SİDAS MEDYA
Akademik Gıda®
ISSN Online: 2148-015X
http://www.academicfoodjournal.com

Akademik Gıda 15(3) (2017) 222-232, DOI: 10.24323/akademik-gida.345252

Research Paper / Araştırma Makalesi

Optimized Top-Spray Fluidized Bed Coating Method of Rice Coated with *Bauhinia strychnifolia* Craib. Solution

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Received (Geliş Tarihi): 15.08.2017, Accepted (Kabul Tarihi): 06.10.2017
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ABSTRACT

A top-spray fluidized bed coating method aiming at improving health benefits of white rice using *Bauhinia strychnifolia* Craib. (BSC) solution, containing bioactive compounds was optimized in this study. The BSC solution was mixed with maltodextrin as a coating solution, and dextrose equivalent (DE) of maltodextrin was varied (DE10 and DE20). Both milled and instant rice were coated by using the top-spray fluidized bed coater with an optimal coating condition. Chlorophyll *a* and *b* and total phenolic content (TPC), as well as antioxidant activities (DPPH and FRAP assays) of BSC coated rice samples before and after cooking were analyzed. In addition, textural properties of both BSC coated milled and instant rice were evaluated. Results showed higher chlorophyll *a* and *b* as well as total phenolic contents in coated milled rice compared with coated instant rice. However, percent loss of these compounds for instant rice was lower after cooking. DPPH and FRAP values showed improvement of antioxidant activity after cooking for both coated milled and instant rice. Results suggested that factors influencing BSC coating included the coating and sample preparation methods as well as the nature of sample. Moreover, the appropriate coating method was to coat instant rice with DE10 maltodextrin as a carrier in coating material to obtain the minimal loss of bioactive compounds and maximum antioxidant activities, while the coated rice maintained good textural qualities compared with those of the conventionally cooked rice.

Keywords: Dextrose equivalent, Fluidization, Spray granulation, DPPH, FRAP

Bauhinia strychnifolia Craib. Çözeltisi ile Kaplanmış Pirincin Optimize Edilmiş Üst Sprey Akışkan Yatak Kaplama Yöntemi

ÖZ

Biyoaktif bileşenler içeren *Bauhinia strychnifolia* Craib. (BSC) çözeltisi kullanarak beyaz pirincin sağlığa olan faydalarını arttırma amacıyla bir üst sprey akışkan yatak kaplama yöntemi optimize edilmiştir. BSC çözeltisi kaplama çözeltisi olarak dekstroz eşdeğeri (DE) farklı (DE10 ve DE20) maltodekstrin ile karıştırılmıştır. Öğütülmüş ve instant pirinç, optimum spreyleme koşuluyla üst sprey akışkan yataklı kaplayıcı kullanılarak kaplanmıştır. BSC kaplı pirinç numunelerinin pişirme öncesi ve sonrasında klorofil a, klorofil b, toplam fenolik içeriği (TPC) yanı sıra antioksidan aktiviteleri (DPPH ve FRAP testleri) de analiz edilmiştir. Ayrıca, hem BSC kaplı öğütülmüş hem de instant pirincin tekstürel özellikleri değerlendirilmiştir. Elde edilen sonuçlar, kaplanmış instant pirinç ile karşılaştırıldığında, kaplanmış öğütülmüş pirincin, daha yüksek toplam fenolik içeriği ve klorofil a ve b içerdiğini göstermiştir. Bununla birlikte, instant pirinç numunesi için bu bileşiklerin yüzde kaybının pişirmeden sonra düşük olduğu görülmüştür. DPPH ve FRAP değerleri, hem kaplanmış öğütülmüş hem de instant pirinç için pişirmeden sonra antioksidan aktivitesinin iyileştiğini göstermiştir. Bulgularımız, BSC kaplamayı etkileyen faktörlerin sadece kaplama yöntemi değil aynı zamanda numune hazırlama ve numunenin doğası olduğunu düşündürmektedir. Ayrıca, kaplanmış pirinç, konvansiyonel olarak pişirilmiş pirincinkine kıyasla iyi tekstürel niteliklerini korumuştur. En uygun kaplama yöntemi, biyolojik olarak az miktarda biyoaktif bileşik kaybı ve maksimum antioksidan aktivite elde edilen kaplama materyalinde bir taşıyıcı olarak DE10 maltodekstrin ile kaplanan instant pirinçte elde edilmiştir.

Anahtar Kelimeler: Dekstroz eşdeğeri, Akışkanlaştırma, Püskürtme granülasyonu, DPPH, FRAP

INTRODUCTION

White rice or milled rice has been preferred by consumers due to its flavor and texture even though brown rice has been alternatively consumed as a result that it contains higher nutritional value and phytochemicals content [1]. Up to date, many attempts have been made to improve health benefits of white rice by adding natural extract containing bioactive compounds [1, 2].

