International Journal of Agriculture Innovations and Research
Volume 9, Issue 4, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 21/12/2020 | Accepted on: 28/01/2021 | Published: 12/02/2021

Application of Supercritical Carbon Dioxide for Production of Instant Rice

Mohammad Naghi Eshtiaghi [1*] and Nithima Nakthong [1]
[1] Mahidol University, Department of Chemical Engineering, 25/25 puthamonthon Sai 4, Salaya, 73170 Nakhorn Pathom, Thailand.
*Corresponding author email id: mohammand.esh@mahidol.ac.th

***Abstract* – In this study the effect of 3 different pretreatment methods for producing instant rice (quick cooking rice) from white and brown rice were investigated. The methods applied in this study were cooking, freezing, and supercritical carbon dioxide ($ScCO_2$) pretreatments. Cooking of rice and subsequent fluid bed drying resulted drastic decrease in rehydration time of both white and brown rice from 20-25 min to 6 min. Freezing pretreatment of cooked rice before drying resulted shorter rehydration time (5 min) of dried cooked rice compare to without freezing. The best results could be achieved when the cooked rice treated with supercritical carbon dioxide ($ScCO_2$) at pressure 400 and 600 bar for 20 min before drying. Cooking and subsequent drying up to 50 % of initial cooked rice weight followed by supercritical carbon dioxide treatment at 400 bar resulted short rehydration time (5 min) for both white and brown rice. The rehydration time reduced to 4 min for samples treated with $ScCO_2$ at 600 bar. Investigation of porosity using scanning electron microscopy (SEM) has shown that the porosity of dried white and brown rice increased with increasing of pressure during $ScCO_2$ treatment.**

***Keywords* – Rice, Instant Rice, Supercritical Carbon Dioxide, Freezing.**

I. Introduction

Rice is a one of the most important food for human especially in Latin America and in Asian countries [1]. In additions, rice is the most valuable for the fundamental of Thai economic. Thailand is one of the largest exporters of rice in the world. The life style of new generation has been changed considerable [2]. Most people prefer to consume rice with reduced cooking time. In general, rice needs 20-30 min. for cooking. Food industry interested to reduce the cooking time of rice by developing easy to prepare rice products such as instant rice. There are many attempts to produce instant rice in commercial scale. Multi steps technologies are involved for production of instant rice including pre-cooking and drying. Variation of pre-cooking and drying conditions has significant effect on cooking time and quality of instant rice [3]. Lan et al. [4] studied the effect of different cooking methods on the structural and functional properties of parboiled and non-parboiled freeze dried rice. They observed that the non-parboiled rice have up to 50% bracken grain after processing. The highest rehydration capacity (367%) was observed in the case of white rice with oven cooking pretreatment followed by parboiled rice (193%). In contrary, the texture of freeze dried parboiled rice was more similar to freshly cooked rice compare to non-parboiled rice. The effects of different processing techniques like boiling, steaming and pressure cooking on the physiochemical and organoleptic properties and storage stability of instant rice was studied by Ali et al. [5]. According to their finding pressure cooking would result higher sensory acceptance and shorter cooking time compare to other processing techniques. They also reported increasing of free fatty acid concentration in instant rice after 10 weeks storage from 0.99% to 1.18%. Prapluettrakul et al. [6] reported a suitable method for producing an instant rice product from Thai Jasmine rice for young children. They suggested instant rice preparation by boiling followed by freezing for 24 h at –20ºC, drying at 70 ºC, and final rehydration by boiling for 3 min. Sasmitaloka et al. [7] observed a significant difference between freezing temperature and duration and the physicochemical characteristics of instant rice. They suggested freezing at -4

°C for 24 hours as the best freezing condition for instant rice production. Phukasmas etal. [8] reported the effect of different precooking method and subsequent microwave drying of cooked rice on texture and appearance of rehydrated instant rice. They suggested boiling in pressure cooker as the recommended method for instant rice processing, due to porous structure and fast rehydration time of 3 min of instant rice. Similarly, Piyawanitpong et al. [9] investigated the effect of superheated steam treatment at 250 °C and 300 °C on quality of black glutinous rice. They reported faster drying, shorter rehydration time of about 1 to 5 min and comparable texture and overall sensory acceptance of rehydrated instant rice compare to control.

Up to date rare investigation results are available about application of novel technique such as supercritical carbon dioxide (ScCO_2) for producing quick cooking rice. Therefore, the aim of this study was to produce quick cooking rice using supercritical carbon dioxide pre-treatment.

