Kasetsart J. (Nat. Sci.) 45 : 891 - 899 (2011)

Osmotic Dehydration of Coconut Pieces: Influence of Vacuum Pressure Pretreatment on Mass Transfer and Physical Characteristics

Pimjai Maneepan and Wichamanee Yuenyongputtakal*

ABSTRACT

The effects of vacuum pressure pretreatment on the osmotic dehydration of coconut pieces and on mass transfer parameters were studied and some physical characteristics were evaluated. The coconut pieces were immersed in sucrose solution (60% (w/w)) for 8 hr at room temperature. Samples were subjected to vacuum pressure at 50 and 65 mbar with different pretreatments: 1) vacuum pressure for 20 min, then atmospheric pressure and 2) vacuum pressure for 10 min, atmospheric pressure for 10 min, vacuum for 10 min, then atmospheric pressure. The results indicated that there was an interaction effect between the vacuum pressure levels and vacuum pretreatments on solid gain ($P < 0.05$) while the main effects of those two factors were found on water loss ($P < 0.05$). The vacuum pretreatment affected weight reduction ($P < 0.05$). The sample pretreated with 50 mbar had lower whiteness than the sample treated at atmospheric pressure ($P < 0.05$). The vacuum pressure pretreated sample had lower firmness and a lower cell disintegration index than the nonpretreated sample ($P < 0.05$). Microscopic observations revealed the integrity of the cellular matrix associated with mass transport behavior and mechanical properties.

Keywords: osmotic dehydration, vacuum pressure, coconut

INTRODUCTION

Coconut (*Cocos nucifera* Linn.) is widely grown in tropical and subtropical regions and is one of the major fruits in Thailand. Minimal processing of coconut flesh that preserves its characteristic properties is of interest to extend its shelf life or that of its associated ready-to-eat products. One of the possible methods for obtaining minimally processed coconut flesh is osmotic dehydration. Osmotic dehydration is widely used for the partial removal of water from plant tissue by immersing the product in a hypertonic solution. During the osmotic process, there are two major simultaneous countercurrent flows due to water and the osmotic solute activity, with the flow of water from the food into the osmotic solution and the flow of solutes from the solution into the food. In this multiphase food system, mass transfer rates are attributed to the water and solute activity gradients across cell membranes as both the solutes and water seek equilibrium. In addition, other solutes present in the cells can be leached into the osmotic solution, but these amounts are considered to be quantitatively negligible (Lerici *et al*., 1985). The

Department of Food Science, Faculty of Science, Burapha University, Chon Buri 20131, Thailand.
* Corresponding author, e-mail: wich@buu.ac.th

Received date : 15/06/10 Accepted date : 22/07/11

osmotic dehydration process traditionally has been carried out at atmospheric pressure. However, several authors have focused on vacuum pressure conditions (Fito *et al*., 1996; Mújica-Paz *et al*., 2003). Vacuum in osmotic dehydration (VOD) is the application of reduced pressure to a solid-liquid system for a short period at the beginning of the process. The use of VOD allows improvement in the mass transfer kinetics, increasing the rate of water and weight loss and of solid gain (Shi *et al*., 1995). VOD leads to an exchange of internal gases or liquids by the external solution through hydrodynamic mechanisms promoted by pressure changes. The operation is carried out in two steps after product immersion in a container during the liquid phase. In the first step, vacuum pressure is imposed on the system for a short time in the closed container, thus promoting the expansion and outflow of internal gases in the product. In the second step, atmospheric pressure is restored in the container leading to a great volume reduction of the gas remaining in the pores, and thus to the subsequent influx of external liquid into the porous structure (Fito *et al*., 2001). The application of VOD can reduce the process time and energy costs. Pulsed-vacuum osmotic dehydration (PVOD), as a variation of VOD, consists of the use of an initial VOD process for different periods followed by the application of osmotic dehydration at atmospheric pressure (Tapia *et al*., 1999). Vacuum pressure treatment has been reported to increase the mass transfer rate in the dehydration of fruit and vegetables (Barat *et al*., 2001). However, little has been reported about the effect of vacuum pressure treatment in coconut. Moreover, the application of a vacuum in osmotic dehydration requires an understanding of how the mass transfer, physical properties and cell structure are affected by varying the vacuum pressure level and the vacuum pretreatment method. A sound understanding of these factors is important for the successful application of the osmotic dehydration process, for efficient treatment and it can be beneficial to the food industry. The aim of this research was to study the influence of vacuum pressure pretreatment on the mass transfer parameters, by quantifying water loss (WL), solid gain (SG) and weight reduction (WR) and to investigate the effect of vacuum pressure pretreatments on color and texture characteristics. Additionally, cell conditions were examined in terms of a cell disintegration index (z_p) and microscopic micrographs.

