CHAPTER 3 EFFECTS OF INLET FLUIDIZING AIR TEMPERATURE AND SPRAY RATE OF COATING SOLUTION ON QUALITY ATTRIBUES OF TURMERIC EXTRACT COATED RICE USING TOP-SPRAY FLUIDIZED BED COATING TECHNIQUE

3.1 Introduction

In recent times, food products that have natural ingredients or natural additives are preferred by consumer. Natural antioxidants are one of the food additives used to extend the shelf life and improve nutritional value and functionality of foods. Phenolic compounds which are one of natural antioxidants are widely used as additive of many foods because they have many benefits to health (Larson, 1988; Gerber et al., 2002; Kim et al., 2003; Kris-Etherton et al., 2002; Jang et al., 2007; Wojdylo et al., 2007; Tawaha et al., 2007). Curcuminoids which mainly consist of curcumin, demethoxycurcumin and bisdemethoxycurcumin are a major active component of turmeric rhizomes (Jayaprakasha et al., 2005). They have been found to be a rich source of phenolic compounds that possess high antioxidant activity. Much research has reported about the biological, physiological and chemical properties of the curcuminoids, for example anti-inflammatory, antimicrobial, antiparasitic, antitumor, antiviral and antimutagenic (Polasa et al., 1991; Selvam et al., 1995; Ruby et al., 1995; Ahsan et al., 1999; Masuda et al., 1999; Ramsewak et al., 2000; Jayaprakasha et al., 2006; Ak & Gülçin, 2008; Itokawa et al., 2008). Curcuminoids are also moderately stable to heat (Khatun et al., 2006; Temitope et al., 2010; Paramera et al., 2011) which is an added advantage in the current content.

Rice is one of the leading cereals worldwide and it is a staple food of over half of the world's population (Juliano, 1990). White rice or milled rice is preferred more by consumers than brown rice although nutritional value and phytochemicals content of brown rice are higher than white rice. This is because the bran layers are a rich source of minerals, vitamins and phytochemicals including antioxidants which are removed from rice grain during milling process (Choi et al., 2007; Shen et al., 2009). Coating the white rice with turmeric extract is a possible way to improve its antioxidant property.

There are many ways to coat the solid particles with some additional substance. The rotating pan, rotating drum, fluid bed and other mixers are given as examples. Of these, the spray coating in the rotating pan and fluid bed are most widely used for the coated particles (Maronga, 1998). In the rotating pan coating process, particles are moved by rotating a pan and the coating solution is then sprayed onto the surface of particles. The hot air is used to dry the deposited solution to form a coating layer on the particle surface. This method has been widely used for a long time, but the rotating pan has low reproducibility and it is not suitable for coating particles that require high coating uniformity (Maronga, 1998). On the other hand, fluidized bed coating technique has been increasingly applied in the food industries (Dziezak, 1988; Dewettinck and Huyghebaert, 1999; Werner et al., 2007). There are three different configurations for this coater but the top-spray has a greater possibility of success in the food industries when compared to bottom-spray and tangential-spray. This is due to its high versatility, relatively high batch size and relative simplicity (Dewettinck and Huyghebaert, 1999). With top-spray fluidized bed coating the coating solution is sprayed onto the surface of fluidizing particles by a nozzle that may be placed above the bed or submerged inside the bed. The coating solution that is adhesive on the particle surface is dried due to the heat supplied by the fluidizing gas. The advantage of this coating technique is that the coating and drying takes place simultaneously in only one unit operation. Moreover, it can be used to coat the particle that has a size in the range from 0.1 to several millimetres (Guignon et al., 2002).

In current study, the turmeric extract solution used to coat the Jasmine white rice kernels to produce turmeric extract coated rice (TECR) using top spray fluidized bed coating technique; and the effects of operating parameters including inlet air temperature and spray rate of coating solution on quality attributes of TECR were also investigated. Quality attributes of the TECR were evaluated in terms of moisture content, percentage of fissured kernels, head coated rice yield, color, textural properties, total antioxidant capacity (TAC), total phenolics content (TPC) and curcuminoids content.

3.2 Materials and Methods

3.2.1 Materials

Jasmine white rice (Khao Dawk Mali-105) was purchased from Chiameng Company Bangkok, Thailand. It had an equivalent spherical diameter of 3.43 mm and true density of 1419 kg/m^3. The turmeric extract powder was purchased from Specialty Natural Products Company, Chonburi province, Thailand. The white rice and turmeric extract powder were stored in a dark room at a temperature of 4-6 °C prior to the experiment.

3.2.2 Top-Spray Fluidized Bed Coating Configuration

Figure 3.1 shows a schematic diagram of a small scale batch top-spray fluidized bed coating apparatus that was used in this study. This system consists of two main parts, fluidized bed unit and a spraying unit. In the fluidized bed unit, it consists of a stainless steel coating chamber with an inner diameter of 0.27 m and a height of one meter. A high-pressure blower (Venz, model HB 2.2, Thailand) was used to supply the fluidizing air. The velocity of inlet air was adjusted by butterfly valve and measured by the hot wire anemometer (Testo, model 445, Lenzkirch, Germany). The inlet air temperature was heated by electric 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 that was made from a stainless steel perforated plate. The perforated plate had a hole diameter of 1.5 mm. The exhaust air flows through the cyclone separator in order to remove the dust and then the clean air of about 80% of total exhaust air is reused again. 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 0.21 m height from the distributor plate. The atomization air is supplied by an air compressor and its pressure is controlled by a pressure regulator.