II. MATERIAL AND METHODS

A. *Materials*

White Jasmine rice and brown Hom Mali rice were purchases from local shop in Thailand.

B. *Equipments*

Dryer: For hot air oven drying a laboratory hot air oven was applied. Fluid bed drying carried out in a laboratory scale fluid bed dryer, designed in Mahidol University, with adjustable temperature up to 90 ° ± 2 °C.

ScCO_2 Equipment: A pilot plant scale ScCO_2 equipment with max. working pressure of 1000 bar and high pressure vessel of 1 liter volume was used for ScCO_2 treatment.

Freezing: For freezing of cooked rice a subzero freezer was used for freezing before drying.

C. *Pre-treatment Methods*

Cooking: White and brown rice raw materials were cooked in tap water with rice to water ratio1:2 w/w at boiling temperature (≈100 °C) for 20-25 min or 40 min respectively until rice was completely cooked. The cooked rice was divided into two groups. The first group was dried by hot air oven at temperature 70 °C until constant weight. The second group was dried in fluidized bed dryer at temperature 70 °C until constant weight.

Freezing: Rice raw materials were cooked in top water as described above. Then the cooked rice were freeze at subzero temperature (-20 °C) fir 6 hours. After that, frozen rice was dried in fluid bed dryer at 70 °C until constant weight.

Supercritical Carbon Dioxide (ScCO_2) Treatment: Rice raw materials were cooked in tap water as described above. The cooked rice was pre-dried in fluid bed dryer at 70°C until 50% weight reducing. Cooked pre-dried rice samples were put into the cotton bag for supercritical carbon dioxide treatment. The conditions during supercritical carbon dioxide were 400, and 600 bar at room temperature for 20 min. After that the supercritical carbon dioxide treated rice was dried in fluidize bed dryer at temperature 70 °C until weight constant.

D. *Drying:*

The weight of samples during drying was measured for each time interval of 5 min (fluid bed drying) or each time interval of 20 min (hot air oven drying). The moisture content of samples was determined gravimetric. 10 g of sample was dried at 103 ± 1 °C for 2 h. Moisture content was measured after drying as follow: Moisture content (%) $= \frac{A}{B} * 100$

A = weight of rice after drying.

B = weight of rice before drying.

E. *Rehydration*

10 g of dried pre-treated rice was given in a beaker containing 100 ml of hot water at temperature of ≈ 90 °C. The rehydration time defined as the time necessary to achieve rehydrated rice. For calculation of rehydration rate the following equation was used:

$$\text{Rehydration rate (\%)} = \frac{\text{(Final wt.} - \text{Initial wt.)}}{\text{Initial wt.}} \times 100$$

Initial wt. = Weight of rice before rehydration.

Final wt. = Weight of rice after rehydration.

F. *Structure Analysis*

Scanning electron microscope (SEM) applied to investigate the porous structure of untreated and pretreated and subsequent dried rice.

III. Results and Discussions

A. *Drying Rate*

Drying of cooked white and brown rice resulted different drying time in hot air oven dryer and fluidized bed dryer (figures 1 and 2). The drying time was in the case of fluidized bed dryer up to 6 times shorter than hot air oven dryer. This was true for cooked and subsequently with or without freezing or $ScCO_2$ pre-treatment dried white and brown rice. The shorter drying time in the case of fluid bed drier is may be because of higher mass and heat transfer during fluid bed drying compare to hot air oven drying.