MATERIALS AND METHODS

Material

Coconut (*Cocos nucifera* Linn.) in the mature stage 10 mth after flowering was used. Coconut flesh samples were selected according to their texture attributes (firmness 21-23 N). The average moisture content of samples was 56.68 ± 3.04% (wet basis). Then, the coconut flesh was cut into 2 × 2.5 × 1cm (width × length × thickness) pieces.

Osmotic treatment

Osmotic treatments were carried out at atmospheric pressure (OD) and by applying vacuum pressure treatment. Samples (about 500 g) were immersed into 60% (w/w) sucrose solution at room temperature with an osmotic solution to sample ratio of 5:1 by weight. Vacuum pressure treatments at 50 and 65 mbar were applied as: 1) vacuum pressure for 20 min, then atmospheric pressure (vacuum osmotic dehydration; VOD) and 2) vacuum pressure for 10 min, atmospheric pressure for 10 min, vacuum for 10 min, then atmospheric pressure (pulsed-vacuum osmotic dehydration; PVOD). The vacuum pressure treatments were carried out in a vacuum chamber connected to a vacuum pump where the chamber contained samples and a sucrose solution. For all experiments, the moisture content and weight of the coconut samples were monitored every hour for 8 hr. Three of the samples were then removed

from the solution, quickly rinsed with running water (for about 30 s) to remove any adhered solution and gently blotted with tissue paper (for about 2 min) to remove excess water. All experiments were carried out in triplicate. The osmotic mass transfers were evaluated using coconut water loss, solid gain and weight reduction. After 8 hr of osmotic treatment, coconut pieces were characterized according to their color and texture. Additionally, a cell disintegration index and microscopic observations were evaluated.

Measurements of mass transfer parameters

In each treatment, the mass transfer parameters of water loss (WL) solid gain (SG) and weight reduction (WR) of the samples were calculated using Equations 1–3:

$$WL(\%) = \frac{\left(W_0 M_0 - W_t M_t\right)}{W_0} \times 100 \quad (1)$$

$$SG(\%) = \frac{\left[W_t\left(100 - M_t\right)/100\right) - \left(W_0\left(100 - M_0\right)/100\right)\right]}{W_0} \times 100 \quad (2)$$

$$WR(\%) = \frac{\left(W_0 - W_t\right)}{W_0} \times 100 \quad (3)$$

where W_o is the initial weight in grams of the sample; W_t is the weight in grams of the osmosed sample at time t; M_0 is the initial moisture content of sample (g/g) and M_t is the moisture content of the osmosed sample at time t (g /g).

Color measurement

Color was obtained from the sample surface reflectance using a colorimeter (BYK-Gardner, USA). Color co-ordinates based on CIE L* a* b* were obtained using the standard D65 illuminant and 10° observer. The measurements were made in triplicate and in three different places from each sample, and then mean values were reported. The color was expressed as a whiteness index according to Aguayo *et al*. (2004) as shown in Equation 4:

$$\text{Whiteness index} = 100 - [(100 - L^*)^2 + (a^*)^2 + (b^*)^2]^{1/2} \quad (4)$$

Texture measurement

Firmness was analyzed using a TA-XT2 texture analyzer (Stable Micro Systems, England) with a P/2 cylindrical probe (2 mm diameter), test speed of 1.5 $mm.s^{-1}$ and a distance of 5 mm. Firmness was represented by the maximum peak force (N). The data were presented as the means of five independent measurements.

