International Food Research Journal 24(3): 1192-1198 (June 2017)

Journal homepage: *http://www.ifrj.upm.edu.my*

Textural property improvement of black sticky rice during postharvest drying by a fluidization technique

[1*]Rattanamechaiskul, C., [2]Junka, N. and [3]Wongs-Aree, C.

[1]*Department of Engineering, King Mongkut's Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon 86160, Thailand*

[2]*Division of Crop Production Technology, Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom 73000, Thailand*

[3]*Postharvest Technology Program, School of Bioresources and Technology, King Mongkut's University Technology Thonburi, Bangkok 10150, Thailand*

Article history

Received: 27 December 2015
Received in revised form: 19 April 2016
Accepted: 19 June 2016

Keywords

Black sticky rice
Gelatinization
Textural property
Fluidized bed dryer

Abstract

This research was focused on improving the textural properties of black sticky rice by using a starch gelatinization process on the rice during postharvest and by drying using a fluidization technique. The test was initiated by drying black sticky rice exhibiting a harvested moisture of 28.3-33.3% (d.b) at a temperature of 100-150^{o}C until the moisture content was reduced to 22.0% (d.b). It was found that, as a result of this procedure, the level of starch gelatinization increase correlated well with the initial moisture content of the paddy and with the drying temperature, and the texture of the rice samples tended to change with the level of gelatinization; in particular, with increasing gelatinization the hardness value exhibited a decreasing trend and the stickiness value increased linearly.

Introduction

Although sticky rice does not approach the levels of production of the more popular jasmine rice, which is planted in Thailand as an export crop, domestic consumers, particularly those in Northern and Northeastern Regions, are fond of consuming it as a main dish (Butso and Isvilanonda, 2010). Sticky rice may be consumed in two forms: as white, or milled, sticky rice and as brown, or non-milled, sticky rice. Typically, consumers typically use the steaming method of cooking, which gives cooked milled sticky rice a tender and sticky texture that is noticeably different from non-milled sticky rice, which has a hard and less sticky texture (Jaiboon *et al*., 2010); this is because the fat and wax present in the bran layer of non-milled sticky rice hinders water absorption into the rice kernel during the cooking process (Mohapatra and Bal, 2006; Billiris *et al*., 2012). For this reason, non-milled sticky rice is usually not the choice of consumers, who favor consuming cooked sticky rice with a tender and sticky texture. However, it is well known that the bran layer covering the grains consists of protein, fat, fiber, ash, vitamins and minerals (Heinemann *et al*., 2005; Babu *et al*., 2009). Moreover, some species of sticky rice found in Northern Thailand, such as KUMDOISAKET black sticky rice, in addition to having a nutritional value, contain anthocyanins mixed within the bran layer that are potent in resisting free radicals and stopping cancerous cells (Chen *et al*., 2006; Netzel *et al*., 2007; Gamel and Abdel-Aal, 2012; Mapan *et al*., 2014).

Drying by using a fluidization technique and high temperature hot air, besides being a highly efficient method for reducing the moisture of the paddy down to a suitable level before storing, is also thought to stimulate starch gelatinization during the drying period (Soponronnarit *et al*., 1995). The gelatinization process was found to originate when the paddy harvested with a moisture content in the range of 28.3-33.3% (d.b.) was dried with suitable drying conditions (Tirawanichakul *et al*., 2004; Rattanamechaiskul *et al*., 2014). When gelatinization occurred in the rice grain, the starch granule would swell in its amorphous region, thus causing a loss in the molecular order within the starch granule and irreversible swelling. This change in the texture of the rice was observed as the loss of birefringence; the loss of crystallinity, with molecules of amylose and amylopectin leaching out from the starch granule; and the destruction of the orderly structure of the starch (Donald, 2004; Salmenkallio-Marttlia *et al*., 2004).