3.2.3 Turmeric Extract Solution Preparation

The turmeric extract powder was slowly dissolved in 70% (v/v) of ethanol solution to obtain turmeric extract solution at a concentration of 4% (w/v). The turmeric extract solution was then filtered through four layers of white cloth. Finally, the concentration of ethanol in the filtered solution was diluted to 40% (v/v) by adding some distilled water. In this study, the prepared turmeric extract solution did not dilute to low concentration of ethanol since the turmeric extract in the solution is easy to precipitate at low concentration of ethanol.

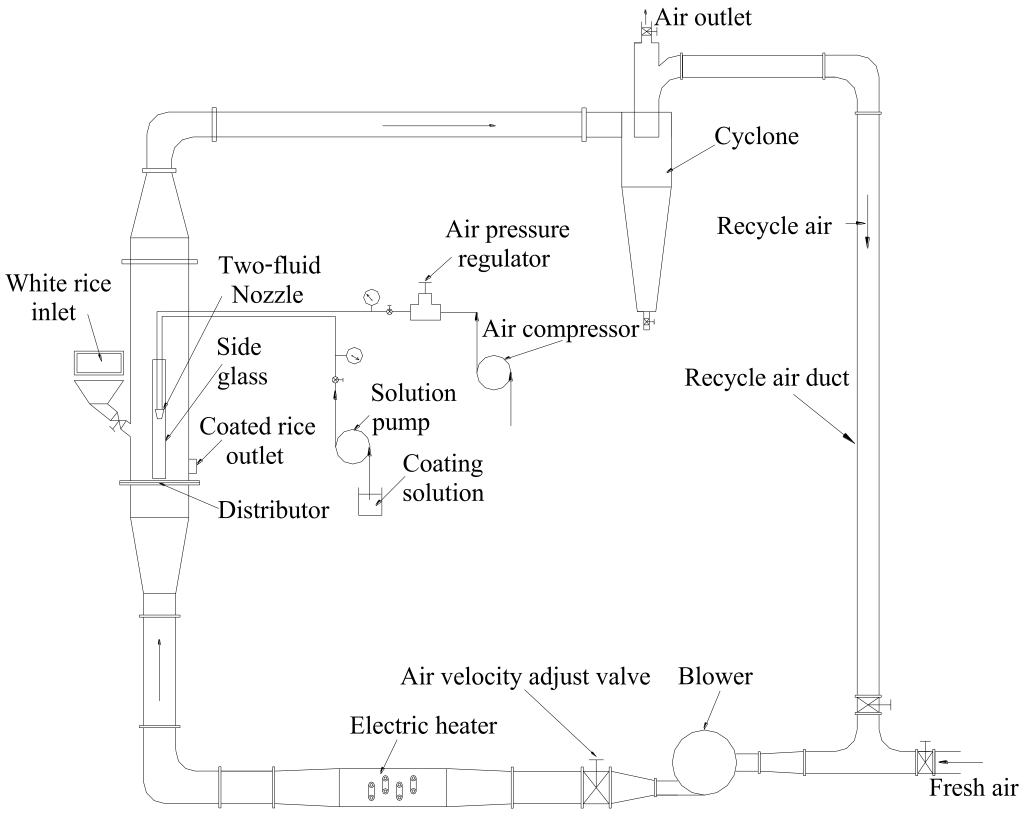

Figure 3.1 A schematic diagram of top-spray fluidized bed apparatus

3.2.4 Coating Procedure

Five kilograms of Jasmine white rice was fed into a coating chamber via inlet hopper as shown in Figure 3.1 and at this amount it corresponded to the static bed height of 10 cm. The fluidizing air was supplied to the bed through the distributor plate. As soon as the fluidizing air reached a desired inlet air temperature, the coating solution was sprayed from the two-fluid nozzle, which was placed above the distributor plate of 0.21 m. For the experimental conditions, the experiments were carried out at spray rates of coating solution (S_r) of 34, 40 and 46 mL/min, atomization air pressure of 1.5 bar (gauge pressure), spraying time of 12 min, superficial air velocity of 3 m/s, which is 2.7 times of minimum fluidization velocity, inlet air temperatures (T_{ai}) of 50, 55 and 60 °C and 80% recycled exhaust air. After spraying, the coated rice was dried for 5 s and then the TECR was kept in a sealed plastic bag at a temperature of 4-6 °C before quality analysis.

3.2.5 Moisture Content Determination

The moisture content (MC) of initial white rice and TECR was determined by a drying method. 30 g of sample was dried at 103 °C in a hot air oven for 72 hours (Memmert, model ULE500, Schwabach, Germany) and then it was kept in the desiccator for a period of time to cool down to ambient temperature before weighing. The MC of the sample was calculated from the equation (3.1) and presented on wet basis. The measurement was carried out in triplicate for each experiment and an average value was reported.

$$MC = \frac{M_{\mathrm{i}} - M_{\mathrm{f}}}{M_{\mathrm{i}}} \times 100 \qquad (\%) \tag{3.1}$$

where,

MC is the moisture content of sample (% wet basis (w.b.))