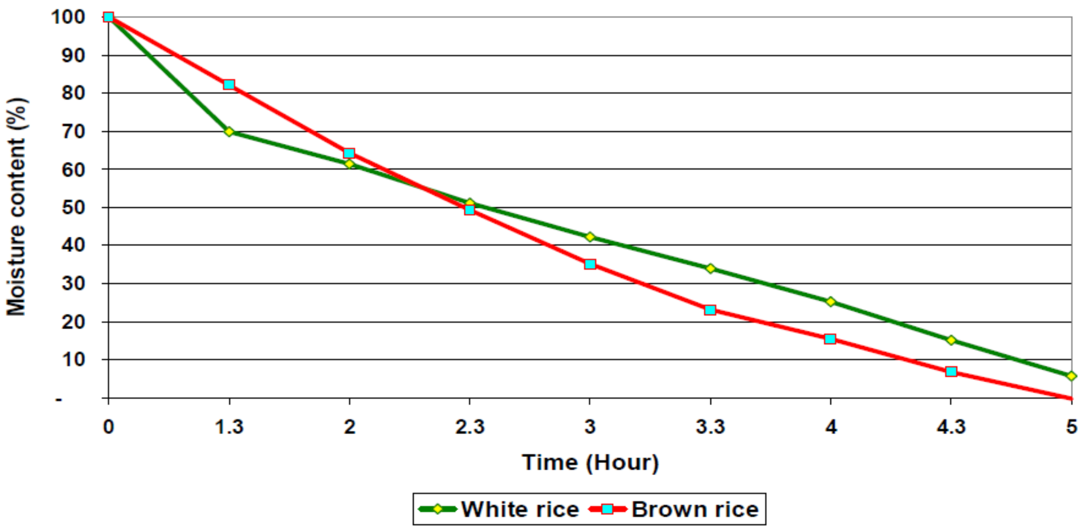

Fig. 1. Drying rate of cooked rice in hot air oven dryer.

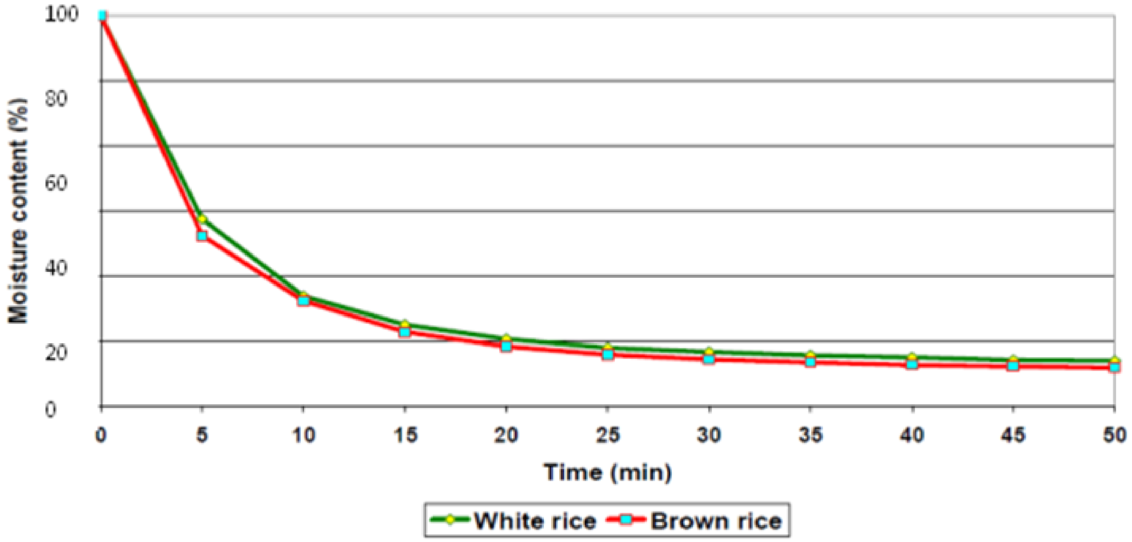

Fig. 2. Drying rate of cooked rice in fluid bed dryer.

B. *Appearance*

The appearance of cooked white rice grain remains after fluid bed drying nearly unchanged as it shown in figure 3. In the case of brown rice, the dried samples showed partially opened brown skin of rice grain (figure 4). In contrast, the color of $ScCO_2$ or freeze pretreated white rice was after fluid bed drying brighter than white rice from not pretreated cooked rice (figures 5 and 7). The appearance of $ScCO_2$ pretreated and subsequent fluid bed dried samples very similar to fresh brown rice grain (figure 8).

Fig. 3. Fluid bed dried cooked white rice.

Fig. 4. Fluid bed dried cooked brown rice.

Fig. 5. Fluid bed dried cooked, freeze pretreated white rice.

Fig. 6. Fluid bed dried cooked, freeze pretreated brown rice.

Fig. 7. Fluid bed dried cooked, $ScCO_2$ pretreated white rice.

Fig. 8. Fluid bed dried cooked, $ScCO_2$ pretreated brown rice

C. *Rehydration*

The effect of different pretreatments on rehydration time as well as shape of rehydrated samples is summarized in Table 2. Generally, the rehydration time of brown rice is longer than white rice. The shortest rehydration time was achieved in the case of rice pretreated with $ScCO_2$, followed by freeze pretreated samples. The rehydration time of 4 min for white rice and 5 min for brown rice is possible if the sample pretreated with $ScCO_2$ at 600 bar, 20 min and room temperature. In contrast, cooked rice without $ScCO_2$ treatment or freezing need 6 min rehydration time.

