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TOP-SPRAY FLUIDIZED BED COATER PERFORMANCE FOR COATED RICE

*Arkom PALAMANIT[1], Somchart SOPONRONNARIT[1],Somkiat PRACHAYAWARAKORN[2]
and Patcharee TUNGTRAKUL[3]

[1]School of Energy, Environment and Materials, King Mongkut's University of Technology Thonburi 126 Pracha Uthit Road, Bang Mod, Thung Khru, Bangkok 10140, Thailand

[2]Faculty of Engineering, King Mongkut's University ofTechnology Thonburi 126 Pracha Uthit Road, Bang Mod, Thung Khru, Bangkok 10140, Thailand

[3]Institute of Food Research and Product Development, Kasetsart University 50 Phahon Yothin Road, Chatuchak, Bangkok, 10900, Thailand

Corresponding author: Arkom PALAMANIT. E-mail: energy_man001@hotmail.com

ABSTRACT

Performance of top-spray fluidized bed coating (TSFBC) depends on many factors such as operating parameters, coating solution properties and core materials properties. Therefore, the objective of this study was to investigate the effects of operating parameters, including the fluidizing air velocities (Vf), atomization air pressures (Ap) and percentages of recycle air (Ra) on the performance of TSFBC for producing the turmeric extract coated rice (TECR). Its performance was evaluated in terms of TECR qualities and coating efficiency. It was found that Vf, Ap and Ra had significant effect on the final moisture content (MC) of TECR. Operating at 0% of Ra not only provided the low final MC of TCER but also provided a high number of fissure kernels. Coating at Vf of 2 m/s provided the low coating efficiency of TSFBC, more number of uncoated white rice and low redness value (a^*) of TECR. At Vf of 2 m/s an increase in Ap improved the coating efficiency of TSFBC, but the percentage of uncoated white rice of TECR was still high. When the Vf was increased to 2.5 or 3 m/s, the coating efficiency of TSFBC was higher than 80%. Operating at Vf of 2.5 and 3 m/s, the Ap and Ra had a small effect on the coating efficiency of TSFBC.

INTRODUCTION

Coating is important to many food industries. It is applied for various objectives for example appearance modification, nutrition addition, functionality improvement and shelf life extension. Coating can be performed by different methods such as dip coating, paint coating and spray coating. However, spray coating is the popular method since it provides many advantages such as uniform coating, thickness control and multilayer coating. Spray coating by pan or drum coater is the conventional coating method that has been used for a long time. Coating with such both equipments, the coating solution is sprayed onto agitated particles and then the coated particles are dried by the dryer, which is different from the fluidized bed coater that the coating and drying are combined in one apparatus.

Top-spray fluidized bed coating (TSFBC) is one of fluidized bed coating configurations. It is more interested in food industries [1-3] since this coating technique has high versatility, relatively high batch size and relative simplicity as compared to bottom-spray or tangential-spray fluidized bed coating. Coating with TSFBC the coating solution is sprayed onto the surface of fluidized particles by a nozzle. The suspended particles will receive the droplets of coating solution only at the top of bed, namely coating zone. The level or size of coating zone can be varied depending on the bed design and operating conditions. The droplets of coating solution that are adhesive on the particle surface are partially dried in coating zone and the remaining solution is dried in drying zone by the fluidizing gas.

However, TSFBC process is complicated coating process because the complete coverage of coating layer on particle surface does not occur during a single pass of particles but it relies on many passes to the coating zone. The droplet formation, collision of droplet and particle, droplet spreading on particle surface and droplet evaporation occur almost simultaneously during coating process [2]. To obtain a complete coating, fluidizing air temperature, fluidizing air velocity, spray rate of coating solution, atomization air pressure and so on are the important parameters [2-4]. These parameters both directly and indirectly influence the coating qualities. The coating qualities are measure of coater performance including coating efficiency and product quality [5-6].