M_{i} is the mass of sample before drying in oven (g)

M_{f} is the mass of sample after drying in oven (g)

3.2.6 Fissure Determination

The determination of fissure of kernels was performed by randomly choosing 100 kernels of TECR and then each kernel was inspected using visual inspection with modified method of Iguaz et al. (2006). The TECR kernel was inspected by visual inspection through a magnifying glass under the light from fluorescent bulb. The magnifying glass was placed over the sample by about 15 cm. The percentage of fissured kernels can be calculated from the equation (3.2). The inspections were repeated five times for each experiment and the average value was presented.

$$\text{Percentage of fissured kernels} = \frac{N_{\text{fk}}}{100} \times 100 \quad (\%) \tag{3.2}$$

where N_{fk} is the number of fissured kernels.

3.2.7 Determination of Head Coated Rice Yield

Normally, the broken kernel is defined as the kernel that has the kernel length less than 75% of its original length. But, in this study the broken kernels of TECR were separated by an indent cylinder separator (Satake, model TRG-05A, Hirochima, Japan) (Jaisut et al., 2008; Jaiboon et al., 2009). An amount of 200 g of sample was fed into an indent cylinder separator and the broken kernels were removed. After separation, the separated sample remained the head coated rice and the head coated rice yield of TECR was calculated by dividing the head coated rice mass of TECR by the total sample mass. The measurement was performed in triplicate and the result is presented as an average value.

3.2.8 Color Measurement

The color of TECR was measured by a 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), b^* (yellowness-blueness) and the hue angle was calculated from $H^\circ = \tan^{-1}(b^*/a^*)$. The measurement was carried out in ten individual replicates of each experiment and the average value is presented.

3.2.9 Scanning Electron Microscopy

The fissuring feature of TECR was observed by a scanning electron microscope (SEM). Prior to observation, TECR kernel was placed on the double-adhesive tape that was glued on a brass stub and it was then coated with gold by a sputter-coater. The sample was photographed at its surface by a scanning electron microscope (JEOL, model JSM-5800LV, Tokyo, Japan) at 350X magnification and an accelerating voltage of 15 kV.

3.2.10 Textural Quality Measurement

Before testing, the TECR was cooked by a following method. 35 g of TECR was placed in an aluminium cylindrical cup and distilled water was added at a ratio of 1:1.5 (rice to water by weight) and it was steamed in electric cooker for one hour. After complete cooking, the cooked TECR was left at ambient temperature for 10 min prior to texture analysis. The textural properties of cooked TECR in terms of hardness and stickiness were determined by a bench-top textural analyzer (Stable Micro system, model TA.XT

Plus, Surrey UK). 12 cooked TECR kernels were placed onto the aluminium rectangular plate. The aluminium cylindrical probe with a diameter of 50 mm was used to compress the sample at 85% strain. The probe was compressed at a pre-test speed of 60 mm/min and post-test speed of 600 mm/min (Srisang et al., 2011). After compression, the values of hardness and stickiness value were recorded. The hardness of the cooked TECR was defined as the maximum compressive force while the stickiness was the negative force which occurs after pulling out the probe. In each experiment, the test was performed in ten replicates and the average value was reported.

3.2.11 Extraction of TECR and Cooked TECR to Evaluate TAC and TPC and Curcuminoids Content

The extraction was performed by randomly choosing 5 g of finely ground initial white rice, TECR or cooked TECR (cooked TECR was prepared by cooking the TECR with water at the ratio of 1:1.5 in electric rice cooker for one hour) and then it was mixed with 100 mL of methanol (99.9% v/v) 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 No. 4 filter paper. After that, the supernatant solution was evaporated by a vacuum rotary evaporator at 40 °C (Buchi, Switzerland). The dry solid was redissolved in methanol (3 mL) to produce liquid-soluble extract and it was stored at a temperature of -20 °C until analysis. The extraction was carried out in three individual replicates of each experiment.

3.2.12 Total Phenolics Content Determination

Total phenolics content (TPC) of TECR and cooked TECR were determined using Folin-Ciocalteu reagent with modified method of Singleton and Rossi (1965). An amount of 100 µL of extract solution was diluted to 1 mL 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, UV 2101 PC, Japan) at a wavelength of 765 nm. The TPC of sample was determined against the standard curve of gallic acid. The sample of gallic acid standard curve is as shown in Figure 3.2. The coefficient of determination (R^2) of standard curve should be higher than 0.99. The result was expressed as mg gallic acid equivalent (GAE) per 100 g of dry TECR (or dry cooked TECR). The measurement was carried out in triplicates for each experiment and the average value was presented.

