Optimization of Rice Coating Process Using Response Surface Methodology

W. Duangkhamchan and J. Jamradloedluk

***Abstract*—The objectives of this study were to optimize the operating condition of the top-spray fluidized bed coating process on rice and to investigate the effects of coating factors on physical properties of coated rice. The coating factors tested in this work consisted of inlet temperatures (60-80°C), spraying times (5-15 min) and feed rates (6-10 ml/min). Maltodextrin solution (20 °Brix) mixed with red food color was used as coating solution. Response surface methodology was used to describe the effects of all factors with respect to responses including %fissure, %head rice yield (HRY) and chroma. Full factorial design was used for the experimental design with the use of three levels. In addition, the subsequent experimental data was fitted to quadratic regression models to describe the relationship between all factors and each response. The surface plots obtained from the experimental results revealed that all factors reasonably affected the physical properties of the coated rice. The increasing inlet temperature resulted in higher percentage of fissure. The %HRY and chroma was not affected by the inlet temperature. When the spraying time increased, it was found that chroma was higher, while %fissure and %HRY were not affected by this parameter. Furthermore, the coating solution feed rate led to a decrease in %fissure and %HRY, while the chroma increased. With the respect to the regression of determination (R^2), the quadratic models were found to be the suitable model for each response with high R^2 ranging from 0.83 to 0.93. Based on maximized %HRY and chroma, and minimized %fissure, the maximum desirability of operating condition was 0.51 at feed rate of 8.80 ml/min, spraying time of 10.23 min and inlet air temperature of 60°C.**

***Index Terms*—Coated rice, desirability, fluidized-bed, spray granulation.**

I. Introduction

Rice is one of the world's major food crops, particularly in Asia. Even though brown rice contains higher nutritional value and phytochemicals content, including antioxidants, white rice or milled rice has been preferred for consumers due to its flavor and texture [1]. In order to maintain such value, coating the white rice with natural extract containing antioxidants is a possible way to improve its antioxidant property.

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 [2]. Coating the solid particles can be made by means of rotating pan, rotating drum, fluid bed and other mixers [1]. Among them, the spray coating in the rotating pan and fluid bed are most widely used for the coated particles [3]. However, even though the rotating pan coating process has been widely used for a long time, it is still not suitable technique in food industries where high reproducibility and coating uniformity are required [3]. On the other hand, fluidized bed coating technique has been increasingly applied in the food industries [1]. 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 a coating layer on the particle surface. Among three different configurations including top-spray, bottom-spray and tangential-spray, the former in which a nozzle may be placed above or submerged inside the bed has been successfully employed in food industries due to its high versatility, relatively high batch size and relative simplicity [1].

As a result that coating and drying takes place simultaneously in only one unit operation, many attempts have been made to apply the fluidized bed coating process to improve functional properties of white rice. Palamanit *et al.* [1] improved the antioxidant property of white rice by coating turmeric extract solution using a top-spray fluidized bed coating technique. Moreover, the effects of inlet air temperature and spray rate on quality attributes of the turmeric extract coated rice were investigated. This work revealed high potential to increase total phenolic content and total antioxidant capacity of white rice. However, the information of other parameters affecting on coated rice qualities such as spraying time is still needed to be investigated. Therefore, in this work, the effects of operating parameters including inlet air temperature, feed rate and spraying time on physical properties in terms of percentage of fissured kernel, head rice yield and chroma were investigated. Finally, the response surface methodology was applied to optimize the top-spray fluidized bed coating condition for white rice.

II. Materials and Methods

A. Materials

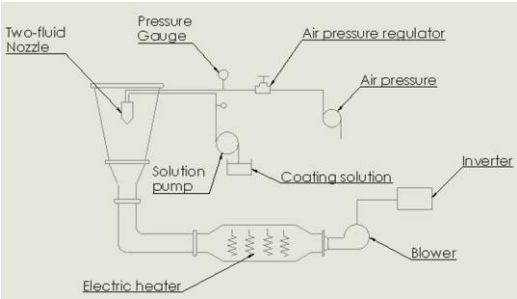
Jasmine white rice purchased from the local market in Mahasarakham province, Thailand, was used in this work. Prior to testing, its moisture content, %head rice yield and %fissure were analyzed, and the white rice was kept in a dark room at temperature of 4-6°C. Maltodrextirn solution with 20°Brix was mixed with food-grade red colorant, used as coating solution.

Manuscript received September 13, 2014; revised January 5, 2015.