Measurement of cell disintegration index

The cell condition was examined in terms of the cell disintegration index (z_p), where z_p is an integral parameter which indicates the relative reduction in the proportion of intact cells in the cell system. During osmotic treatment, a reduction in the number of cells can occur due to disintegration or shrinkage of the cell membrane. According to Angersbach *et al*. (1999) and Ade-Omowaye *et al*. (2001), z_p can be determined by Equation 5:

$$Zp = \frac{\left(\frac{\sigma_h^i}{\sigma_h^t}\right) \cdot \sigma_l^t - \sigma_l^i}{\sigma_h^i - \sigma_l^i} \quad (5)$$

where σ is the electrical conductivity, the superscripts ^{i} and ^{t} refer to conductivities before and after osmotic treatment, respectively, and subscripts $_l$ and $_h$ refer to the low and high frequency, respectively. For this experiment, the characteristic low and high frequencies used were 1 kHz and 1 MHz, respectively. The electrical conductivity was measured using parallel plate disk electrodes (Precision LCR meter, 4284A, Canada). The z_p values were determined immediately after the osmotic treatment. The value of z_p ranges between 0 (for intact cells system) and 1 (for complete membrane rupture).

Microscopic observation

Microscopic observations were carried out using a light microscope (Olympus ZM 100,

Germany) equipped with a CCD camera (SONY SSC-DC50AP, Tokyo, Japan). Samples were immersed in 0.1% methylene blue solution for 15 s. Micrographs of each sample were taken at 60× magnification.

Statistical analysis

Analysis of variance (ANOVA) was carried out on the vacuum pressure levels and vacuum pretreatments on the mass transfer parameters (WL, SG and WR). The effects of vacuum pretreatment on firmness and color were also analyzed. SPSS version 13 software (now a part of IBM software, NY, USA) was used to analyze the experimental results. The mean values were tested for significance using Duncan's multiple range test at the 95% confidence level.

RESULTS AND DISCUSSION

Effect on mass transfer

The effect of atmospheric pressure and vacuum pressure treatments on the WL, SG and WR values of coconut during osmotic dehydration are shown in Figures 1–3. The three mass transfer parameters adequately represented the osmotic process, with weight reduction indicating the net weight loss from the fruit, water loss indicating the water that diffuses from the fruit to the solution and solid gain indicating the solid that diffuses from the solution to the fruit. Regardless of the treatment, a fast initial rate of water removal and solute uptake was observed followed by a progressive decrease in the rate. The rapid water loss and solid gain in the beginning were apparently due to a high concentration difference between the fruit and the surrounding hypertonic medium that provided the driving force for the mass transfer of water and solids from the fruit. Several research groups published similar curves for the osmotic dehydration of other food (Azoubel *et al*., 2004).

Figures 1–3 show the effect of the vacuum pressure pretreatment, as the values of WL, SG and WR were higher than those of the atmospheric pressure treatment (OD) due to the action of the hydrodynamic mechanism (Zhao and Xie, 2004), which could have increased the

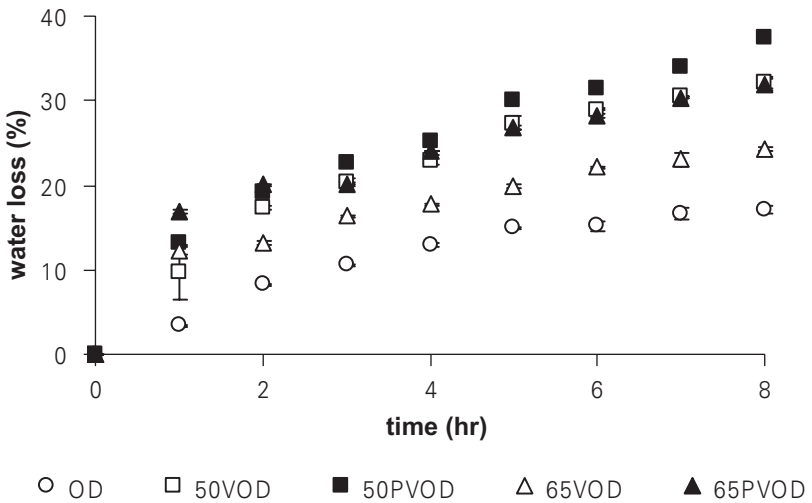


Figure 1 Variation in water loss with time during osmotic dehydration of coconut samples. (OD = osmotic dehydration at atmospheric pressure; VOD = vacuum osmotic dehydration; PVOD = pulsed vacuum osmotic dehydration. Numbers preceding the abbreviations indicate the vacuum pressure levels. Vertical error bars indicate ± SD)

interfacial area resulting from increased pore filling by the osmotic solution and increased capillary action. The pressure gradients during the vacuum condition promoted the outflow of internal gases. Compression of the residual gases took place when restoring the atmospheric pressure with an uptake of osmotic solution, thus higher mass transfer was obtained.