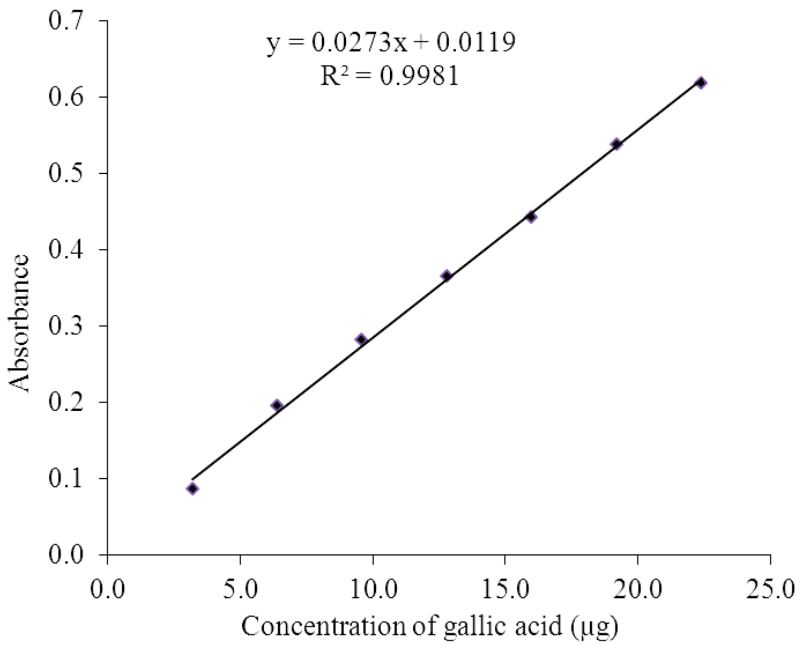

Figure 3.2 Sample of gallic acid standard curve

3.2.13 Total Antioxidant Capacity Determination

Total antioxidant capacities (TAC) of TECR and cooked TECR extract solution were evaluated based on the free radical scavenging effect of 2, 2-diphenyl-2-picryl-hydrazyl (DPPH). The DPPH scavenging activity of extract samples were determined using a modified method of Onichi et al. (1994). An extract solution of 100 µL was diluted to one millilitre with pure methanol. 270 µL of diluted sample was mixed with 1620 µL of 0.10 mM DPPH which was prepared in pure methanol. The mixture was vortexed for 10 s and let to stand at room temperature in dark for 20 min. Then, the mixture was measured for the absorbance at a wavelength of 517 nm by a UV-VIS scanning spectrophotometer (Shimadzu, UV 2101 PC, Japan). The percentage of DPPH scavenging activity (SCA) was calculated from the equation SCA (%) = $((Ab_{\text{blank}}-Ab_{\text{sample}})/Ab_{\text{blank}}) \times 100$, where Ab_{blank} is the absorbance of blank (0.1 mM of DPPH solution) and Ab_{sample} is the absorbance of sample. A standard curve of free radical scavenging activity of t-butylated hydroxyanisole (BHA) at each concentration was prepared. The TAC of extract sample was analyzed against the standard curve of BHA. The sample of BHA standard curve is shown in Figure 3.3. The coefficient of determination (R^2) of standard curve should be higher than 0.99. The results were expressed as mg BHA equivalent (BHAE) per 100 g of dry TECR or dry cooked TECR. The measurement was carried out in triplicate for each experiment and the average value is presented.

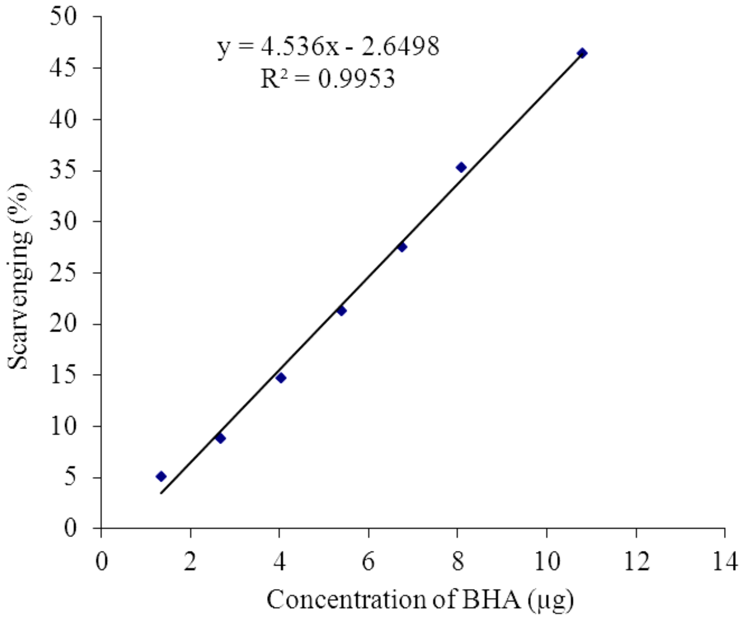

Figure 3.3 Sample of BHA standard curve

3.2.14 Estimation of Curcuminoids Content

The curcuminoids content of TECR and cooked TECR were determined using high performance liquid chromatography (HPLC) method with some modifications of Jayaprakasha et al. (2005). The extract sample of 150 µL was diluted to 2 mL with methanol, the mixtures were centrifuged at 6000 rpm and the supernatant was filtered through a 0.45 µm nylon filter. The clear supernatants were subjected to HPLC (Agilent 1100 Series, UK) that was equipped with synergi 4 µ Fusion-RP 80A column (250 x 4.60 mm, 4 µm, Phenomenex). The mobile phase consisted of acetonitrile and 1% (v/v) of acetic acid at the ratio of 55:45% v/v. The injection condition was set at a mobile phase flow rate of 1 mL/min, the injection volume of 4 µL, the column temperature of 40 °C and the detector wavelength of 425 nm. The curcuminoids concentration in sample was calculated against the concentration of standard curcuminoids solution (C1386, Sigma, USA) as shown in Figure 3.4.