Table 1. Rehydration time for all pretreatment methods.

		Rehydration Time (min)		
Pretreatment Method	**Drying Method**	**White Rice (W)**	**Brown Rice (B)**	**Notice**
Cooking	Hot air oven	6	9	W and B Remaining Shape
Cooking	Fluidized bed dryer	6	6	W and B Remaining Shape
Freezing	Fluidized bed dryer	5	5	W crack, B Remaining shape
$ScCO_2$ 400 bar	Fluidized bed dryer	5	5	W and B Remaining Shape
$ScCO_2$ 600 bar	Fluidized bed dryer	4	5	W and B Remaining Shape

W = White rice, B = Brown rice.

The study of rehydration rate for different pretreated and finally dried rice has indicated that the rehydration of rice follows nearly first order drying (data not shown). In general, brown rice showed lower rehydration at given rehydration time compare to white rice. This was especially for cooked rice with freezing or $ScCO_2$ (600 bar) pretreated sample apparent (Table 2 and 3). Comparison between the rehydrated white and brown rice has indicate that the rehydrated white rice could achieve higher rehydration than brown rice. This is may be because of existing thin layer of rice bran on grain that reduces the water diffusivity inside the grain during rehydration (Table 3).

Table 2. Rehydration (%) of white rice.

Pretreatment Method	Rehydration (%)
Cooking	180 %
Freezing	314 %
$ScCO_2$ 400 bar	176 %
$ScCO_2$ 600 bar	190 %

Table 3. Rehydration (%) of brown rice.

Pretreatment Method	Rehydration (%)
Cooking	164 %
Freezing	192 %
$ScCO_2$ 400 bar	138 %
$ScCO_2$ 600 bar	120 %

D. *Porous Structure*

SEM's image analysis of different pretreated white and brown rice samples are shown in figures 9 to 16. The raw materials of white and brown rice showed very compact structure without any visible pore in the grain (figure 9 and 13). In contrast, freezing of cooked rice induced many small pores inside the grain (figures 10 and 14). In addition the existence of big crake inside the grain is obvious (figures 10 and 14). Similar to freeze pre-cooked sample there were many pores (pore size of ≈1 to 2 μm) in the $ScCO_2$ pretreated (at 400 and 600 bar) observed (figures 11 to 12 and 15 to 16). The $ScCO_2$ treated sample, in contrast to freeze pretreatment sample, did not have any crake inside the grain (figures 11 to 12 and 15 to 16). Increasing the pressure during $ScCO_2$ treatment caused bigger pore size (≈2 to 5 μm) in the sample (figures 12 and 16).

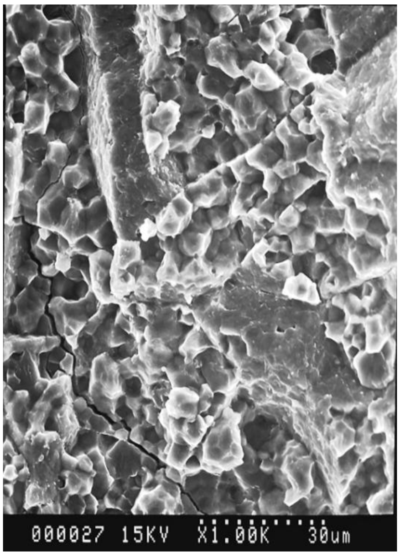

Fig. 9. Fresh white rice.

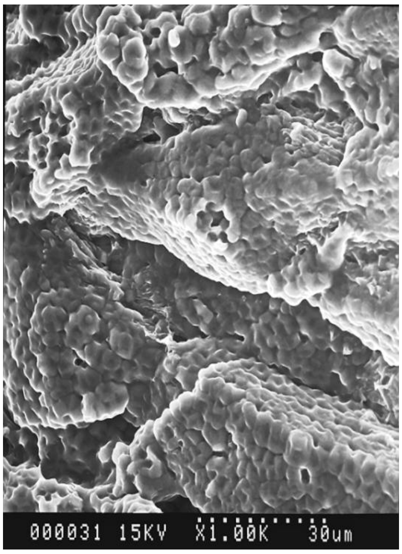

Fig. 10. Fluid bed dried cooked white rice.