Bauhinia strychnifolia Craib. (BSC) is one of many phytochemical plants which contain bioactive compounds, including chlorophylls and phenolic compound. It is the green leafy plant (*Leguminosae-Caesalpiniaceae* spicies) mainly containing chlorophylls. As medicinal plants, BSC's green leaves with the obovate shape are commonly as a tonic and detoxification products [3]. In addition, their leaves and stems have been used to alleviate alcoholic toxication, fever, cancer and allergy in Thai traditional medicine [3, 4, 5]. However, when applying these compounds in food processes, heat degradation has to be taken into account as a result that chlorophylls are susceptible to pH, light, oxygen, enzymatic activities, and especially heat [6]. Therefore, the appropriate processes should be considerably chosen.

Among rotating drum, rotating pan, mixer and fluidized bed, the latter associated with coating spray has been used as the value-added means for grains [1, 2, 7] due to its high reproducibility and coating uniformity [2, 8]. As a unique operation in which coating and drying processes take place simultaneously in only one equipment, fluidized bed coating has been successfully used in order to improve health promoting properties in white rice, as reported by Palamanit et al. [2] and Duangkhamchan and Siriamornpun [1]. In addition, functional properties of other grain products have been promoted by means of fluidized bed coating process; for instance, Solís-Morales et al. [9] applied a top-spray fluidised bed reactor to increase sweetness of puffed wheat with sweet chocolate, and Duangkhamchan and Inchuen [7] enhanced the antioxidant properties of puffed pounded-unripe rice by spraying marigold extract in the fluidized bed coating equipment.

Therefore, in this work, we improved the health promoting properties of milled rice by means of a top-spray fluidized bed coating process along with BSC coating solution. However, milled rice coated with the extract still needs to be cooked prior to consuming which could affect the bioactive compounds. In addition to investigation of applying the fluidized bed coating process to promote health benefits in milled rice, in this work, we also studied the effects of cooking processes, including instant rice cooking, on bioactive compounds and antioxidant properties as well as textural properties of cooked coated rice. Moreover, due to chemical-structure change of maltodextrin with different dextrose equivalents (DEs), influence of coating solution with varied DEs of maltodextrin was also investigated. We expect to obtain an appropriate coating and cooking process for preserving not only bioactive compounds but also textural properties of rice coated with BSC.

MATERIALS and METHODS

Materials

Rice Samples

Milled rice (Chainat variety: CNTBR82075-43-2-1) was purchased from the local market in Maha Sarakham province, Thailand. Comparing with Khao Dawk Mali 105 (KDML 105), it is not preferred by consumers due to its texture and aroma. It was therefore chosen as a sample to be value-added in this work. Prior to each experiment, initial moisture content of the rice sample was measured regarding the standard procedure for grain moisture content analysis [10].

Bauhinia strychnifolia Craib. (BSC) Solution

BSC leaves obtained from Maha Sarakham province, Thailand were firstly sorted by selecting only the green ones with the size of 3-7 cm wide and 6-12 cm long and cleaned with tap water. The BSC leaves were added into distilled water with a ratio of 1:2 (w/v), then blended with speed of 10,000 revolutions per minute for 2-3 min. The resultant mixture was filtered using cotton cloth to provide the solution. In order to minimize degradation of chlorophylls, the BSC solution was stored in a dark container under 4-5°C until used.

Coating Solution

The prepared BSC solution was mixed with maltodextrin with different values of dextrose equivalent (DE10 and DE20) in order to study its effect on encapsulability of bioactive compounds. The resultant concentration of coating solution was kept constant as 10°Brix. The coating solution was stored in a dark container under cold condition, 4±1°C, until used.

Preparation of Instant Rice

Instant rice was prepared by using the microwave-hot air drying method. The cooked milled rice sample was dried under air temperature of 80°C combined with 300-W microwave and air velocity of 1±0.05 m/s until its moisture content reached approximately 10% (wet basis). Air temperature and velocity were measured by a hot-wire anemometer (Testo, testo425). Domestic microwave oven (Samsung, ME711K/XST) was connected to the hot-air supply system of the top-spray fluidized bed coating unit when producing instant rice. Details of instant rice preparation were referred to Jiao et al. (2014). The instant rice was kept in an aluminum-foil bag under cold storage (4±1°C) until used. In the final stage of investigation, bioactive compounds including chlorophyll *a*, *b* and total phenolic content and antioxidant activities as well as textural qualities of coated rice cooked by different methods were evaluated. Therefore, the rehydration condition of coated instant rice was first optimized by means of response surface method (RSM). The details regarding the RSM were described in section 2.7.

Coating Procedure

Rice samples including milled rice and instant rice were subjected to coating process using a top-spray fluidized bed coating reactor, as shown in Fig. 1. Five hundred grams of rice sample was coated with BSC coating solution under optimal coating condition reported in our previous study [1]. Briefly, an inlet temperature, spraying time, feed rate and fluidization air velocity were 50°C, 15 min, 10 mL/min and 4.7 m/s, respectively. The BSC coated rice sample was sealed in a laminated bag and stored under 4±1°C until analysis. Each experiment was carried out in triplicate.