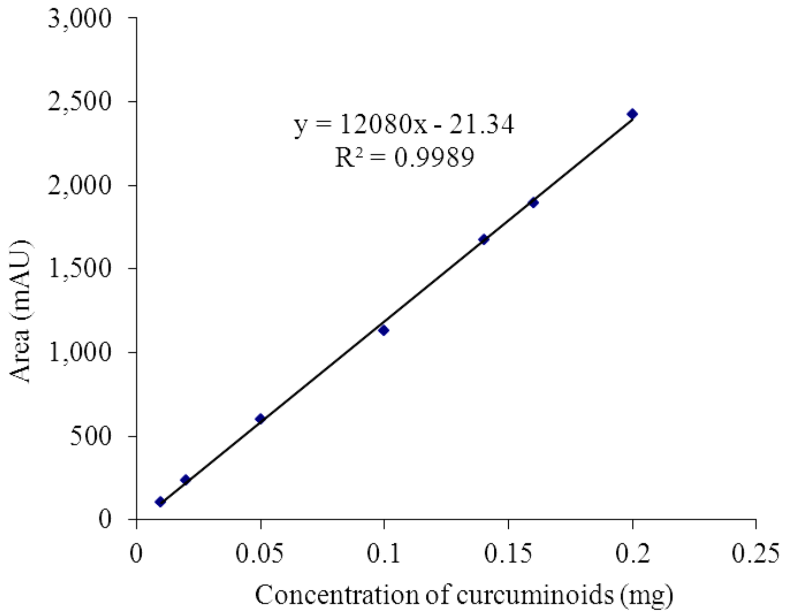

Figure 3.4 Sample of curcuminoids standard curve

3.2.15 Statistical Analysis

All data were analysed to indicate the significance difference of quality among treatments by the analysis of variance (ANOVA) using SPSS software (SPSS, Version 13, Inc., Chicago, IL). Differences between mean values were established using Tukey's HSD at a confidence level of 95%. The results were presented as mean values ± standard deviations (SD).

3.3 Results and Discussion

3.3.1 Effect of Operating Parameters on Final MC of TECR

Table 3.1 shows the final moisture contents (MCs) of TECR at different inlet air temperatures (T_{ai}) and spray rates of coating solution (S_r). It revealed that the final MCs of TECR were in a range of 11.20-12.80% (w.b.) while the initial MC of white rice before coating was 12.51% (w.b.). These results indicated that both inlet air temperature and spray rate of coating solution played an important role in the final MC of TECR. The final MC of TECR was higher than 12.0% (w.b.) when operated under conditions of inlet air temperature of 50 °C and spray rates of coating solution of 34, 40 and 46 mL/min as well as under the condition of inlet air temperature of 55 °C and spray rate of 46 mL/min. But, at the other operating conditions the final MC of TECR became lower than 12% (w.b.). This is because operating at these conditions provided more evaporation rate of moisture from the rice kernel than the amount of coating solution that adhered on the surface of white rice kernels. Hence, the existing moisture of white rice kernels will be evaporated in order to compensate the required amount of moisture evaporation rate of drying air, which led to the lower final MC of TECR.

On the other hand, if the evaporation capacity of fluidizing drying air was lower than the spray rate of coating solution, it still remained in the solution onto the surface of white rice kernels, resulting in the higher final MC of TECR than that before coating as mentioned above. The increase of final MC of TECR affected the fluidization quality, particularly at the condition of inlet air temperature of 50 °C and spray rate of 46 mL/min. During coating at this condition, the movement of white rice kernels during processing was rather slow and the kernels could not mix well because their surface was rather wet. Hence, the fluidization quality of white rice kernels was rather poor.

Table 3.1 Final moisture content (MC), fissured kernels and head coated rice yield of TECR

Operating condition		Final MC (%w.b.)	Fissured kernels (%)	Head coated rice yield (%)
T_{ai} (°C)	S_r (mL/min)			
50	34	12.03±0.06^{e}	6.40±1.67^{a,b,c}	93.60±0.17^{b}
	40	12.30±0.00^{f}	4.60±1.95^{a,b}	93.47±0.15^{a,b}
	46	12.80±0.00^{h}	8.80±1.48^{c}	93.13±0.29^{a,b}
55	34	11.63±0.06^{b}	96.60±1.67^{d}	93.20±0.17^{a,b}
	40	11.90±0.00^{d}	6.40±2.07^{a,b,c}	93.37±0.25^{a,b}
	46	12.30±0.00^{f}	4.60±1.14^{a,b}	93.07±0.15^{a,b}
60	34	11.23±0.06^{a}	100.00±0.00^{e}	92.80±0.50^{a}
	40	11.30±0.00^{a}	97.60±1.67^{d,e}	93.33±0.21^{a,b}
	46	11.80±0.00^{c}	7.80±1.30^{b,c}	93.10±0.10^{a,b}
White rice before coating		12.51±0.01^{g}	4.40±1.82^{a}	93.70±0.26^{b}

Different superscripts in the same column mean that the mean values are significantly different at $p<0.05$.

3.3.2 Fissure and Head Coated Rice Yield of TECR

The effects of inlet air temperatures and spray rates of coating solution on the percentage of fissured kernels and the head coated rice yield of TECR are shown in Table 3.1. It is seen that the number of fissured kernels varied widely from 4.6% to 100%, depending on the inlet air temperature and spray rate of coating solution. The fissure of TECR was lower than 8.8% at coating conditions that provided the final MC of TECR in the range of 11.80% (w.b.) to 12.80% (w.b.). But, when the final MC of TECR dropped below 11.8% (w.b.), the number of fissured kernels increased tremendously. The number of fissured kernels was 96% at the final MC of TECR of 11.6% (w.b.) and became 100% at the final MC of 11.2% (w.b.). These results implied that the final MC of TECR played an important role in the fissure of TECR. Operation under inappropriate condition caused a large number of fissured TECR kernels.