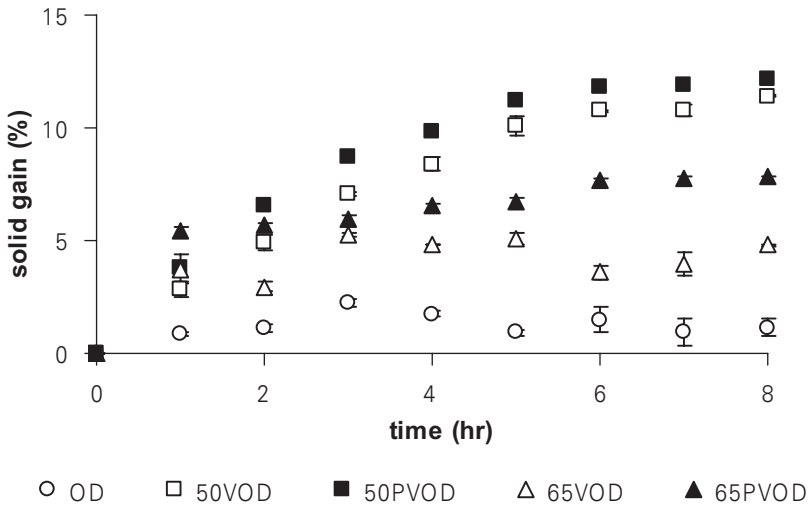


Figure 2 Variation in solid gain with time during osmotic dehydration of coconut samples. (OD = osmotic dehydration at atmospheric pressure; VOD = vacuum osmotic dehydration; PVOD = pulsed vacuum osmotic dehydration. Numbers preceding the abbreviations indicate the vacuum pressure levels. Vertical error bars indicate ± SD)

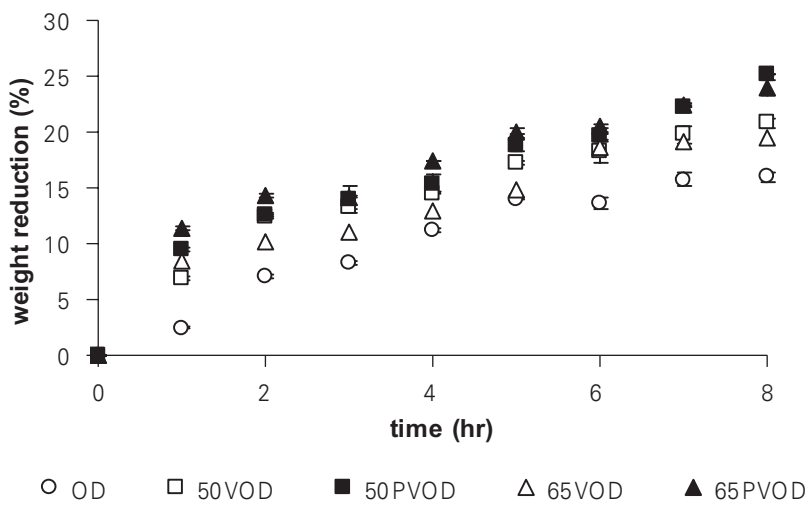


Figure 3 Variation in weight reduction with time during osmotic dehydration of coconut samples. (OD = osmotic dehydration at atmospheric pressure; VOD = vacuum osmotic dehydration; PVOD = pulsed vacuum osmotic dehydration. Numbers preceding the abbreviations indicate the vacuum pressure levels. Vertical error bars indicate ± SD)