In the past, many works had studied the effect of operating parameters on the coating quality of TSFBC. Dewettinck and Huyghebaert [7] investigated the agglomeration tendency of core particle during coating of gelatin and starch hydrolysate onto glass bead surface. They found that the coating layer of hydrolyzed gelatin that adheres on the surface of glass bead was cracked due to the shrinkage during the drying process. Palamanit et al. [8] studied the effects of inlet air temperature and spray rate of coating solution on the qualities of turmeric extract coated rice. They found that operating at higher inlet air temperature and lower spray rate of coating solution led to the lower final moisture content of coated rice, and the coated rice was fissured higher than 95% when its final moisture content was lower than 11.8% wet basis, resulting in the poor cooking quality.

For the effect of operating parameters on the coating efficiency of TSFBC, Kage et al. [9] studied the effect of

various operating conditions on the coating efficiency of the system by coating of glass beads with nylon and silica powder. They found that operating at a low bed temperature, high inlet gas humidity and high spray rate of coating solution provided a high coating efficiency. Dewettinck and Huyghebaert [7] and Ronsse et al. [10] studied the effect of particle size, atomization air pressure and inlet air temperature on the coating efficiency of TSFBC. They revealed that the higher inlet air temperature and larger particle size led to the lower coating efficiency. However, Dewettinck and Huyghebaert [7] commented that if coating was done at very low inlet air temperature, the moisture content of particles became too high, resulting in more difficulty of particles fluidization, and the formation of particle agglomeration will be occurred, resulting in the low coating efficiency of TSFBC. Saleh et al. [11] found that coating efficiency increased with decreasing the particle size, due to the larger specific surface area and they more frequent contact with the coating solution droplet in the coating zone. For the effect of atomization air pressure on coating efficiency, Saleh et al. [11] reported that an increase in atomization air pressure provided the lower coating efficiency of TSFBC.

As mentioned above, it is clear that numerous variables affected the coated particle qualities and coating efficiency of TSFBC. Therefore, the objective of this study was to investigate the effects of operating parameters including fluidizing air velocity (Vf), atomization air pressure (Ap) and percentage of recycle air (Ra) on the performance of TSFBC. Its performance was evaluated by the product qualities and coating efficiency. The product qualities were evaluated in terms of final moisture content (MC), color, percentage of fissured kernels (PFK), head coated rice yield (HCRY) and percentage of uncoated white rice (UCWR).

MATERIALS AND METHODS

Raw Materials

In this work Jasmine white rice kernels (Khao Dawk Mali-105) was used as the core particle. It was purchased from Chia Meng Company, Bangkok, Thailand. The mean equivalent spherical diameter of white rice kernels was 3.43 mm and the true density was about 1419 kg/m³. The turmeric extract powder was purchased from Specialty Natural Products Company, Chonburi province, Thailand. The white rice kernels and turmeric extract powder were stored in a dark and cold storage at 4-6 °C prior to an experiment.

Top-Spray Fluidized Bed Coating Configuration

A schematic diagram of a small scale batch top-spray fluidized bed coating apparatus that was used in this work is shown in Fig. 1. It consists of two main parts, fluidized bed unit and spraying unit. In the fluidized bed unit, it consists of a stainless steel coating chamber with an inner diameter of 0.27 m and height of 1 m. A high-pressure blower (Venz, model HB 2.2, Thailand) was used to supply the fluidizing air. The velocity of fluidizing air was adjusted by the butterfly valve (V1) and measured by the hot wire anemometer (Testo, model 445, Lenzkirch, Germany). The fluidizing air was heated by electrical heater and its temperature was controlled by proportional-integral-differential (PID) controller (Linking, model LT400, Taiwan). The heated air enters the bed through the air distributor plate which it was made from a stainless

steel perforated plate. The perforated plate has the hole diameter of 1.5 mm. The fluidizing air that leaves the coating chamber flows through the cyclone separator in order to remove the dust and the amount of recycle air was adjusted by butterfly valve (V2). In the part of spraying unit, the diaphragm dosing pump (Grundfos, model Alldos DMS 12-3, France) was used to supply the coating solution to the internal mixing two-fluid nozzle (Spraying system, USA). The nozzle was a downward facing and located in the bed at 21 cm height from the distributor plate. The atomization air was supplied by the air compressor and its pressure was controlled by pressure regulator that equips with air filter.
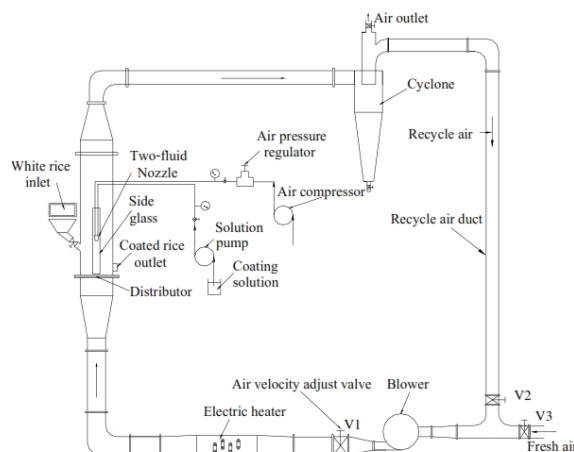