A large number of fissured TECR kernels might be due to the fact that the existing moisture at the surface of white rice kernels loss rapidly, while the moisture at the inner layer moves slowly to the surface, leading to the stress formation (Iguaz et al., 2006). If the stresses are higher than the failure strength of material, the fissure appears (Kunze and Choudhury, 1972). As observed from the experiment, the fissure occurring during coating covered over the entire surface of TECR kernel as shown in Figure 3.5. The fissure found in this case was only a surface crack. Cnossen et al. (2003) have reported that the fissure in rice drying can be classified in two types, surface crack and internal fissure. The surface crack is mostly found in the case of drying temperature below glassy temperature. The glassy temperature is given in the range of 50-55 °C for rice at a moisture content of 12% (w.b.) (Cnossen et al., 2003). This glassy temperature corresponded to the temperature range used in this work. However, in spite of a large amount of fissured kernels in the case of the lower final MC of 11.63% (w.b.), the head coated rice yield of TECR slightly changed from the head rice yield of initial white rice. This indicated that operating at severe drying condition did not affect the head coated rice. From this result, it implied that the collision among fluidizing particles was not strong enough and thus the head coated rice yield was not decreased although the TECR kernels in the bed cracked. Nonetheless, a large number of fissured TECR may not be accepted by consumer since they broke to small pieces after cooking.

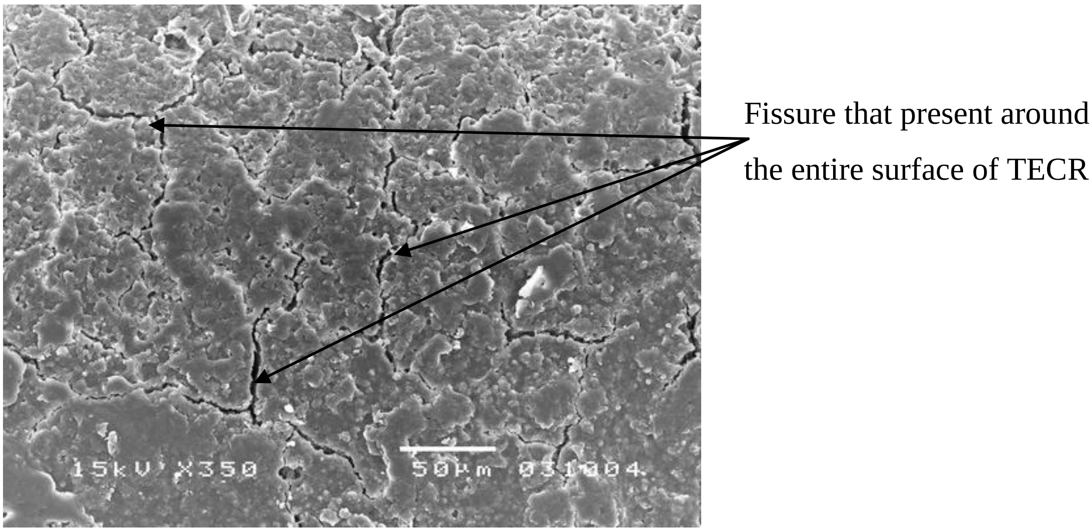

Figure 3.5 Scanning electron micrograph of fissuring feature of TECR at coating condition of inlet air temperature of 60 °C and spray rate of coating solution of 34 mL/min

3.3.3 Color of TECR

The effects of inlet air temperatures and spray rates of coating solution on the color change of TECR are shown in Table 3.2. It was found that the color of TECR was in the reddish-yellow range corresponding to the redness value (a^*) of 11.29-14.18, yellowness value (b^*) of 73.11-74.04, lightness value (L^*) of 71.17-73.85 and hue angle (H°) of 79.10-81.30. An increase in the spray rate of coating solution affected the color of TECR significantly; its color was darker and redder as indicated by lower L^* value and higher a^* value. The more intense color of TECR is due to the fact that the larger amount of turmeric extract adhered on the surface of white rice kernel at a higher spray rate of coating solution. It was noted that the poor fluidization quality at above mentioned condition of inlet air temperature of 50 °C and a spray rate of 46 mL/min did not affect the color uniformity of TECR as will be seen in Table 3.2.

Considering the effect of inlet air temperature, it was found that an increase in inlet air temperature from 50 °C to 60 °C under constant spray rate of coating solution resulted in the higher *L** value and lower *a** value. The changes of such color parameters did not involve with the browning reactions. This is due to the fact that if it is involved with the browning reactions, the lightness should decrease and the redness should increase (Bhattacharya, 1996; Lamberts et al., 2006; Jaiboon et al., 2009). But, the changes of *L** and *a** in this case are possibly caused by the lower coating efficiency at higher inlet air temperature (Kage et al., 1996; Dewettinck and Huyghebaert, 1998). This is because an increase in inlet air temperature resulted in higher premature droplet evaporation, leading to lower amount of turmeric extract on white rice kernels. This can be observed from Table 3.4 which shows the lower amount of TPC with increasing drying temperature. In addition, the small cracks that present around the entire surface of TECR may influence the measure of sample color since the small cracks of TECR produced the surface roughness, which resulted in the diffusion reflection of light from the sample to the observer of measurement. Briones et al. (2006) have reported that the surface roughness of chocolate samples strongly influenced the *L**; the lower *L** value was found at higher roughness. Table 3.2 also shows the standard deviation value of each color parameters for samples coated under different operating conditions. Each color parameters had very small standard deviation value, implying that the turmeric extract uniformly adhered on the surface of white rice kernels.