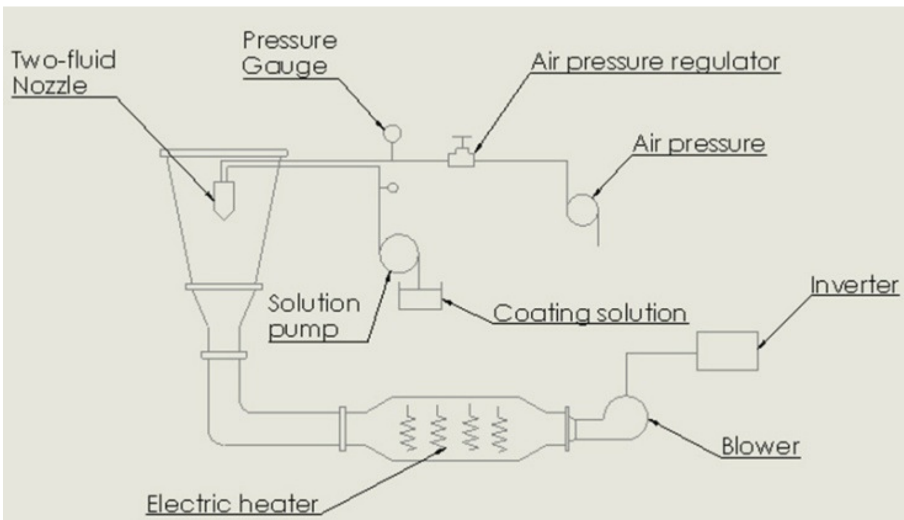


Figure 1. Schematic diagram of the top-spray fluidized bed coating unit [1].

Texture Analysis

The textural properties of cooked rice (milled rice) and rehydrated rice (instant rice) were determined by using a texture analyzer (Stable Micro System, TA-XT2i, Surrey, UK) with a rice extrusion rig. Twenty three grams of cooked rice was immediately placed in the rig's testing cell. It was pushed down by a plunger of similar cross-section to the cell, compressing the sample and extruding it at test and post-test speed of 1.6 and 10 mm/s, respectively, through holes in the base extrusion plate. A force time curve was obtained from the test and the measurements of hardness and stickiness were computed using the Texture Expert software supplied with the instrument.

Bioactive Compounds Analysis

Chlorophyll Analysis

In this work, total chlorophyll *a* and *b*, mostly found in green leafy plants such as BSC [11] were chosen for analysis. As modified from Chen and Pei [12], the BSC coated samples were extracted with 80% acetone. The mixture was then centrifuged at 8000 g for 15 min and filtered through Whatman paper no.1. Chlorophyll *a* and *b* were measured using a double beam spectrophotometer (UV-160 A, Shimadzu Corporation, Kyoto, Japan) associated with absorbance at 663 nm and 645 nm, respectively. The following correlations were used to calculate the content of chlorophyll *a* (chl-*a*) and chlorophyll *b* (chl-*b*).

$$\text{Chl-}a = 12.72A_{663} - 2.59A_{645} \quad (1)$$

$$\text{Chl-}b = 22.9A_{645} - 4.67A_{663} \quad (2)$$

Total Phenolic Content

Total phenolic content (TPC) in the BSC coated rice samples was determined using the Folin-Ciocalteu reagent as following the methods of Zhou and Yu [13], and Kubola and Siriamornpun [14]. Briefly, Folin-Ciocalteu reagent was first diluted 10-fold with distilled water, and 2.25 mL of this was subsequently mixed with 30 µL of the sample extract. After leaving under room condition for 5 min, the resultant mixture was added by 2.25 mL of sodium carbonate solution with concentration of 60 g/mL, and then was stabilized at room temperature for 90 min. The total phenolic content was eventually determined using the absorbance of the sample mixture at 725 nm associated with the standard curve obtained from gallic acid. Therefore, the total phenolic content was reported as milligram gallic acid equivalents per gram dry matter (mg GAE/g DM).

Antioxidant Activity Analysis

We selected two different methods for determining the antioxidant activities on basis of their chemical mechanism. The first DPPH radical scavenging assay, which is routinely practiced for assessment of free radical scavenging potential of an antioxidant molecule, measures the antioxidant content of plant tissues in different solvent systems including ethanol, aqueous acetone, methanol, aqueous alcohol, and benzene [15]. On the other hand, FRAP assay measures the reducing potential of an antioxidant reducing with a ferric tripyridyltriazine (Fe^{3+}-TPTZ) complex and producing a colored ferrous tripyridyltriazine (Fe^{2+}-TPTZ) [16]. Generally, the reducing properties are associated with the presence of compounds which exert their action by breaking the free radical chain by donating a hydrogen atom [17].

DPPH Radical Scavenging Activity

As described in Braca et al. [18], the antioxidant activity of the BSC coated rice samples, the scavenging activity was determined based on the stable 1,1-diphenyl-2-picrylhydrazy (DPPH) free radical. Briefly, the sample extract (0.1 mL) was added to 3 mL of a 0.004% MeOH solution of DPPH, and subsequently its absorbance was measured at 517 nm by a spectrometer. The inhibition activity was calculated as $[(A_0 – A_e)/A_0] \times 100$, where A_0 and A_e is absorbance without and with extract, respectively. The antioxidant activity measured by this method was presented in mg Trolox/100 g dry matter.