Fig.1 Schematic diagram of top-spray fluidized bed coating apparatus [8]

Coating Solution Preparation

The coating solution was prepared by dissolving the turmeric extract powder into the 70% (v/v) of ethanol solution to obtain the turmeric extract solution at the concentration of 4% (w/v). The mixture was then filtered through white cloth with four layers. Finally, the concentration of the ethanol in the filtered solution was diluted to 40% (v/v) by adding some distilled water.

Coating Procedure

Five kilograms of Jasmine white rice kernels were fed into coating chamber via inlet hopper as shown in Fig 1. At this amount, it corresponded to the static bed height of 0.1 m. As soon as the fluidizing air reached a desired temperature, the coating solution was sprayed from the two-fluid nozzle. The experimental conditions were carried out at spray rates of coating solution of 40 mL/min, inlet fluidizing air temperatures of 50 °C, spraying time of 12 min, atomization air pressures (Ap) of 1, 1.5 and 2 bar$_g$ (gauge pressure), fluidizing air velocities (Vf) of 2, 2.5 and 3 m/s and percentages of recycle air of 0 and 80%. After stopping the spraying coating solution the coated rice was dried for 5 seconds and then the coated rice was kept in a sealed plastic bag at temperature of 4-6 °C before quality analysis.

Moisture Content Determination

The moisture content (MC) of initial white rice kernels and turmeric extract coated rice (TECR) were determined by drying a 30 g sample at the temperature of 103 °C in a hot air oven for 72 hours (Memmert, model ULE500,

Schwabach, Germany). The measurement was carried out in triplicate of each experiment and an average value was reported.

Fissure Determination

The fissure of TECR kernels was determined by randomly choosing 100 TECR kernels and then each kernel was inspected by visual inspection through the digital microscope (Dino digital microscope, model AM351, Taiwan) at the magnification power of 100-200X, which is modified the method of Iguaz et al. [12] The inspections were repeated five times for each experiment and the average value was presented.

Head Coated Rice Yield Determination

The head coated rice yield of TECR was separated by an indent cylinder separator (Ngek Seng Huat, model I-1, Thailand) [13-14]. The separator has the hole size of 5 mm in diameter. The broken TECR in 200 g of TECR that had the length lower than the hole size of separator was separated. After separation, a separated sample remained only head coated rice and the head coated rice yield of TECR was calculated by dividing the head coated rice mass of TECR by total sample mass. The measurement was performed in triplicate and the result was presented by average value.

Color Measurement

The color of TECR was measured by spectrophotometer (model ColorFlex, HunterLab Reston, VA, USA) with a D65 illuminant and observer angle of 10°. The CIE L*a*b* color scale was used as color descriptor. Before measuring TECR color, the colorimeter was calibrated with a standard white plate (L* = 93.19, a* = -1.12, b* = 1.33). The TECR kernels were randomly selected and filled into a glass sample cup and their color was measured. The color values of TECR were expressed as L* (lightness-blackness), a* (redness-greenness) and b* (yellowness-blueness). The measurement was carried out in ten individual replicates of each experiment and the average value was presented.

Uncoated White Rice Kernels Determination

The determination of uncoated white rice was performed by randomly choosing 500 g TECR. The sample was inspected visually by naked eye. The white rice kernel that was not coated or partially coated by turmeric extract solution is considered as the uncoated white rice. The percentage of uncoated white rice kernels of TECR was calculated by dividing the mass of uncoated white rice by the total sample mass. The measurement was performed in triplicate and the result was presented by average value.