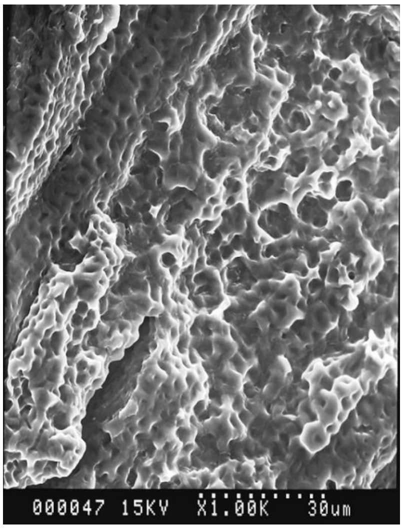

Fig. 11. Fluid bed dried cooked and white rice.

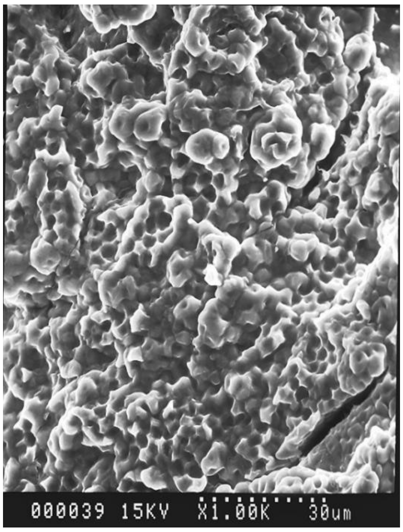

Fig. 12. Fluid bed dried cooked and freeze pretreated $ScCO_2$ pretreated white rice.

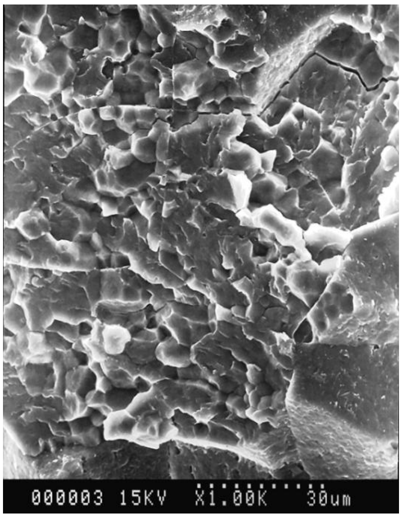

Fig. 13. Fresh white rice.

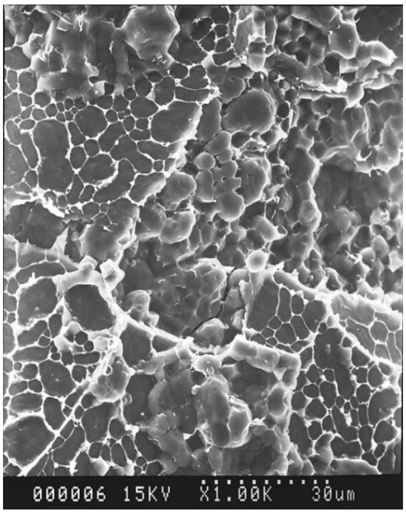

Fig. 14. Fluid bed dried cooked white rice.

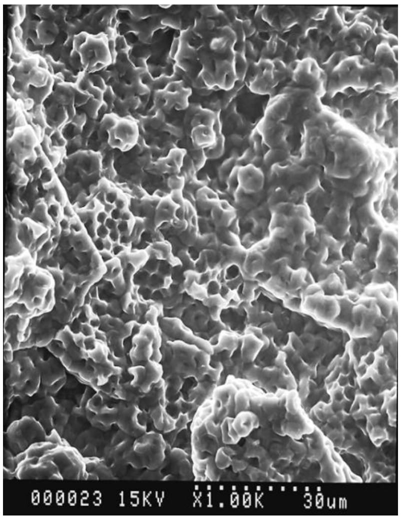

Fig. 15. Fluid bed dried cooked and white rice.