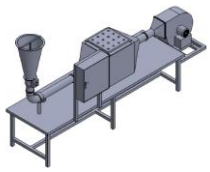
The authors are with the Mahasarakham University, Kamriang, Kantarawichai 44150, Thailand (e-mail: kimhun1976@hotmail.com, jindaporn.msu@gmail.com).

B. Experimental Setup

A laboratory scale top-spray fluidized bed coater consisted of a stainless steel tapered (8.1° inclination) vessel with a top diameter of 0.30 m, a base diameter of 0.14 m and a height of 0.56 m. At the bottom of the vessel, a stainless perforated plate with a hole size of 1 mm was used as an air distributor. Fig. 1 shows a schematic diagram of the apparatus. A high-pressure blower was used to supply the fluidizing air of which the inlet air velocity was adjusted by a frequency inverter. The velocity of inlet air was measured by the hot wire anemometer. The inlet air heated by 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 [4]. 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 the atomization air was supplied by an air compressor.



(a)



(b)

Fig. 1. The top-spray fluidized bed coating unit: (a) schematic diagram and (b) three dimensional experiment setup.

C. Experimental Procedure

1) Coating procedure

Five hundred grams of white rice, corresponding to the static bed height of 2 cm, 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 coating solution was subsequently sprayed from the nozzle, as the onset of coating process. The experimental conditions carried out in this work included the variations of inlet air temperature (60, 70 and 80°C), coating solution feed rate of 6, 8 and 10 ml/min and spraying time ranging from 5 to 15 min, while fluidizing air velocity and atomization air pressure were kept constant as 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. It was subsequently kept in a sealed aluminium-foil bag at temperature of 4-7°C before quality analysis. Each condition was carried out in triplicate.

2) Moisture content determination

Moisture content of both white 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. Five replicates were carried out for each experiment and the average value was presented.

3) Head rice yield 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 [1] was examined visually associated with a high resolution digital camera. The head rice yield was calculated by dividing a number of broken kernels by total kernels. The measurement was replicated ten times and the average result was presented.

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.

5) Chroma measurement

The chroma of coated rice was examined by the colorimeter (model ColorFlex, Hunter *Lab* 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-greeness) 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.

6) Response surface methodology

The effects of multistage-drying conditions on milling qualities were evaluated by means of RSM widely used in order to determine the appropriate process conditions for multivariate problems. In this method, the three steps of factor identification, model building and solution search are applied to provide the consistency between the responses (Y) and the factors (x_i, i = 1, …, n) by using a second-order polynomial model associated with the experimental design [5]:

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

where the coefficients a_0, a_i, and a_{ii} represent the constant, linear and quadratic effects, respectively, and a_{ij} represents the interaction effect between factors. In addition to the quadratic equation (equation 1), contour plots describing the effects of factors on responses can be applied in both 2 and 3 dimensions. Prior to provide the contour plots, the values of

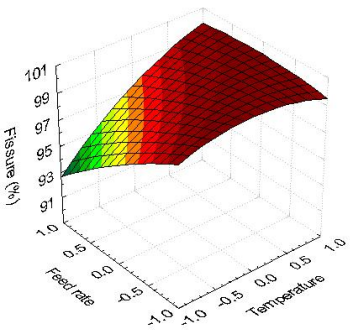
independent variables had to be coded, ranging from +1 to -1 corresponding to the maximum and minimum values of each factor, respectively, using the following equation:

$$X_i = \frac{X_i - X_{i(\text{mean})}}{X_{i(\text{mean})} - X_{i(\text{min})}} \tag{2}$$

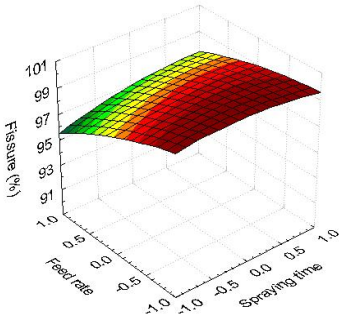
where X_i indicates the actual value of the ith factor; $X_{i(\text{mean})}$ is the mean of high and low levels of the ith factor; and $X_{i(\text{min})}$ is the minimum value of the ith factor. In this work, X_1, X_2 and X_3 were defined as coating solution feed rate (ml/min), inlet air temperature (°C) and spraying time (min), respectively.