Total Phenolics Content Determination for Coating Efficiency Evaluation

A 5 g of finely ground sample was mixed with 100 mL of methanol in a flask and the mixture was shaken by a shaker at 175 rpm for 24 h at room temperature. The mixture was then filtered through a Whatman filter paper No.4. The supernatant solution was evaporated by a vacuum rotary evaporator at 40 °C (Buchii, Switzerland). The dry solid that obtained after evaporation was dissolved with methanol three times (one milliliter per time) to produce 3 mL of liquid-soluble extract and it was stored at temperature of -20 °C until analysis. The extraction was carried out in three individual replicates of each experiment.

Total phenolics content (TPC) of initial white rice, TECR and prepared turmeric extract solution was determined using Folin-Ciocalteu reagent with modified method of Singleton and Rossi (1965) [15]. An amount of 100 µL of extract was diluted to 1000 µL with methanol. An amount of 320 µL of the diluted sample was mixed with 1600 µL of Folin-Ciocalteu reagent, which was previously diluted ten-fold with the deionized water. After that, 800 µL of 7.5% (w/v) of sodium carbonate (Na_2CO_3) solution was added into the mixture. After 3 min, 1600 µL of deionized water was added into the mixture. The mixture was heated in a water bath at 40 °C for 30 min. The absorbance of mixture was measured using a UV-VIS scanning spectrophotometer (Shimadzu, model UV 2101 PC, Japan) at the wavelength of 765 nm. The TPC of sample was determined against the standard curve of gallic acid and the result was expressed as mg gallic acid equivalent (GAE). The measurement was carried out in triplicates of each experiment and the average value was presented.

Coating Efficiency Evaluation

Total phenolics content of TECR was chosen to calculate the coating efficiency (CE) since curcuminoids in turmeric extract are phenolic compounds. In addition, curcuminoids are also stable to heat at temperature below 60 °C [16-17] and thus they did not degraded during coating process. The coating efficiency of top-spray fluidized coating was calculated from equation (1).

$$CE = \frac{TPC_{TECR} - TPC_{WR}}{TPC_{SOL}} \qquad (1)$$

where CE is coating efficiency (%); TPC_{TECR} is total phenolics content of total TECR (mg GAE); TPC_{WR} is total phenolics content of total initial white rice (mg GAE); TPC_{SOL} is the total phenolics content of total turmeric extract solution that was sprayed on white rice kernels (mg GAE).

Statistical Analysis

All data were analysed to indicate the significance difference of quality among treatments by the analysis of variance (One-way ANOVA) using SPSS software. Differences between mean values were established using Tukey's HSD tests at a confidence level of 95% (p<0.05). The results were presented as mean values ± standard deviations (SD).

RESULTS AND DISCUSSION

Final Moisture Content of TECR

The final moisture contents (MCs) of TECR at different fluidizing air velocities, atomization air pressures and percentages of recycle air are shown in Table 1. It was found that the final MCs of TECR were in the range of 11.45-12.74% wet basis (w.b.), while the initial MC of white rice kernels was 12.50% (w.b). The experimental results indicated that the fluidizing air velocity, atomization air pressure and percentage of recycle air had significant effect on the final MC of TECR. At constant an atomization air pressure and percentage of recycle air, an increase in fluidizing air velocity led to the lower final MC of TCER. This is due to the fact that at the higher fluidizing air velocity leads to more turbulence of particles

in the bed and subsequent the heat transfer rate is higher, yielding the higher evaporation capacity of fluidizing air.

Considering the effects of percentage of recycle air on the final MC of TECR, it was found that the percentage of recycle air significantly affected the final MC of TECR. From Table 1, it is seen that operating at 0% of recycle air and all of fluidizing air velocities and atomization air pressures provided the final MC of TECR lower than 11.85% (w.b.) but the final MC of TECR was higher than 12.37% (w.b.) at 80% of recycle air conditions. This is implied that the percentage of recycle air had significant effect on the evaporation capacity of fluidizing air. Operating with recycle air reduced the evaporation capacity of fluidizing air since the relative humidity of fluidizing air increased as shown in Fig. 3. If evaporation capacity of fluidizing air is higher than the amount of solution sprayed onto the surface of particles, some of initial moisture content of white rice kernels will be removed in order to obtain the required amount of evaporation capacity of fluidizing air which led to the lower final MC of TECR. On the other hand, if the evaporation capacity of fluidizing air was lower than the amount of coating solution on the surface of particles, the final MC of TECR will be increased such in the cases of fluidizing air velocity of 2 and 2.5 m/s, atomization air pressures of 1 and 2 bar and percentage of recycle of 80%.