Table 1 shows the mass transfer parameters of osmosed samples at the end of the process. It was clear that treatments of VOD and PVOD for both 50 and 65 mbar led to greater amounts of mass transfer compared with samples using the OD treatment. The water losses in samples under vacuum pretreatments were 7–12 times greater than those at atmospheric pressure (approximately 17 times the water loss for 8 hr). These trends were similar to Taiwo *et al*. (2003), who reported an 8–73-times increase in the water loss from strawberries under vacuum at 0.3 mbar for 0.5–2 hr compared with the water loss from atmospheric pressure for 4 hr under the different types of pretreatments. Deng and Zhao (2008) showed that pulsed-vacuum pretreatment promotes water loss, attributing it to the action of hydrodynamic mechanisms coupled with diffusional osmotic phenomena that enhanced mass transfer. At the end of 8 hr of osmotic treatment, it was found that vacuum pretreatment resulted in about 4–12% solid gain which was higher than the approximately 1% solid gain under atmospheric pressure. This was similar to findings of Deng and Zhao (2008) that solute uptake in apple under pulsed vacuum (3.02%) was higher than under atmospheric osmotic treatment (2.49%). Moreno *et al*. (2004) also found that vacuum treatment of papaya resulted in a 2.5–3.8% increase in solid gain compared with that without applying a vacuum at the end of 4 hr of osmotic processing, because only a small amount of solid was taken up by the sample which implied that the weight reduction was more dependent on water loss.

The experimental pressure level conditions used were obtained from preliminary testing to minimize the disintegration of the samples during experimentation. The statistical analysis of variance at the 95% confidential level was carried out with the aim of establishing if the vacuum pressure levels (50 and 65 mbar) and vacuum pretreatment methods (VOD and PVOD) had a significant influence on several mass transfer parameters (WL, SG and WR).

Table 1 shows the F-ratio values of each variable and their interactions with the WL, SG and WR values of coconut samples after 8 hr of osmotic dehydration. In all cases except SG, there was no significant difference in the interactions between the vacuum pressure levels and vacuum pretreatment. The vacuum pressure level (50 and 65 mbar) had a significant effect on WL. The WL in samples under vacuum pressure treatment at 50 mbar was greater than in those at 65 mbar. The vacuum pulse helped the formation of the pressure gradients and enhanced the outflow of the internal gas. With the pulsed-vacuum conditions, gas was removed from the fruit tissue and this affected the pressure inside the pores. When the pressure was restored, the pores were occupied by osmotic solution, increasing the available mass transfer area. More reduction in pressure caused greater expansion and the escape of gas occluded the pores (Rastogi *et al*., 2002; Mújica-Paz *et al*., 2003; Lombard *et al*., 2008).

Table 1 F-ratio values obtained from ANOVA analysis for water loss (WL), solid gain (SG) and weight reduction (WR).

Source of variation [a]	WL	SG	WR
P	152.85*	816.98*	7.24ns
T	137.12*	97.52*	89.36*
P × T	4.86 ns	34.98*	0.07ns

ns = Not significantly different ($P \geq 0.05$); * = significantly different ($P < 0.05$).

[a] = The factors for the analysis were vacuum pressure level (P), vacuum pretreatment (T) and their interaction.

Effect on color

Table 2 shows the effects of atmospheric pressure and vacuum pressure pretreatment on the whiteness of coconut pieces at the end of osmotic dehydration. The samples pretreated with 50 VOD and 50 PVOD had the lowest whiteness ($P < 0.05$). This reduction in whiteness may have contributed to the shrinkage change in the samples. A process which results in faster water loss may also results in greater shrinkage in the product, resulting in a darker color (Eshtiaghi *et al*., 1994). There were no significant differences in whiteness among between samples pretreated with OD, 60 VOD and 60 PVOD.

Effect on texture

The effects of atmospheric pressure and vacuum pressure pretreatment on the firmness of coconut pieces at the end of osmotic dehydration are shown in Table 2. The samples pretreated with vacuum pressure had lower firmness than those without vacuum treatment ($P < 0.05$). The decreased firmness resulted from reduced integrity in the cell wall components and a consequent loss in the turgor pressure within the fruit cells (Deng and Zhao, 2008). The losses of cell turgor and elasticity were responsible for alterations in cell resistance, changes in the air and volume fractions in the product and changes in sample size and shape (Chiralt *et al*., 2001; Fito and Chairalt, 2000)

Cell disintegration index (z_p)

To quantify the number of cells in each tissue sample affected by each treatment, an index for all the disintegration (z_p) has proven effective (Angersbach *et al*., 1999). The index z_p can be considered as a reliable and accurate indicator for cell disintegration of various biological materials (Ade-omowaye *et al*., 2001). The effects of atmospheric pressure and vacuum pressure pretreatment on the cell disintegration index were compared (Table 2). The z_p values in all the vacuum pressure pretreatments were higher than in the samples treated at atmospheric pressure ($P < 0.05$). The increase in the z_p values of samples pretreated under vacuum pressure was due to the destruction of cell membranes and partial liberation of cell substances. The vacuum treatment may have caused partial inactivation of polymethylesterase (PME). This reaction continued with time even after the vacuum pretreatments and resulted in softening of potato tissue; the alteration in pectin resulted in the loss of water and soluble solids after vacuum pretreatment (Rastogi *et al*., 2002)