III. Results and Discussion

The coded values of all factors and their responses were plotted in order to investigate the effects of coating parameters including feed rate of coating solution, temperature and spraying time on physical properties of coated rice. The response values presented in this work were %fissure, %head rice yield (HRY) and chroma. Fig. 2(a), Fig. 2(b) show the response surface plots describing the effects of X_1 versus X_2, and X_1 versus X_3, respectively, on %fissure of coated rice. It was found from these Fig. 2(a) that the response reached the minimum value at the coded X_1 and X_2 equal to 1.0 and -1.0, respectively, meaning that the appropriate feed rate and temperature were 10 ml/min and 60°C, respectively, while the highest %fissure was observed when using feed rate of 6 ml/min at high temperature. However, even though the minimum %fissure (~93%) was reached, a number of fissured coated kernels were still large. It could be explained by the stress formation, resulting from slower movement of moisture from inside the kernels to their surface than the existing moisture lost at the surface [1]. With regard to the effect of spraying time (X_3), the surface plot (Fig. 2(b)) shows similar trend of %fissure.



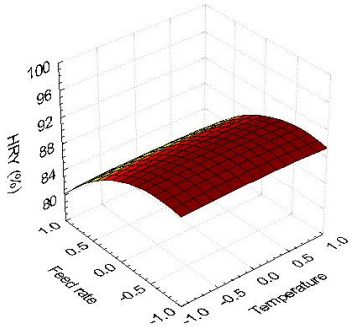
(a)



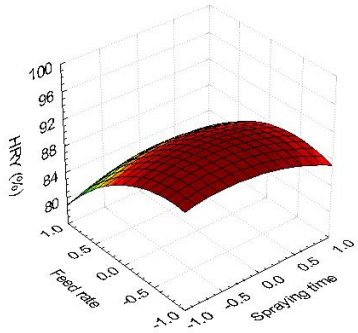
(b)

Fig. 2 Response surface plots of the effects on fissure as a function of (a) X_1vsX_2 and (b) X_1vsX_3

Fig. 3 (a), Fig. 3(b) demonstrate the response surface plots of HRY as a function of X_1 versus X_2, and X_1 versus X_3, respectively. These figures were similar, revealing that temperature and spraying time did not affect the percentage of HRY, while higher response was found when the feed rate decreased. The possible explanation could be that when supplying larger amount of feed, the resulting agglomerates may be broken by shear force, collision or bouncing to the walls.

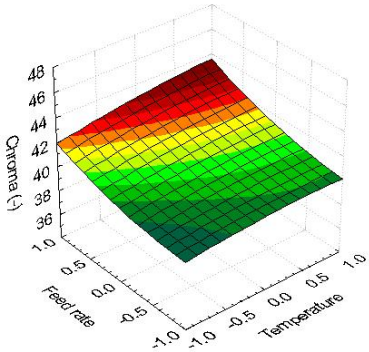


(a)

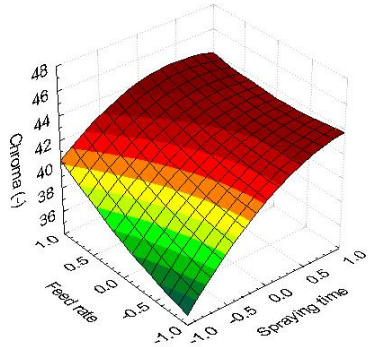


(b)

Fig. 3. Response surface plots of the effects on HRY as a function of (a) X_1vsX_2 and (b) X_1vsX_3



(a)



(b)

Fig. 4. Response surface plots of the effects on chroma as a function of (a) X_1vsX_2 and (b) X_1vsX_3

In addition, the effects of inlet air temperature, feed rate and spraying time on the chroma of coated rice are shown in Fig. 4 (a), Fig. 4 (b). It was found from Fig. 4(a) that increasing chroma was observed when feed rate increased, meaning that the larger amount of coating solution, while temperature did not affect this factor. Regarding to the spraying time, the chroma increased obviously with longer spraying time, as shown in Fig. 4(b). However, the explanation of high chroma could be considered together with %fissure, as a result that the increase in fissured coated rice could result in the higher chroma, because fissure feature could be occupied by the amount of coating solution. On the basis of response surface methodology, the correlations for %fissure, %HRY and chroma are expressed in equations (3), (4) and (5), respectively.

$$\text{Fissure} = 99.07 - 1.64X_1 + 1.76X_2 + 1.80X_1X_3 - 1.02(X_2)^2;\ R^2 = 0.83 \quad (3)$$

$$\text{HRY} = 89.84 - 4.43X_1 - 0.38X_3 + 1.35X_1X_3 - 3.49(X_1)^2 - 1.98(X_3)^2;\ R^2 = 0.90 \quad (4)$$

$$\text{Chroma} = 42.43 + 1.44X_1 + 0.57X_2 + 3.15X_3 - 1.31X_1X_3 - 1.90(X_3)^2;\ R^2 = 0.93 \quad (5)$$

Nevertheless, determination of an appropriate drying condition for coated rice was dependent on all tested operating parameters. The optimization of the top-spray fluidized bed coating process for white rice could be made based on the maximized HRY and chroma and minimized fissure. Fig. 5 presents the desirability of operating conditions. It was found from this figure that the maximum desirability was 0.51at coded spraying time, inlet air temperature and feed rate of 0.36 (10.23 min), -1.0 (60°C) and 0.398 (8.80 ml/min), respectively.