For the effects of atomization air pressure on the final MC of TECR, it was found that at 0% of recycle air conditions for all fluidizing air velocities, the final MC of TECR decreased with increase in atomization pressure. This is due to the fact an increase in atomization air pressure provides the small size of coating solution droplet. As a result, it is easy to evaporate before contact with the particle, which is called premature droplet evaporation. But, operating at 80% of recycle air provided the opposite effect from 0% of recycle air. At 80% of recycle air, an increase in atomization air pressure from 1 to 1.5 bar decreased the final MC of TECR but the final MC was increased when an atomization air pressure was increased from 1.5 to 2 bar. This might be because the fraction of the coating solution droplets that completely evaporated before they contact with the fluidized particles decreased since the droplets of coating solution penetrate more deeply into fluidized particle. As a result, the fluidized particles received the coating solution droplets increased and hence the final MC of TECR was higher. Moreover, the loss of coating solution droplets may be reduced at 80% of recycle air conditions because the evaporation capacity of fluidizing air decreased. However, these results are not clear at fluidizing air velocity of 2 m/s.

Fissure and Head Coated Rice Yield of TECR

The effects of fluidizing air velocities, atomization air pressures and percentages of recycle air on the percentage of fissured kernels (PFK) and head coated rice yield (HCRY) of TECR are shown in Table 1. It was found that the percentage of fissured kernels varied widely from 5% to 100%, depending on operating conditions. It is seen that the fissure of TECR did not exceed 10% at the coating conditions that provided the final MC of TECR higher than 11.75% (w.b.). But, the fissure of TECR was increased to 100% at the coating conditions that provided the final MC of TECR lower than 11.75% (w.b.). A high number of fissured TECR is usually occurred at 0% of recycle air conditions. This is due to the fact that the evaporation capacity of fluidizing air at 0% of recycle air

is higher than at 80% of recycle air and thus some amount of moisture that was the initial moisture of white rice kernels was evaporated while the moisture at the inner layer moves slowly to the surface, resulting in the stress formation [12]. The fissure of materials will appear when the stresses that are formed are higher than the failure strength of material. As observed from the fissuring determination, it was found that the fissuring feature of TECR presented over the entire surface of TECR kernel as shown in Fig. 2. It is seen that the occurred fissure is a small crack and it is not more deeply in the TECR kernel. For the effects of fluidizing air velocities, atomization air pressures and percentage of recycle air on the HCRY of TECR, it was found that the HCRY of TECR was in the range of 94.20-94.87%, which did not different from the head rice yield of initial white rice with a value of 95.06%.
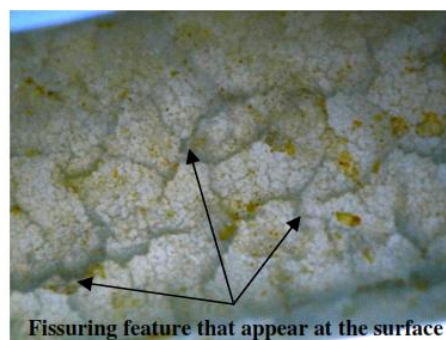

Fissuring feature that appear at the surface

Fig. 2 Fissuring feature of TCER sample (Captured by Dino digital microscope (AM 351) using 100-200X lens)

Color of TECR

Table 2 shows the color of TECR at different fluidizing air velocities, atomization air pressures and percentages of recycle air. It was found that the color of TECR was in the reddish-yellow range which corresponded to the lightness (L^*) of 69.50-70.79, redness (a^*) of 12.69-14.68 and yellowness (b^*) of 69.55-72.35. In the work of Palamanit et al. (2013), they reported that the amount of turmeric extract adhered on coated rice was dependent on the redness value (a^*). Thus, in this study the redness value of TECR will be mentioned. From Table 2, it is seen that operating at fluidizing velocity of 2 m/s provided the low redness value of TECR, except at the condition of atomization air pressure of 1.5 bar and 0% of recycle air, and the condition of atomization air pressure of 2 bar and 80% of recycle air, implying the lower amount of turmeric extract adhered on the white rice kernels. When fluidizing air velocity was increased from 2 m/s to 2.5 m/s, the redness value of TECR under the same atomization air pressure clearly increased. But, an increase in inlet air velocity from 2.5 to 3 m/s at each atomization air pressure did not clearly affect the redness value of TECR.