*Corresponding author.
Email: *rat.chaiwat@gmail.com*

Past research has studied the difference in the change of the texture caused by starch gelatinization in rice species having quantities of amylose that varied from medium (20%-25%) to high (26%-33%) (Juliano, 1992; Suwannaporn *et al*., 2007), and it was found that the hardness value of the rice increased and the stickiness value decreased after the starch gelatinization because free molecules of amylose leaching out of the starch granule during the gelatinization process would form a gel network anew after the starch granules were cooled down after drying. Such a network would prevent water penetration and absorption into the rice during the cooking process, thereby increasing the hardness value of the cooked rice and decreasing the stickiness value (Singh *et al*., 2005; Jaisut *et al*., 2009; Zavareze *et al*., 2012). Such changes are directly related to the level of starch gelatinization (Rattanamechaiskul *et al*., 2013). However, the aforementioned result is contradictory to the case of sticky rice, in which the amylose content is less than 5%. In a study investigating the result of increasing gelatinization on the texture of milled sticky rice after the heating process, it was found that it is difficult for molecules of amylopectin leaching out from the starch granule during starch gelatinization to reform a gel network because the molecules of amylopectin are highly branched. Therefore, when the structure of the starch granule was destroyed, it would result in a much higher water uptake of the gelatinized starch than seen in the non-gelatinized starch during the cooking process. The consequence was that the hardness value of milled sticky rice decreased and the stickiness value increased (Jaiboon *et al*., 2011). Though there has been work studying the change in the texture of rice after the aforementioned heating process, up until the present time, the change in the textural properties of black sticky rice that results from gelatinization induced by rying by the fluidization technique has not been investigated.

This research work is, therefore, focused on studying the change in the texture of black sticky rice after being dried with high temperature hot air fluidization. The results of this test provide data demonstrating the correlation between the degree of starch gelatinization and the change of the textural properties of black sticky rice at various drying conditions, and can be used to determine how to treat black sticky rice to meet the needs of diverse consumers and to provide the enriched nutritional value of the rice bran that is not milled.

Materials and Methods

Preparation of dried sample

The rice species used in this experiment was KUMDOISAKET black sticky rice harvested from the Purple Rice Research Unit of the Department of Plant Science and Natural Resources belonging to the Faculty of Agriculture at Chiang Mai University, Thailand. For the experimental study, the moisture of the harvested paddy was reduced to 14.0% (d.b.) by a sun drying method for storing. Therefore, before the paddy could be dried via the fluidization technique, it had to be rewetted by spraying it with water to simulate a harvested moisture in the range of 28.3% – 33.3% (d.b.). Thereafter, the paddy was stored in a cold room at 4^{o}C and mixed every 24 hours for a period of 7 days to spread the moisture evenly. Before experiments were conducted on the rewetted sample, the paddy was first left to reach the temperature of the surrounding environment.

Fluidized bed dryer

The fluidized bed dryer used in this study was a batch model, consisting of a drying chamber of cylindrical shape made of stainless steel with a diameter of 20 cm and a height of 100 cm. The entirety of the drying surface and the chamber wind ducts were covered by insulation with a thickness of 2.5 cm. The dryer was heated by a heater with a 12 kW capacity, and this was controlled by a proportional integral derivative or PID controller with an accuracy of ±1^{o}C; the fan used was a backward-curved blade centrifugal blower driven by a 1.5 kW motor. In addition, at the air out tube, there was a damper to adjust the fraction of the air within the system to obtain the rate of flow required.

Drying of black sticky rice

The drying process was initiated by putting the rewetted paddy in the paddy inlet until a bed height of 10 cm was obtained. Next, air was passed at a flow rate of 0.08 kg/s through the heater to increase the temperature of the paddy until it was in the test range of 100-150^{o}C. When hot air was flowed through the drying chamber, a portion of the air flowed out of the system and another portion was recycled, and the ratio of these two flows was 0.8. In this manner, the paddy was dried until the moisture content was reduced to 22.0% (d.b.), at which point it was removed from the drying chamber (Soponronnarit and Prachayawarakorn, 1994) and stored in closed jar for 30 minutes to reduce the cracks which could occur during the course of the drying process. The paddy was then ventilated in ambient air for 30 minutes until the moisture was further reduced to 13%-15% (d.b.) (Poomsa-ad *et al.*, 2002).

Thermal property analysis

Samples of black sticky rice that had been processed with ventilation only and of black sticky rice that had been dried under various conditions were ground using an ultra centrifugal mill (Retsch, model no. ZM 100, Hann, Germany). After that, the rice starch powder acquired was refined by passing through a 0.25 mm sieve and was taken for thermal property testing by a differential scanning calorimeter, or DSC (Perkin Elmer Co., Ltd., model DSC-7, Norwalk, USA). The method involved putting 3 µg of starch powder into the aluminium pan and adding 10 µg of distilled water to it before completely sealing the aluminium pan with a cover and leaving it to stand for 1 hour. After that, the sample pan was heated from 40°C to 100°C at a ramp rate of 10°C/min to acquire a DSC curve that contained the values of the onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and delta enthalpy (ΔH). From these, the level of starch gelatinization (SG) could be calculated from the equation (Normand and Mashall, 1989):

$$SG(\%) = \left(1 - \left[\frac{\Delta H}{\Delta H_c}\right]\right) x100$$

where ΔH is the transition enthalpy of the black sticky rice dried by the fluidized bed dryer (J/g dry matter) and ΔH_c is the transition enthalpy of black sticky rice dried by ventilation (J/g dry matter).