Table 3.2 Color values of turmeric extract coated rice

Operating condition		L^* value	a^* value	b^* value	Hue angle (H°)
T_{ai} (°C)	S_r (mL/min)				
50	34	72.10 ± 0.22^{d}	12.32 ± 0.28^{c}	73.91 ± 0.50^{c}	80.54 ± 0.20^{e}
	40	71.75 ± 0.12^{c}	12.94 ± 0.23^{d}	73.11 ± 0.69^{a}	79.97 ± 0.15^{c}
	46	71.17 ± 0.22^{a}	14.18 ± 0.25^{f}	$73.62\pm0.68^{b,c}$	79.10 ± 0.12^{a}
55	34	73.06 ± 0.15^{f}	11.84 ± 0.18^{b}	74.04 ± 0.50^{c}	80.92 ± 0.11^{f}
	40	71.69 ± 0.16^{c}	13.07 ± 0.19^{d}	$73.59\pm0.46^{b,c}$	79.93 ± 0.13^{c}
	46	71.39 ± 0.24^{b}	14.22 ± 0.30^{f}	$73.70\pm0.70^{b,c}$	79.08 ± 0.19^{a}
60	34	73.85 ± 0.19^{g}	11.29 ± 0.24^{a}	$73.68\pm0.52^{b,c}$	81.30 ± 0.16^{g}
	40	72.85 ± 0.26^{e}	12.46 ± 0.18^{c}	$73.32\pm0.50^{a,b}$	80.36 ± 0.15^{d}
	46	71.82 ± 0.23^{c}	13.69 ± 0.30^{e}	$73.76\pm0.52^{b,c}$	79.49 ± 0.19^{b}

Different superscripts in the same column mean that the mean values are significantly different at $p<0.05$.

3.3.4 Textural Properties of TECR

The effects of inlet air temperatures and spray rates of coating solution on textural properties of cooked TECR in terms of hardness and stickiness are shown in Table 3.3. The result showed that the hardness and stickiness of cooked TECR which was obtained from different coating conditions were insignificantly different from those properties of cooked white rice at the significant level of 95%. This indicated that coating of turmeric extract solution onto white rice kernels under different inlet air temperatures and spray rates of coating solution did not affect the hardness and stickiness of cooked TECR. Except, in the cases of inlet air temperature of 55 ºC and spray rate of coating solution of 34 mL/min as well as inlet air temperature of 60 ºC and spray rates of coating solution of 34 and 40 mL/min, the texture test could not be performed because most TECR kernels were broken to small pieces after cooking.

Table 3.3 Texture of cooked TECR

Operating condition		Hardness (N)	Stickiness (N)
T_{ai} (°C)	S_r (mL/min)		
50	34	70.91±5.10[a]	5.76±0.45[a]
	40	71.54±4.03[a]	4.85±0.34[b,c]
	46	72.87±5.59[a]	5.58±0.51[a,b]
55	34	N/A	N/A
	40	71.19±5.44[a]	4.66±0.34[c]
	46	72.86±3.31[a]	5.81±0.51[a]
60	34	N/A	N/A
	40	N/A	N/A
	46	72.45±4.28[a]	5.75±0.49[a]
Initial white rice		71.41±5.61[a]	4.79±0.68[c]

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

3.3.5 Total Phenolics Content of TECR and Cooked TECR

Table 3.4 shows the total phenolics content (TPC) of TECR and cooked TECR under different coating conditions. Before coating, white rice kernel had a TPC of 4.4 mg GAE/100 g of dry weight. After coating the TPC of TECR clearly increased and it was given in the range of 21.74-33.03 mg GAE/100 g of dry TECR. The amount of TPC of TECR depended strongly on the spray rate of coating solution. An increase in spray rate of coating solution resulted in higher TPC. This is because a higher spray rate of coating solution led to an increase in the turmeric extract on white rice kernel. The increase of TPC corresponded to the higher redness (a^*) at higher spray rate of coating solution as previously discussed. Considering the effect of inlet air temperatures on TPC of TECR, it was found that at constant spray rate of coating solution an increase in the inlet air temperature slightly affected the amount of TPC. The reduction of TPC in this case was not caused by the degradation of curcuminoids during coating process because curcuminoids were stable at temperature below 70°C (Wang et al., 2009; Paramera et al., 2011), but it might be due to the lower coating efficiency as explained early in previous section. After cooking, the TPC of cooked TECR slightly decreased from that of the uncooked TECR; the TPC retention of cooked TECR was higher than 91% as shown in Table 3.4.

Table 3.4 Total phenolics content (TPC) of TECR and cooked TECR

Operating condition		TPC of TECR (mg GAE/100 g of dry TECR)	TPC of Cooked TECR (mg GAE/100 g of dry cooked TECR)	Retention (%)
T_{ai} (°C)	S_r (mL/min)			
50	34	22.62 ± 0.67^{a}	20.60±0.28	91.07
	40	27.66 ± 0.70^{c}	25.67±0.24	92.80
	46	33.03 ± 0.71^{e}	30.88±0.37	93.49
55	34	22.34 ± 0.58^{a}	N/A	N/A
	40	$27.04 \pm 0.74^{b,c}$	N/A	N/A
	46	$32.04 \pm 0.69^{d,c}$	30.07±0.65	93.85
60	34	21.74 ± 0.51^{a}	N/A	N/A
	40	26.02 ± 0.41^{b}	N/A	N/A
	46	31.66 ± 0.69^{d}	N/A	N/A

Different superscripts in the same column mean that the mean values are significantly different at $p<0.05$, Retention (%) = (mean $TPC_{after\ cooking}$/mean $TPC_{before\ cooking}$)x100

N/A means not available

3.3.6 Total Antioxidant Capacity of TECR and Cooked TECR

In this work, the TAC of TECR and cooked TECR was investigated at the coating conditions that provided the final moisture content of TECR higher than 12% (w.b.).