The effect of atomization air pressures on the color of TECR was also analyzed, as shown in Table 2. It is seen that the atomization air pressure had a significant effect on the color of TECR especially the redness value. At fluidizing air velocity of 2.5 and 3 m/s, the redness value of TECR at the atomization air pressure of 1.5 bar was lower than at the atomization air pressures of 1 and 2 bar. This is because an increase in atomization air pressure

from 1 bar to 1.5 bar tended to have a lower coating efficiency. But, the loss of coating solution droplets due to premature droplets evaporation was reduced when the atomization air pressure was increased from 1.5 bar to 2 bar. Except at the fluidizing air velocity of 2 m/s, atomization air pressure of 1.5 bar and 0% of recycle air that the redness value is not clear.

Coating Efficiency of TSFBC

Coating efficiencies (CE) of TSFBC at fluidizing air velocities, atomization air pressures and percentages of recycle air are shown in Table 2. It was found that the coating efficiency of TSFBC was in the range of 74.54% to 86.08%, depending on the fluidizing air velocity, atomization air pressure and percentage of recycle air. Operating at the fluidizing air velocities of 2.5 and 3 m/s provided the coating efficiency higher than 80% in all atomization pressures and the percentages of recycle air. At these fluidizing air velocities the effects of atomization air pressures and recycle air amount did not significantly affect the coating efficiency of TSFBC according to the statistical analysis at the confidence level of 95%. But, at the fluidizing air velocity of 2 m/s it was found that the atomization air pressure affected the coating efficiency significantly. As shown in Table 2, most coating efficiency of TSFBC were lower than 80% at the fluidizing air velocity of 2 m/s. Except, at the condition of fluidizing air velocity of 2 m/s, atomization air pressure of 1.5 bar and 0% of recycle air and at the condition of fluidizing air velocity of 2 m/s, atomization air pressure of 2 bar and 80% of recycle air that provided the coating efficiency higher than 80%. The low coating efficiency of TSFBC at those conditions might be due to the fact that the expansion of white rice kernels bed was reduced, which is led to a longer distance between nozzle and fluidized particles. As a consequence, some droplets of coating solution that were sprayed from the nozzle would evaporate before they contact with white rice kernels. In addition to the evaporation of droplets, the movement of white rice kernels within the bed was not good.

However, it is observed that at fluidizing air velocity of 2 m/s and 80% of recycle air, an increase in atomization air pressure from 1.5 to 2 bar improved the coating efficiency as 82%. The improvement of coating efficiency at this condition might be involved with the droplets penetration into the bed. The speed of coating solution droplets increased with increasing an atomization pressure. The increase of droplet speed resulted in more droplets penetration depth to the bed before they were evaporated and thus yielding the higher coating efficiency. Such result caused moisture content of TECR to be increased significantly as well, as already shown in Table 1. However, when the inlet air velocity increased to 2.5-3 m/s, the effect of atomization pressures on the coating efficiency was insignificant since a short distance between nozzle and expanded bed provided most droplets of coating solution reaching the white rice kernels before evaporation. For the effect of percentage of recycle air on the coating efficiency of TSFBC, it is seen that at fluidizing air velocities of 2.5 and 3 m/s the coating efficiency of TSFBC at 0% of recycle air conditions slightly lower than at 80% of recycle air conditions. This might be due to the loss of coating solution droplets since premature droplet evaporation decreased because the humidity of fluidizing air increased at the 80% of recycle air.