Ferric Reducing/Antioxidant Power (FRAP) Assay

The FRAP assay adapted from Moyer et al. [19] was used to determine the antioxidant activity of the BSC coated rice samples. Briefly, the FRAP reagent was freshly prepared by mixing 100 mL of acetate buffer (300 mM, pH 3.6), 10 mL TPTZ solution (10 mM TPTZ in 40 mM/HCl), 10 mL $FeCl_3{\cdot}6H_2O$ (20 nM) in a ratio of 10:1:1 and 12 mL distilled water, at 37°C. The FRAP reagent (1.8 mL) was then added into 180 µl Milli-Q water and 60 µL of the sample extract, followed by standard or blank. After incubation at 37°C for 4 min, an absorbance of the resultant mixture was subsequently measured at 593 nm by a spectrometer associated with the FRAP working solution as a blank. The antioxidant activity of sample was determined against a standard curve of ferrous sulphate ($FeSO_4{\cdot}7H_2O$) with concentrations ranging from 0 to 3 nM in Milli-Q water or methanol with 0.1% (v/v) HCl. The antioxidant activity measured by FRAP assay was reported in mg Fe^{2+}/100 g dry matter.

Response Surface Method and Desirability Approach

Response surface method has been widely used to determine the appropriate process condition for multivariate problems. In this work, RSM and desirability approach were employed for two circumstances – determinations of optimal rehydration condition and coating process. In this work, a second-order polynomial equation was applied to describe the effects of factors on responses, expressed as follows [20].

$$Y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i}^{n} a_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} a_{ij} x_i x_j \quad (3)$$

In equation (3), 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.

The estimated response obtained from equation (3) was subsequently transformed into a scale free value (d_i) called desirability ranging from 0 to 1 of which 0 represents one or more responses are being outside their acceptable limits and 1 indicates the ideal case. Various desirability functions $d_i(Y_i)$ can be used depending on a particular response which can be maximized or minimized or assigned to a target value. The individual desirabilities were subsequently combined using the geometric mean providing the overall desirability, D [21].

$$D = \left(d_1(Y_1)d_2(Y_2)...d_k(Y_k)\right)^{1/k} \quad (4)$$

Where k denotes the number of responses.
If a response was assigned to a target value, the individual desirability function was

$$d_i(Y_i) = \begin{cases} 0 & \text{if } Y_i(x) < L_i \\ \left(\frac{Y_i(x) - L_i}{T_i - L_i}\right)^s & \text{if } L_i \le Y_i(x) \le T_i \\ \left(\frac{Y_i(x) - U_i}{T_i - U_i}\right)^t & \text{if } T_i \le Y_i(x) \le U_i \\ 0 & \text{if } Y_i(x) > U_i \end{cases} \quad (5)$$

where L_i, U_i and T_i are the lower, upper and target value, respectively.

If a response value was minimum, the $d_i(Y_i)$ function was expressed as

$$d_i(Y_i)=\begin{cases} 1 & \text{if } Y_i(x)<T_i \\ \left(\dfrac{Y_i(x)-U_i}{T_i-U_i}\right)^s & \text{if } T_i\le Y_i(x)\le U_i \\ 0 & \text{if } Y_i(x)>U_i \end{cases} \quad (6)$$

If a particular response was maximized, the individual desirability function was

$$d_i(Y_i)=\begin{cases} 0 & \text{if } Y_i(x)<L_i \\ \left(\dfrac{Y_i(x)-L_i}{T_i-L_i}\right)^s & \text{if } L_i\le Y_i(x)\le T_i \\ 1 & \text{if } Y_i(x)>T_i \end{cases} \quad (7)$$

The exponents s and t in equations (5-7) determine how important it is to hit the target value. Details concerning the desirability approach have been described in Derringer and Suich [21].

In order to optimize a rehydration condition for coated instant rice, a full factorial experimental design was employed with two factors including a ratio of rice to water (1:1.5 and 1.2) and microwave heating time (1 and 2 min). A microwave power was kept constant as 800 W. Hardness and stickiness of rehydrated sample were used as responses in order to provide the consistency with the factors.

Finally, suitable coating process with respect to bioactive compounds and their antioxidant activities as well as textural qualities was examined by means of desirability approach associated with RSM as aforementioned. The particular responses were first estimated and subsequently transformed into an individual desirability function. Four categories of coating process were coded as A denoting a type of rice sample (-1 for milled rice and 1 for instant rice) and B representing a level of DE (-1 for DE10 and 1 for DE20). The overall desirability for each coded coating process was determined based on the criteria of minimized %loss of chlorophylls and TPC, maximized antioxidant activities for both assays (DPPH and FRAP), and targeted textural qualities (hardness and stickiness). The coating process with highest overall desirability was considered the appropriate one.

