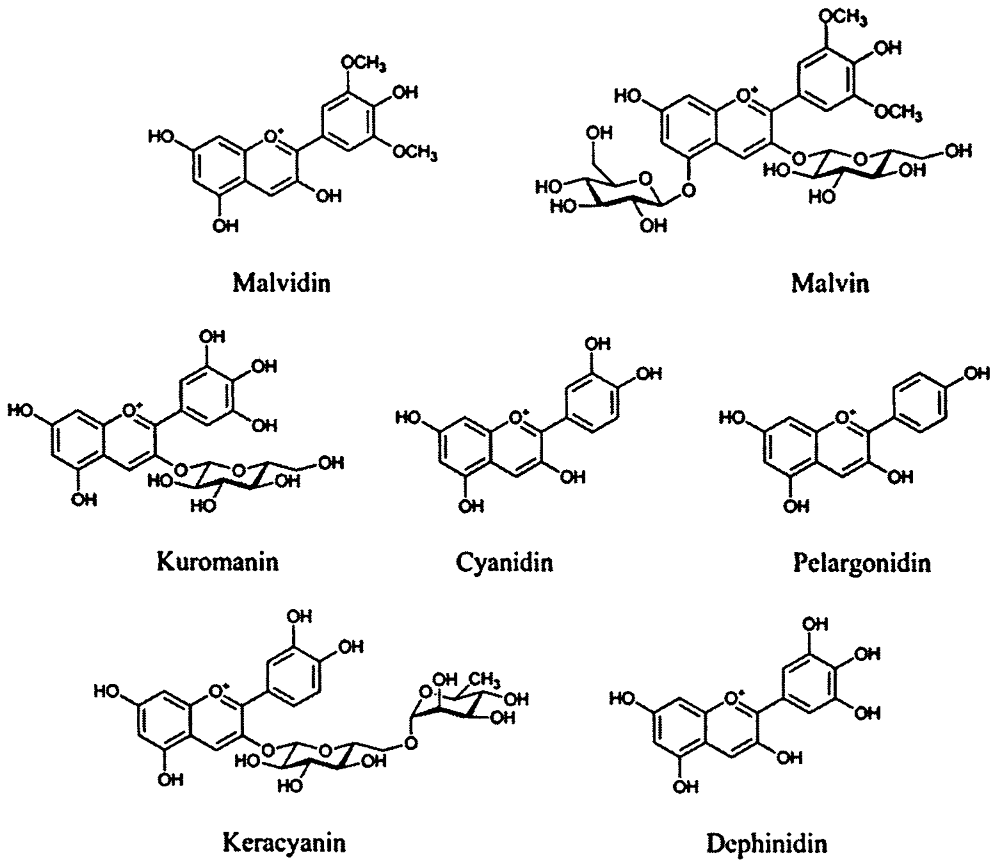

Figure 3 Chemical structure of anthocyanins.