Uncoated White Rice Kernels of TECR

Percentages of uncoated white rice (UCWR) of TECR at different inlet air velocities, atomization air pressures and percentage of recycle air are shown in Table 1. It indicated that fluidizing air velocity had significant effect on the number of uncoated white rice kernels. Operating at the fluidizing air velocity of 2 m/s and all atomization pressures and percentages of recycle air provided the percentage of uncoated white rice kernels higher than 0.12%. When the fluidizing air velocity was increased to 2.5 and 3 m/s the amounts of UCWR significantly decreased, indicating that operating at fluidizing air velocity of 2 m/s the movement of white rice kernels within the bed during coating process was not good and subsequently some white rice kernels did not contact with the droplet of coating solution at the coating zone. An increase in fluidizing air velocities as 2.5 or 3 m/s improved the movement of white rice kernels in the bed, resulting in the white rice kernels more coming into the coating zone and thus the number of UCWR was lower. However, it is seen that operating at fluidizing air velocity of 2.5 and 3 m/s did not provided the zero UCWR. This was indicated that there is some white rice kernels present in the dead zone of coating chamber and they did not received the coating solution droplets during coating process.

For the effects of atomization air pressure and percentage of recycle air on the number of UCWR, it was found that these parameters had a small effect on the number of UCWR. However, it is observed that operating at 0% of recycle air provided the number of UCWR lower than at 80% of recycle air conditions at all fluidizing air velocities and atomization air pressures. This is due to the fact that the evaporation capacity of fluidizing air at 0% of recycle air was higher than at 80% of recycle air, resulting in the good fluidization quality of white rice kernels in the bed during coating process but at the condition of 80% of recycle air the fluidization quality of white rice kernels was rather small because the adhesion of white rice kernels by liquid bridge, particularly at fluidizing air velocity of 2 m/s.
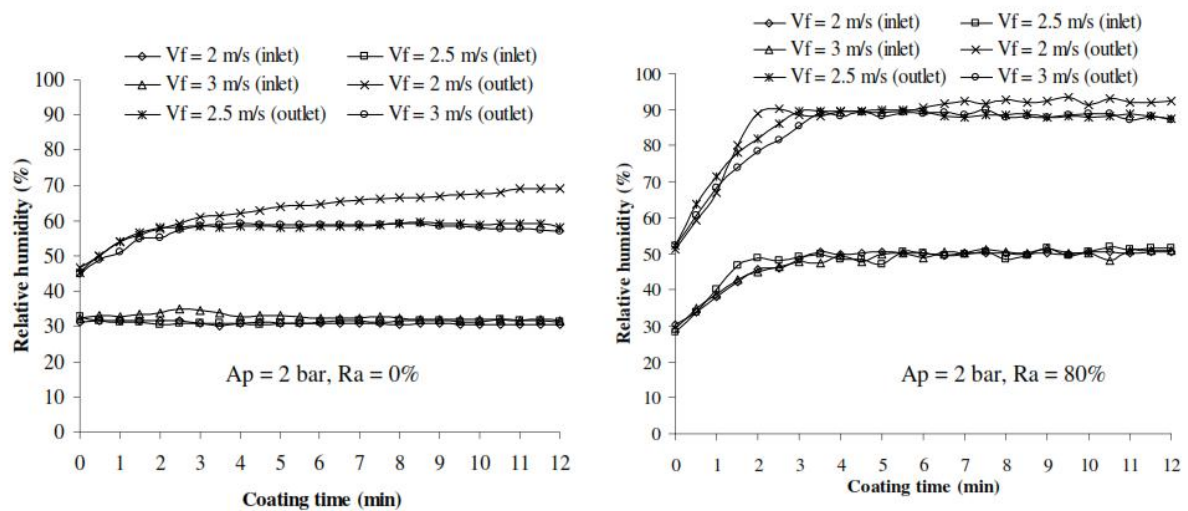
Fig. 3 Relative humidity of inlet and outlet fluidizing air at different fluidizing air velocities and percentages of recycle air

Table 1 Moisture content, fissure, head coated rice yield and uncoated white rice kernels of TECR