RESULTS and DISCUSSION

Our study had applied various fluidized bed coating methods, including coating milled and instant rice with BSC solution with variation of dextrose equivalent of maltodextrin, in order to improve health promoting properties. The experiments were divided into two steps. Firstly, the optimal rehydration condition of instant rice was determined by means of response surface method associated with the targeted textural properties as desirability criteria. Subsequently, bioactive compounds, including chlorophyll *a* and *b* and total phenolic content, and their antioxidant activities measured by DPPH and FRAP assays of coated rice prepared by different methods were both qualitatively and quantitatively compared.

Optimization of Rehydration Condition of Instant Rice Coated with BSC Extract

The ratio of rice to water (RW) and microwave heating time (HT) were varied, while the microwave power was kept constant at 800W. The rehydration condition was optimized associated with the desirability criteria of the targeted hardness and stickiness of conventionally cooked rice, as a control sample. Table 1 shows the hardness and stickiness of rehydrated rice compared with those of the control sample.

Table 1. Textural qualities of rehydrated coated instant rice and control rice

Rehydration condition		Hardness (N)		Stickiness (N)	
RW	HT (min)	DE10	DE20	DE10	DE20
1:1.5	1	120.78±20.98^{c}	112.53±18.67^{C}	13.08±2.48^{b}	16.08±5.84^{B}
1:1.5	2	197.91±30.89^{a}	185.67±14.93^{A}	35.05±3.45^{a}	30.62±2.07^{A}
1:2	1	80.72±16.40^{d}	74.47±8.31^{D}	12.19±3.36^{b}	11.15±4.13^{B}
1:2	2	84.90±15.18^{cd}	80.10±13.81^{CD}	13.37±2.23^{b}	12.74±4.33^{B}
Control		157.40±4.31^{bB}		5.83±1.17^{cC}	

Different superscripts with small letters in the same column denote significant difference at p<0.05 for DE10.
Different superscripts with capital letters in the same column denote significant difference at p<0.05 for DE20.

Table 1 shows the comparison of textural qualities of rehydrated coated instant rice and control rice at various rehydration conditions and different types of maltodextrin (DE) as a carrier in coating solution. From this table, hardness and stickiness of rehydrated coated instant rice changed with different rehydration conditions.

Taking the hardness value of rehydrated instant rice into consideration, it can be observed from Table 1 that at the RW of 1:1.5, HT resulted in higher hardness, while it did not change with heating time when using the same ratio of 1:2 for both DEs. In addition, the influence of RW was also found from Table 1. At the same HT, the hardness of rehydrated sample was dramatically decreased with increasing amount of water. When compared to that of the control sample, most rehydrated instant rice tended to have softer texture.

In addition to the hardness value, stickiness at variations of RW and HT was also investigated, as shown in Table 1. At all rehydration conditions, the rehydrated instant rice was stickier than that of the control rice cooked by a conventional cooking method. The stickiness values of rehydrated instant rice were in a range of about -11 and -35 N, while the control sample had lower value (~6 N). Except at the RW of 1:1.5 and the HT of 2 min, the stickiness values of rehydrated was not changed with varied rehydration conditions. It can be also observed from Table 1 that the dextrose equivalent value of maltodextrin used as a carrier in coating solution did not affect the texture of rehydrated instant rice.

Furthermore, the correlations of hardness and stickiness as a function of RW and HT were obtained by means of RSM, as expressed below.

For DE10;

$$\text{Hardness} = -55.02 + 65.78(RW) + 295.98(HT) - 145.9(RW)(HT);\ R^2=0.88 \quad (8)$$

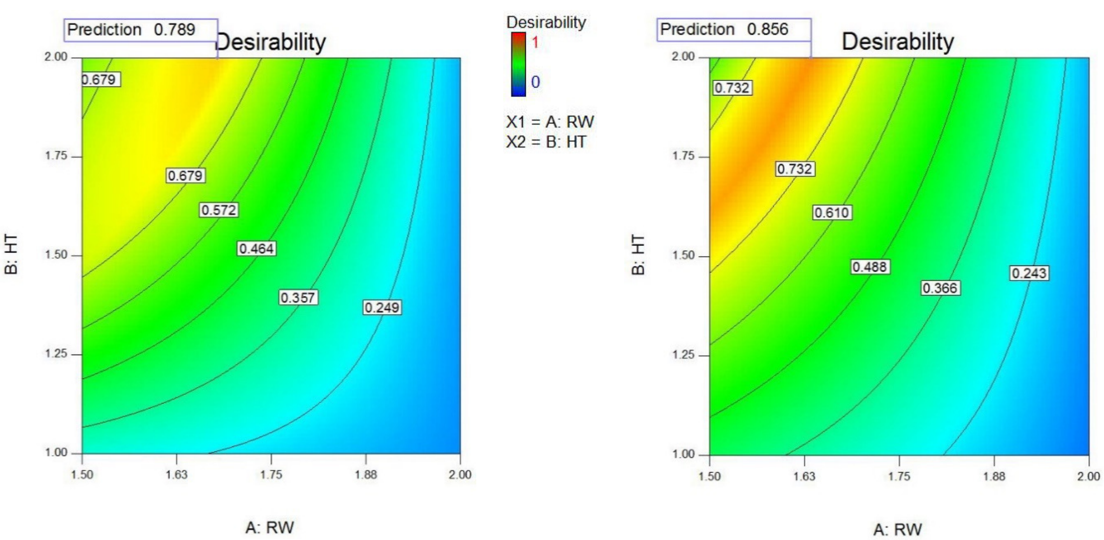
$$\text{Stickiness} = 68.59 - 39.8(RW) - 84.34(HT) + 41.58(RW)(HT);\ R^2=0.94 \quad (9)$$