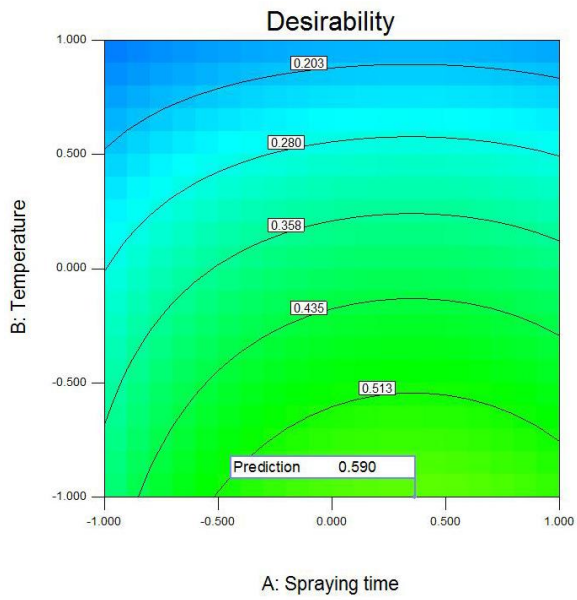


Fig. 5. Desirability of temperature and spraying time at coded feed rate of 0.398.

IV. Conclusion

The present work aimed to study the effects of operating parameters on physical properties of coated rice, and to optimize the top-spray fluidized bed coating process by means of response surface methodology. The surface plots of all responses revealed that the all factors affected the physical properties of coated rice in terms of a percentage of fissure and head rice yield, and chroma. Regarding the regression of determination (R^2), the quadratic models were found to be suitable choice to describe all responses with the R^2 higher than 0.80. However, based on maximized %HRY and chroma, and minimized %fissure, the maximum desirability (0.51) of operating condition still needed to be improved. Consequently, not only factors tested in this work, but other operating parameters, for instance, fluidization air flow rate and atomization pressure should be also taken into account in order to meet higher desirability.

References

[1] A. Palamanit, S. Soponronnarit, S. Prachayawarakorn, and P. Tungtrakul, "Effects of inlet air temperature and spray rate of coating solution on quality attributes of turmeric extract coated rice using top-spray fluidized bed coating technique," *Journal of Food Engineering*, vol. 114, pp. 132-138, 2013.

[2] P. Pathto, N. Meeso, and S. Siriamornpun, "Color and water activities changes of roselle coated rice under low relative humidity air drying," *Journal of Agricultural Science*, vol. 41, no. (3/1)(Suppl.), pp. 189-192, 2010.

[3] S. Maronga, "On the optimization of the fluidized bed particulate coating process," Ph.D. Thesis, Department of Chemical Engineering and Technology, Royal Institute of Technology, Stockholm, Sweden, pp. 1-2, 1998.

[4] W. Duangkhamchan, F. Ronsse, F. Depypere, K. Dewettinck, and J. G. Pieters, "CFD study of droplet atomization using a binary nozzle in fluidized bed coating," *Chemical Engineering Science*, vol. 68, no. 1, pp. 555-566, 2012.

[5] B. Singh, P. S. Panesar, V. Nanda, A. K. Gupta, and J. F. Kennedy, "Application of response surface methodology for the osmotic dehydration of carrots," *Journal of Food Process Engineering*, vol. 29, pp. 592-614, 2006.

Wasan Duangkhamchan recieved his B.Eng in food engineering from Kasetsart University, Thailand, in 1998 and recieved M.Eng in mechanical engineering from Khonkaen University in 2003 in the same country. In 2012, he obtained his Ph.D. in applied biological science (food engineering) from Ghent University, Belgium. At present, he is working in Faculty of Technology, Mahasarakham, Thailand, as an instructor. His research interests are CFD in food applications, encapsulation, drying and food freezing.

Jindaporn Jamradloedluk received her B.Eng in chemical engineering from KMITNB, Thailand in 1999 and received M.Eng in energy technology from KMUTT, Thailand in 2002. In 2005, she obtained her Ph.D. in thermal technology from KMUTT with royal gold jubilee scholarship. At present, she is working at Faculty of Engineering, Mahasakham University, Thailand, as an assistant professor. Her research interests are energy and thermal technology.