Operating conditions			MC (% w.b.)	PFK (%)	HCRY (%)	UCWR (%)
Vf (m/s)	Ap (bar$_g$)	Ra (%)				
2	1	0	11.85±0.08[d]	7±2[a,b]	94.29±0.19[a]	0.209±0.011[e]
		80	12.71±0.06[h]	8±2[a,b]	94.36±0.23[a]	0.274±0.004[f]
	1.5	0	11.64±0.02[b]	100±0[c]	94.87±0.10[a]	0.203±0.014[e]
		80	12.46±0.06[e,f,g]	10±2[b]	94.81±0.60[a]	0.375±0.005[g]
	2	0	11.47±0.02[a]	100±0[c]	94.25±0.19[a]	0.120±0.028[e]
		80	12.74±0.06[h]	10±2[b]	94.43±0.10[a]	0.401±0.008[g]
2.5	1	0	11.75±0.03[c]	7±2[a,b]	94.22±0.17[a]	0.028±0.004[a,b]
		80	12.66±0.05[h]	6±3[a,b]	94.82±0.20[a]	0.075±0.005[d]
	1.5	0	11.62±0.02[b]	100±0[c]	94.68±0.20[a]	0.021±0.005[a]
		80	12.41±0.08[e,f]	5±2[a]	94.82±0.21[a]	0.077±0.005[d]
	2	0	11.45±0.02[a]	100±0[c]	94.20±0.13[a]	0.021±0.005[a]
		80	12.65±0.02[h]	6±2[a,b]	94.44±0.10[a]	0.080±0.008[d]
3	1	0	11.60±0.02[b]	100±2[c]	94.21±0.15[a]	0.027±0.004[a]
		80	12.49±0.03[f,g]	5±3[a]	94.79±0.17[a]	0.069±0.014[c,d]
	1.5	0	11.59±0.04[b]	100±0[c]	94.64±0.28[a]	0.025±0.008[a]
		80	12.37±0.02[e]	8±2[a,b]	94.87±0.13[a]	0.043±0.006[a,b,c]
	2	0	11.45±0.04[a]	100±0[c]	94.31±0.21[a]	0.023±0.004[a]
		80	12.55±0.03[g]	5±2[a]	94.49±0.27[a]	0.058±0.009[b,c,d]
Initial white rice kernels			12.50±0.07[b,c]	4±2[a]	95.06±0.04[a]	N/A

Different superscripts in the same column mean that the mean values are significantly different at $p<0.05$
N/A mean that not available

CONCLUSIONS

The performance of batch top spray-fluidized bed coating (TSFBC) for producing turmeric extract coated rice (TECR) at different fluidizing air velocities, atomization air pressures and percentage of recycle air was evaluated in terms of coating efficiency and TECR qualities. The interested qualities of TECR were considered in terms of final moisture content (MC), color, fissure, head coated rice yield (HCRY) and uncoated white rice (UCWR). The results showed that fluidizing air velocity (Vf), atomization air pressure (Ap) and percentage of recycle air (Ra) significantly affected the final MC of TECR. An increase in Vf provided the lower final MC of TECR. Operating at 0% of recycle air conditions provided the TECR that had the final MC lower than at 80% conditions. This is due to the fact that the evaporation capacity of fluidizing air at 0% of recycle air was higher than at 80% of recycle air conditions. Operating at 80% of Ra and all Vf and Ap did not affect the fissure and HCRY of TECR but operating at 0% of Ra most TECR kernels was fissured when their final MC lower than 11.75% (w.b.). The Vf was more important to coating efficiency than the Ap and Ra. When the Vf was not high enough likes 2 m/s, the bed expansion was very small, resulting in a higher distance between the nozzle and bed of white rice kernels and subsequently more evaporation of coating solution droplets before impacting the white rice kernels. Thus, the coating efficiency of TSFBC at Vf of 2 m/s was lower than 80%, and the color intensity in particular the redness (a*) value was low. In addition, at this velocity the movement of white rice kernels during fluidization was small, which was provided a high number of UCWR. At Vf of 2 m/s, an increase in atomization air pressure from 1.5 to 2 bar improved the coating efficiency, but the percentage of uncoated white rice kernels was still high. Except at the condition of Vf of 2 m/, Ap of 1.5 bar and Ra of 0% that the results of color and coating efficiency are still not clear. When the Vf was increased to 2.5 or 3 m/s, the coating efficiency of TSFBC was higher than 80% and the effects of Ap and Ra was insignificantly important to the coating efficiency. Moreover, the TECR color was redder and the number of uncoated white rice kernels was lower significantly.

ACLMPW;EDGE,EMTS

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