For DE20;

$$\text{Hardness} = -48.96 + 58.9(RW) + 275.67(HT) - 135.02(RW)(HT);\ R^2=0.93 \quad (10)$$

$$\text{Stickiness} = 22.52 - 16.04(RW) - 53.39(HT) + 25.9(RW)(HT);R^2=0.83 \quad (11)$$

It can be observed from equations (8-11) that the second-order terms were omitted due to their insignificance. Both hardness and stickiness for both DEs correlated well with RW and HT as high determination coefficient (R^2>0.8). However, determination of an appropriate rehydration condition for coated instant rice was dependent on both RW and HT. The simultaneous optimization of hardness and stickiness values was therefore investigated by defining a 2-dimension global desirability plot, as shown in Fig. 2. Based on the targeted values regarding the hardness and stickiness values of the control sample, the highest desirability values were 0.79 and 0.86 for coating solution using DE10- and DE20-maltodextrin, respectively, which corresponded to the RW of 1:1.6 and HT of 2 min. Consequently, this rehydration condition was used for the next step.



(a) (b)

Figure 2. Desirability of rehydration condition of instant rice coated by BSC solution: (a) DE10 and (b) DE20

Optimization of Coating Method

Textural Properties of the BSC Coated Rice

Table 2 shows the variations of hardness and stickiness values affected by the BSC extract coating process. Regarding the hardness value, the highest one can be found when the rice sample was conventionally cooked using a domestic rice cooker, as the control sample, while the lowest hardness value was obtained from the fluidized-bed coating method for milled rice with the use of the DE10 maltodextrin as a carrier in coating solution. Using the same process of coating milled rice, it can be observed that DE value affected the hardness of cooked rice; the higher DE, the harder texture. Dextrose equivalent is a measure of amount of reducing sugar. Higher DE means higher amount of reducing sugar (monosaccharide), which is any sugar that is capable of acting as a reducing agent because it has a free aldehyde group or a free ketone group [22]. Therefore, it could be explained that when using maltodextrin with higher DE, monosaccharide reducing sugar could diffuse into the molecule of the rice grains by replacing water molecule, hence increasing total solid of the grains. Unlikely, the hardness of cooked rice was not affected by the DE value when coating the instant rice. Crystalline structure which is responsible for water barrier on its surface could be possible explanation of this result. The formation of amylose-lipid complexes (V-type crystalline structure) occurred during heat-moisture treatment in instant rice process [23, 24]. This pattern of crystalline was detected either because more complexes were formed during heating or crystalline regions had increased in size after gelatinization [25].

Table 2. Textural qualities of cooked rice coated with BSC using different processes

Coating process	Hardness (N)	Stickiness (N)
Coating milled rice (DE10)	83.16±2.39[c]	5.40±0.86[c]
Coating milled rice (DE20)	136.89±6.05[b]	12.81±2.54[b]
Coating instant rice (DE10)	131.53±9.76[b]	20.19±3.39[a]
Coating instant rice (DE20)	127.43±5.24[b]	19.51±3.08[a]
Control	157.40±4.31[a]	5.83±1.17[c]

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

When stickiness of cooked rice was concerned, it can be found from Table 2 that it changed with different coating methods, ranging from 5.40 to 20.19 N. The highest value was obtained from the coated instant rice for both DEs, while the lowest one was found when milled rice was coated with BSC and DE10 maltodextrin which was consistent with that of the control sample.

It can be seen from Table 2 that different coating methods affected both hardness and stickiness of cooked coated rice. Therefore, the correlations of these responses as a function of coating method were determined in order to optimize the overall desirability based on all responses in the final step. The correlations between hardness and stickiness as a function of coating method are expressed as,

$$\text{Hardness} = 119.75 + 9.73A + 12.41B - 14.46AB \quad ; R^2 = 0.94 \qquad (12)$$

$$\text{Stickiness} = -14.48 - 5.37A - 1.68B + 2.02AB \quad ; R^2 = 0.88 \qquad (13)$$

Where A and B denote type of rice sample (-1 for milled rice and 1 for instant rice) and DE level (-1 for DE10 and 1 for DE20), respectively. Again, the second-order terms were not found in equations (12-13) indicating that the first-order function was sufficient to describe the relation between the coating method and the textural properties of cooked coated samples.

Chlorophyll Contents

In addition to the texture of cooked rice coated with BSC solution by various methods, we also aimed at investigating the stability of chlorophyll *a* and *b* as presented in term of % loss after cooking process, as shown in Tables 3 and 4, respectively.