Table 3.5 shows the total antioxidant capacity (TAC) of TECR and cooked TECR. The Jasmine white rice kernels before coating had initial TAC of 1.34 mg BHAE/100 g of dry white rice. After coating, it is seen that the TAC of TECR was increased significantly and it was in the range of 13.10-16.99 mg BHAE/100 g of dry TECR, depending on the spray rate of coating solution. An increase in spray rate of coating solution led to the higher TAC. Such result was related with TPC. Similarly, Ak and Gülçin (2008) have revealed that the DPPH free radical scavenging activity of curcumin increased with increasing curcumin concentration. However, the increase of TAC was not proportional to the increasing TPC. Considering the effect of inlet air temperatures on TAC of TECR, it was found that an increase in inlet air temperature insignificantly affected the amount of TAC but it negatively affected the TPC.

For the effect of cooking on the TAC of TECR, the results showed that the TAC of cooked TECR was in the range of 12.40-16.06 mg BHAE/100 g of dry cooked TECR, which slightly decreased from those of uncooked TECR. The TAC retentions of cooked TCR samples were higher than 93%. The reduction of TAC of cooked TECR because of curcuminoids degradation were due to other substances such as ferulic acid, vanillin and vanillic acid (Suresh et al., 2009), all of which possess lower antioxidant activity than the curcumin, demethoxycurcumin and bisdemethoxycurcumin (Jayaprakasha et al., 2006).

Table 3.5 Total antioxidant capacity (TAC) of TECR and cooked TECR

Operating condition		TAC of TECR (mg BHAE/100 g of dry TCR)	TAC of Cooked TECR (mg BHAE/100 g of dry cooked TCR)	Retention (%)
T_{ai} (°C)	S_r (mL/min)			
50	34	13.22±0.80^{a}	12.40±0.30	93.80
	40	14.74±0.62^{b}	14.01±0.20	95.05
	46	16.99±0.87^{d}	16.06±0.88	94.53
55	34	13.16±0.70^{a}	N/A	N/A
	40	14.91±0.51^{b,c}	N/A	N/A
	46	16.15±0.53^{c,d}	15.37±0.34	95.17
60	34	13.10±0.66^{a}	N/A	N/A
	40	14.32±0.94^{a,b}	N/A	N/A
	46	16.29±0.52^{d}	N/A	N/A

Different superscripts in the same column mean that the mean values are significantly different at $p<0.05$, Retention (%) = (mean $TAC_{after\ cooking}$/mean $TAC_{before\ cooking}$)x100

N/A means not available

3.3.7 Curcuminoids Content

The TECR that had the final MC higher than 12% (w.b.) was conducted to determine the curcuminoids content both before and after cooking. As can be seen in Table 3.6, the curcuminoids content of TECR was in the range of 15.81-25.10 mg/100 g of dry TECR and their quantity depended on the spray rate of coating solution. The curcuminoids content of TECR slightly decreased when inlet air temperature was increased. The reduction of curcuminoids content in this case was not caused by the degradation of curcuminoids by heat during coating process because the curcuminoids are stable to heat at the temperature below 70 °C (Wang et al., 2009 and Paramera et al., 2011). But, the decreasing of curcuminoids content is possibly due to the lower coating efficiency of top-spray fluidized bed at higher inlet air temperature. This is due to an increase in inlet air temperature leading to more premature evaporation of coating solution droplets before contact with core particles (Kage et al., 1996 and Dewettinck and Huyghebaert, 1998). After cooking TECR, the curcuminoids content of cooked TECR was reduced slightly by about 5%, which was similar to the report of Wang et al. (2009) and Paramera et al. (2011). The reduction of curcuminoids content after cooking is due to the fact that curcuminoids changed to ferulic acid, vanillin and vanilic aicd when they were heated to temperature above 100 °C (Suresh et al., 2009). Although the curcuminoids have demonstrated that they could be considered as food ingredient and food additive but the daily intake of curcuminoids for consumer is limited. The pharmacological safety of curcuminoids should be not consumed higher than 100 mg/day (Commandeur and Vermeulen, 1996) and WHO: Series 52 (2004) recommends that the acceptable daily intake (ADI) for curcuminoids is 1-3 mg/kg body weight.

Table 3.6 Curcuminoids contents (CMC) of TECR and cooked TECR

Operating condition		CMC of TECR (mg /100 g of dry TECR)	CMC of Cooked TECR (mg /100 g of dry cooked TECR)	Retention (%)
T_{ai} (°C)	S_r (mL/min)			
50	34	15.81±0.40	14.75±0.60	93.29
	40	18.01±0.65	17.04±0.69	94.61
	46	24.72±0.31	23.90±0.70	96.68
55	34	N/A	N/A	N/A
	40	N/A	N/A	N/A
	46	23.41±0.27	22.45±0.52	95.90
60	34	N/A	N/A	N/A
	40	N/A	N/A	N/A
	46	N/A	N/A	N/A