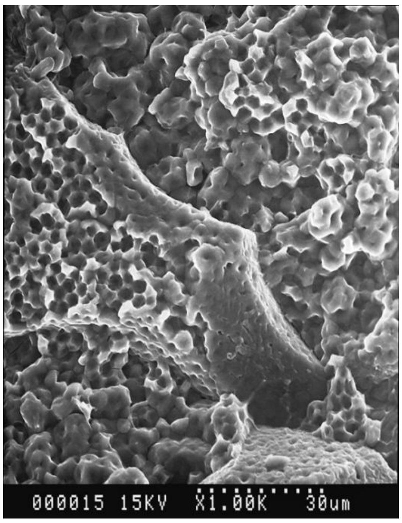

Fig.16. Fluid bed dried cooked and freeze pretreated $ScCO_2$ pretreated white rice.

IV. Conclusion

Fluidized bed drying is more effective for drying of cooked rice grain compare to hot air oven dryer. Up to 6 folds shorter drying time could be achieved if the fluidized bed dryer applied for drying of cooked rice. In addition, samples dried in fluidized bed dryer shown shorter rehydration time compare to hot air oven dried one. The results of this study have shown that the cooking time of rice could be reduced drastic after different pretreatments used in this study. It is possible to produce quick cooking rice using methods investigated in this study. The cooking time of white rice (20-25min) could be reduced up to 4 min after pre-treatment of cooked rice using $ScCO_2$ (at 600bar, 20min) and room temperature. In addition an drastic reduce of cooking time of untreated rice brown (approx. 40 min) to 5min for treated one could be achieved if cooked brown rice pretreated with $ScCO_2$ (600 bar, 20min). Although freezing method result faster rehydration time compare to cooked sample without freezing, but the structure of rehydrated sample was very soft and the grain lose shape after rehydration. The investigation of grain structure using SEM have shown that the highest porosity in grain could be achieved using $ScCO_2$.

Acknowledgement

The authors thank Mahidol University for financial support of this project as postdoctoral Grant.

References

[1] S.S. Gnanamanickam, Rice and Its Importance to Human Life, *Biological Control of Rice Diseases*, Springer Dordrecht Heidelberg London New York, 2009. pp 1-11.
[2] W. Prasert and P. Suwannaporn, Optimization of instant jasmine rice process and its physicochemical properties, Journal of Food Engineering, 95, 2009, pp. 54–61.
[3] Quantity and value of agricultural exports, Office of Agriculture of Economics [Online]. Available from: http://www.oae.go.th/oae_website/oae_imex.php [Accessed 2009 Mar 15]
[4] L.T.T. Bui, R.A. Coada, and R.A.R. Stanley, Properties of rehydrated freeze dried rice as a function of processing treatments, LWT - Food Science and Technology, 91, 2018, pp. 143–150.
[5] M.A. Ali, S.M.K. Hasan, M.S. Mahomud and M.A. Sayed, Processing and storage of instant cooked rice, Bangladesh research publication journal, Vol. 7 (3), 2012, pp. 300-305.
[6] B. Prapluettrakul, P. Tungtrakul, S. Panyachan and T. Limsuwan, Development of instant rice for young children, Silpakorn U. Science & Tech J.6 (1), 2012, pp. 49-58.
[7] K.S. Sasmitaloka, S. Widowati, and E. Sukasih, Effect of freezing temperature and duration on physicochemical characteristics of instant rice, 2nd International conference on agriculture postharvest handling and processing, IOP Conf. Series: Earth and Environmental Science 309 012043, 2019, pp. 1-8.
[8] P. Phukasmas, and S. Songsermpong, Instant rice process development: Effect of rice cooking methods on the quality of Jasmine instant rice dried by industrial microwave oven., Journal of microbiology, Biotechnology and Food Science, vol. 9 (2), 2019, pp. 330-334.
[9] C. Piyawanitpong, N. Therdthai , and W. Ratphitagsanti, Effect of precooking and superheated steam treatment on quality of black glutinous rice, Journal of Food Quality, 2018, Article ID 8496723, pp. 1- 9.

Author's Profile

First Author
Prof. Mohammad Naghi Eshtiaghi has studied in Germany, Technical University of Berlin, Department of Food and biotechnology. He has graduated his PhD at 1998 and achieved his Habilitation degree (equivalent of Prof. Degree) at 2005. He is working since 2005 as professor at Mahidol University, Faculty of Engineering, Department of Chemical Engineering, Tel.:+66 28892138 ext. 6101-2, Thailand. email id: mohammand.esh@mahidol.edu

Second Author
Dr. Nithima Nakthong has studied Materials Science and Engineering at Mahidol University and achieved her PhD degree at 2018. She is now as postdoctoral researched in Mahidol University, Faculty of Engineering, Thailand.
email id: nithimay99@hotmail.com