In Table 3, chlorophyll *a* content was varied depending on coating conditions with a range of 19.92-42.67 and 9.51-13.36 µg/g dry matter for the BSC coated rice before and after cooking, respectively. From this table, cooking process obviously affected the chlorophyll *a* as presented in term of %loss for all cases. In comparison to the BSC coated instant rice, the coated milled rice had higher %loss of chlorophyll *a* (67-68%). This could be due to longer cooking time (~18 min) needed for coated milled rice, resulting in higher loss of heat-sensitive compounds. Chlorophyll *a* content of coated milled rice samples was higher than that of coated instant ones. This could be due to the microstructural change on instant rice surface (amylose-lipid complex) [24], where the coating droplets could not easily deposited onto its surface. In a production process of instant rice, the fully or partially gelatinized grains are dried to specific moisture content, and subsequently rehydrated with optimal condition before consuming [26], leading to higher V-type crystallinity in comparison with milled rice grains [23, 25]. However, chlorophyll *a* retention after cooking/rehydration could be more concerned in order to examine the suitable way of promoting health benefits to milled rice. In Table 3, chlorophyll *a* content for all cases was not significantly different, except for instant rice coated with BSC and DE10 maltodextrin, which was the lowest value. Less number of ramifications with the hydrophilic groups in lower DE maltodextrin resulting in less hydrolysis and water adsorption [27] could be possible explanation.

Table 3. Chlorophyll *a* content of the rice samples coated with BSC extract by different methods.

Sample	Chlorophyll *a* (µg/g dry matter)		%loss Chlorophyll *a*
	Before cooking	After cooking	
Coated milled rice (DE10)	42.67±2.35^{a}	13.36±1.19^{a}	68.60±3.80^{a}
Coated milled rice (DE20)	37.59±1.85^{b}	12.43±1.38^{a}	67.01±2.12^{a}
Coated instant rice (DE10)	19.92±1.51^{d}	9.51±0.69^{b}	51.95±6.44^{b}
Coated instant rice (DE20)	24.37±0.59^{c}	12.24±0.84^{a}	49.75±3.69^{b}

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

Similar trend to chlorophyll *a* was observed for chlorophyll *b*, as shown in Table 4. Chlorophyll *b* contents were in a range of 4.60-23.15 and 3.32-10.51 µg/g dry matter for the BSC coated rice samples before and after cooking, respectively. Stability of chlorophyll *b* was also determined in term of %loss after cooking. Table 4 shows that the BSC coated milled rice lost more chlorophyll *b* (higher %loss of approximately 52-57%), while the coated instant samples did only 29%loss. As described earlier, more chlorophyll *b* degraded with longer cooking time for coated milled rice. Noticeably, higher amount of chlorophyll *b* was found in the BSC coated milled rice before cooking, as also observed previously for chlorophyll *a*. This could be also explained by higher V-type crystallinity of the instant rice surface compared to milled rice [24]. In addition, DE of maltodextrin did not affect chlorophyll *b* of the BSC coated milled rice, while the higher amount was found with higher DE for the coated instant sample, meaning better enhancement of encapsulability.

Antioxidant Properties

In addition to chlorophyll contents, we investigated the effects of coating methods on total phenolic content together with its antioxidant activities, as shown Tables 5 and 6, respectively.

TPC of BSC milled rice were higher than coated instant rice in all samples, as seen in Table 5. Most of TPC are soluble in water. It could be more uptaken into milled rice more easily than did instant rice in which crystalline structure barrier. Possible explanation could be similar to that described for chlorophylls analysis.

After cooking, TPC was decreased up to ≈ 50% for milled rice, while a slightly less decrease was found in coated instant rice. For all coated samples, they were subjected to heat during conventional cooking in a domestic cooker and rehydration process associated with microwave heating for the BSC coated milled rice and BSC coated instant one, respectively. The former cooking process led to a higher degradation of phenolic because they are highly thermo-sensitive [28], hence higher loss percentage of TPC.

Table 4 Chlorophyll *b* content of the rice samples coated with BSC extract by different methods.

Sample	Chlorophyll *b* (µg/g dry matter)		%loss Chlorophyll *b*
	Before cooking	After cooking	
Coated milled rice (DE10)	23.15±2.67^{a}	9.78±1.52^{a}	57.60±5.81^{a}
Coated milled rice (DE20)	22.08±1.35^{a}	10.51±0.72^{a}	52.18±5.58^{a}
Coated instant rice (DE10)	4.60±1.10^{c}	3.32±1.26^{b}	29.02±11.60^{b}
Coated instant rice (DE20)	7.19±1.13^{b}	5.01±0.79^{b}	29.71±11.23^{b}

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

By means of RSM, correlations of %loss of chlorophyll *a* and *b* as a function of fluidized-bed coating method are expressed as,

$$\%\text{loss of chlorophyll } a = 59.33 - 8.48A - 0.95B - 0.15AB \quad ;R^2=0.86 \qquad (14)$$

$$\%\text{loss of chlorophyll } b = 42.13 - 12.76A - 1.18B + 1.53AB \quad ;R^2=0.75 \qquad (15)$$

Table 5. Total phenolic content (mg Gallic acid equivalent/100 g dry matter) of cooked rice coated with BSC solution by different methods.