Textural property evaluation

Black sticky rice samples were washed and soaked in water for 16 hours at ambient temperature. Then, the soaking water was rinsed away and the soaked samples steamed for 30 minutes. After the steaming was complete, the samples were cooled under environmental conditions for 10 minutes before doing textural property tests. Hardness and stickiness values were analysed by a texture analyser (Stable Micro System, TAXT Plus, Surrey, UK). Steamed samples of 6 grains were placed on an aluminium plate, and a 5 cm cylindrical probe was used to compress the sample to 90% deformation twice, at the test and post-test speeds of the probe of 0.5 and 1 mm/s, respectively. The texture profile showing the force acting on the samples as a function of time was acquired and from this the value of hardness was read as the maximum force observed on the first compression while the value of stickiness was the negative force observed in the first cycle during the pulling out of the cylindrical probe (Juliano, 1985).

Table 1. Drying time and grain temperature of black sticky rice under various drying conditions

Drying temp. (°C)	Initial M.C. (% d.b.)	Drying time (min)	Grain temp. (°C)
100	28.3	4.0	64.0
	33.3	6.0	71.9
130	28.3	3.0	74.4
	33.3	4.0	82.1
150	28.3	1.5	84.8
	33.3	3.0	106.0

Results and Discussion

Drying time and grain temperature

Table 1 shows the timing used in reducing the moisture of the black sticky rice from the initial moisture content of 28.3% - 33.3% (d.b.) down to 22.0% (d.b.) and the grain temperature measured before being taken out of the drying chamber under various drying conditions. It was found that when a drying temperature of 100°C was used for drying the paddy with initial moisture content of 28.3% (d.b.), it would take 4.0 minutes to dry, with a measured grain temperature of 64.0°C. When the initial moisture of the paddy was 33.3% (d.b.), it resulted in both an increase in the value of the time of drying and in the grain temperature to 6.0 minutes and 71.9°C, respectively. Based on Table 1, when the initial moisture content of sample is held equal, the resultant drying time and the grain temperature of the samples seems to be directly related to the drying temperature; specifically, the drying time tended to decrease and the grain temperature tended to increase with increasing temperature used for drying. When the initial moisture of the paddy is 28.3% (d.b.) and is exposed to a drying temperature of 150°C, for example, the shortest time it would take for dry would be 1.5 minutes; the highest value of the grain temperature would be 106.0°C when a paddy with an initial moisture of 33.3% (d.b.) was dried under the temperature of 150°C.

The drying time was increased in proportion to the initial moisture content due to the fact that the paddy with 33.3% (d.b.) moisture had a substantial quantity of water in the grains. Therefore, the time required to evaporate water to the level of the required moisture was greater than the paddy with an initial moisture content of 28.3% (d.b.). Similarly, the period of time used for drying was decreased when the drying temperature was increased, because

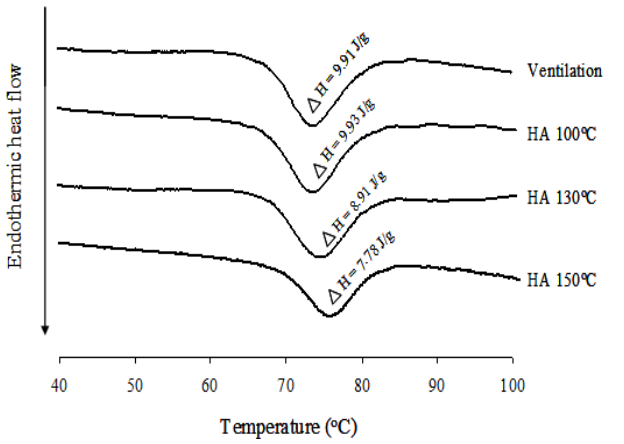

Figure 1. Endothermic heat flow curves of black sticky rice with an initial moisture content of 28.3% (d.b.) treated by ventilation and hot air