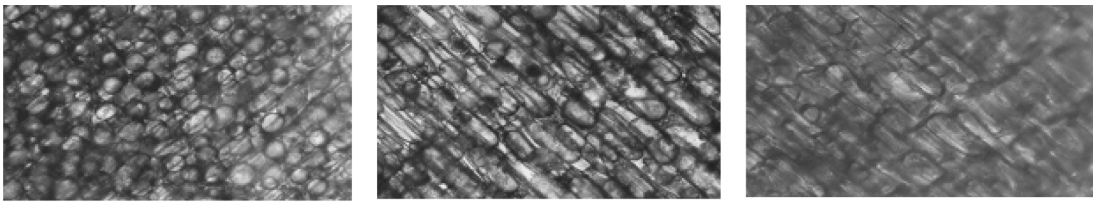
Microscopic observations

The micrographs from a light microscope facilitated the observation of the structure of the cell wall and intercellular spaces. Figure 4(a) shows the microstructure of fresh coconut tissue.

Table 2 Whiteness index, firmness (N) and cell disintegration index (z_p) of coconut under different osmotic treatments after 8 hr of osmotic dehydration. (OD = osmotic dehydration at atmospheric pressure; VOD = vacuum osmotic dehydration; PVOD = pulsed vacuum osmotic dehydration).

Osmotic condition	Whiteness index	Firmness(N)	z_p
OD	62.09 ± 0.31^a	20.76 ± 0.15^a	0.35 ± 0.05^a
50 VOD	58.70 ± 0.28^b	17.06 ± 0.12^b	0.66 ± 0.06^b
50 PVOD	57.41 ± 0.34^b	17.34 ± 0.18^b	0.68 ± 0.03^b
65 VOD	60.54 ± 0.16^a	17.76 ± 0.14^b	0.67 ± 0.02^b
65 PVOD	60.64 ± 0.24^a	17.17 ± 0.13^b	0.66 ± 0.06^b

Values within columns followed by a different letter are significantly different ($P < 0.05$).



(a) (b) (c)

Figure 4 Light microscope micrographs of coconut tissue under different osmotic treatments (60× magnification): (a) Fresh; (b) Osmotic dehydration at atmospheric pressure (c) Pulsed vacuum osmotic dehydration at 50 mbar.

It was found that coconut parenchyma tissue was made up of cells that were quite spherical with well-defined cell walls. A single and central vacuole was observed. The osmotic dehydration of coconut both under OD and PVOD caused changes to its microscopic structure (Figures 4(b) and (c)). Cells deformed to a tubular shape, with cell walls becoming elongated and the plasma membrane folded and separated from the cell wall. However, the PVOD-treated samples had a smaller cell size than the OD-treated samples; cell walls were deformed showing a greater loss of all turgor and intercellular volumes. This phenomenon may have contributed to the higher loss of water from the samples under vacuum pretreatment.

CONCLUSION

The mass transport properties of coconut in osmotic treatments with sucrose solution were affected by vacuum pressure pretreatment conditions. The vacuum pretreatment methods tested (VOD and PVOD) had a significant effect on the %WL, %SG and %WR. The interaction effect between the vacuum pressure level (50 and 65 mbar) and the method of vacuum pretreatment significantly affected the %SG. The results showed that applying a vacuum pressure pretreatment enhanced the quantities of WL SG and WR compared to an atmospheric pressure treatment. The vacuum pretreatment affected the color and texture characteristics of the coconut samples. Samples pretreated at 50 mbar had lower whiteness than samples pretreated under atmospheric pressure. The firmness and z_p value of osmotically vacuum-treated samples were lower than for osmotically dehydrated samples under atmospheric pressure. The microstructure micrographs of PVOD-treated samples showed more deformation in cells than in the non-pretreated samples.

ACKNOWLEDGEMENTS

The authors thank the Thailand Research Fund for financial support.

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