Sample	Total phenolic (mg gallic acid equivalent/100 g dry matter)		%loss
	Before cooking	After cooking	
Coated milled rice (DE10)	67.27±3.89^{a}	36.52±1.27^{a}	45.67±1.26^{b}
Coated milled rice (DE20)	69.92±2.58^{a}	33.51±2.01^{a}	52.10±1.11^{a}
Coated instant rice (DE10)	14.60±0.32^{c}	7.91±0.21^{c}	45.82±0.25^{b}
Coated instant rice (DE20)	16.15±0.38^{b}	10.84±0.55^{b}	32.91±1.83^{c}

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

Table 6. Antioxidant activity (DPPH and FRAP) of cooked rice coated with BSC solution by different methods.

Sample	DPPH (mg Trolox/100 g dry matter)		FRAP (mg Fe^{2+}/100 g dry matter)	
	Before cooking	After cooking	Before cooking	After cooking
Coated milled rice (DE10)	150.45±1.27^{bB}	199.11±16.23^{aA}	38.74±0.79^{bB}	59.19±4.99^{aA}
Coated milled rice (DE20)	189.22±8.17^{aB}	218.02±15.13^{aA}	44.75±1.36^{aB}	53.61±2.27^{aA}
Coated instant rice (DE10)	116.27±8.38^{dA}	116.48±9.50^{cA}	23.25±0.65^{dB}	57.13±1.30^{aA}
Coated instant rice (DE20)	135.22±9.00^{cA}	138.86±7.66^{bA}	25.02±0.39^{cB}	29.46±0.88^{bA}

Different small letter superscripts in the same column denote significant difference at p<0.05.
Different capital superscripts in the same row denote significant difference at p<0.05.

For our present study, we found that FRAP values were significantly increased after cooking in all samples studied (p<0.05), as shown in Table 6. However, DPPH values were significantly increased after cooking for coated milled rice but not for coated instant ones. The reason to explain this phenomenon is that thermal process may enhance the antioxidant activity by activating some bioactive compounds. Mostly, heat highly causes degradation of bioactive compounds such as phenolics, flavonoids and anthocyanins [28]. However, many studies have revealed that it could cause not only losses, but also no change or even improvement of antioxidant properties [29]. 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 [30] in some products such as in dried mulberry leaves using far infrared drying [31]. Our findings were in agreement with those described above.

The %loss of TPC and antioxidant activities for both assays (DPPH and FRAP) correlated well with high R^2 (>0.8), as expressed below.

$$\%\text{loss of TPC} = 44.13 - 4.76A - 1.62B - 4.84AB \quad ; R^2=0.98 \qquad (16)$$
$$\text{DPPH} = 168.28 - 40.28A + 10.49B + 1.03AB \quad ; R^2=0.94 \qquad (17)$$
$$\text{FRAP} = 49.85 - 6.55A - 8.31B - 5.52AB \quad ; R^2=0.96 \qquad (18)$$

Overall Desirability

Finally, all estimated responses (equations 12-18) were transferred into individual desirability function, and the overall desirability value was determined based on the minimized %loss of chlorophylls and TPC, maximized antioxidant activities for both assays (DPPH and FRAP), and targeted textural qualities (hardness and stickiness). The overall desirabilities for all coating methods and their corresponding values of each response are presented in Table 7.

Table 7. Overall desirabilities of all fluidized-bed coating method

Coded coating method		Desirability
A	B	(-)
1	-1	0.405
-1	1	0.363
1	1	0.348
-1	-1	0.267

It can be concluded from Table 7 that the coded coating method of A(1) and B(-1), corresponding to the method of coating instant rice with the use of DE10 maltodextrin as a carrier in coating material was an appropriate method based on highest overall desirability (0.405). Therefore, we recommend this coating method to obtain the minimal loss of chlorophyll contents, total phenolic and antioxidant activities, while the coated rice maintains good textural qualities compared with those of the conventionally cooked rice.

CONCLUSIONS

Our study has revealed that BSC coated milled and instant rice enhanced health promoting properties by adding chlorophyll contents (*a* and *b*), total phenolic content and antioxidant activities. Coating effectiveness involved not only coating parameters (e.g. spray time, inlet temperature and solution feed rate), but also properties of coating solution and nature of core materials. For instance, the DE value resulted in chlorophylls attachment onto the core materials. In addition, the higher V-type crystallinity in instant rice caused lower chlorophylls and phenolic encapsulability. Our findings have provided valuable information for selecting appropriate coating process in terms of natural bioactives and antioxidant properties.

ACKNOWLEDGEMENTS

The authors would like to thank Mahasarakham University Research Fund for financial support (No.5812002/2558). Thanks are also to Mahasarakham University Development Fund for Travel grant.

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