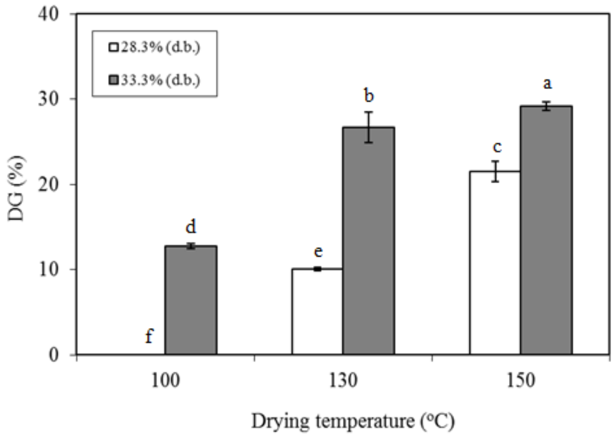

Figure 2. Level of starch gelatinization of black sticky rice under various drying conditions

drying at a high temperature transfers heat energy from hot air to the rice grains more effectively than does drying at a lower temperature, thus resulting in a higher value of the grain temperature. When the value of the grain temperature was high, the consequence was that the moisture within the rice grains could diffuse from the inner part of the grain to the surface and evaporate better than when drying at lower temperature because in the latter case the effective moisture diffusivity varies directly with the grain temperature (Pääkkönen, 2002; Madhiyanon *et al*., 2009; Thuwapanichayanan *et al*., 2011; Junka *et al*., 2015; Moreira *et al*., 2015; Moreira and Chenlo, 2015).

Thermal properties of black sticky rice

Figure 1 shows the endothermic heat flow curves of black sticky rice being processed through moisture reduction by ventilation and hot air at the initial moisture content of 28.3% (d.b.). Such curves showed that the transition temperatures of the samples, consisting of onset, peak and conclusion temperatures, were in the range of 66.0°C – 80.^{3}°C, where the delta enthalpy of the sample dried by ventilation was 9.91 J/g and those of the samples dried by hot air at 100, 130 and 150oC were 9.93, 8.91 and 7.78 J/g, respectively.

These decreasing delta enthalpy values, when calculated by comparing with the ventilated samples, could indicate a rise in the degree of starch gelatinization. The degree of starch gelatinization increased with the decrease in the delta enthalpy value. Figure 2 shows the level of starch gelatinization of black sticky rice under various drying conditions. At a drying temperature of 100°C and an initial moisture content of 28.3% (d.b.), the starch gelatinization could not be initiated. In contrast, drying at temperatures of 130°C and 150°C gelatinized 10.1% and 21.5% of the starch, respectively, while at the initial moisture content of 33.3% (d.b.), the level of gel formation was found to be 12.8%, 26.7% and 29.2% when the sample was dried by hot air at temperatures of 100°C, 130°C and 150°C, respectively.

No decrease in the value of delta enthalpy had occurred, even for the sample that had been through the drying process at 100°C when compared with the value of delta enthalpy of the sample which had not been treated through the drying process, because drying under such conditions heats the rice grains to their maximum temperature before being taken out of the drying chamber - only 64.0°C, as shown in Table 1 - while the temperature which begins to destroy the starch structure and to gelatinize it is 66.0°C. The value of delta enthalpy decreased when the samples were dried at 130°C and 150°C because the drying temperature resulted in the transfer of heat energy to the rice grains and raises the grain temperature higher than gelatinization temperature as long as the value of the moisture of the rice grains was higher than 22.2% (d.b.), and thus stimulated the starch gelatinization process (Lai, 2001). In other words, when the starch gives rise to gels, the ordered structure of the starch is destroyed. The difference in the energy required to destroy the structure of the starch granule, therefore, accounts for the decrease in the delta enthalpy value, and furthermore, such values seem to decrease with increasing drying temperature. The initial moisture content of the sample and the temperature used for drying had an influence on the level of starch gelatinization; the level of gel formation would increase with an increase in the initial moisture content and in the temperature used for drying.

Textural property of black sticky rice

Table 2 shows the hardness and stickiness values of a sample processed using ventilation and a sample

Table 2. Textural properties of cooked black sticky rice samples

Drying temp. (°C)	Initial M.C. (% d.b.)	Hardness (N)	Stickiness (N)
Ventilation		123.9 ± 1.5^{ab}	0.6 ± 0.0^{ef}
100	28.3	121.6 ± 1.6^{b}	0.6 ± 0.0^{f}
	33.3	118.2 ± 0.6^{c}	0.8 ± 0.0^{d}
130	28.3	117.3 ± 0.7^{c}	0.8 ± 0.1^{de}
	33.3	113.9 ± 1.1^{d}	1.6 ± 0.2^{b}
150	28.3	115.4 ± 2.5^{cd}	1.0 ± 0.1^{c}
	33.3	109.2 ± 0.5^{e}	1.9 ± 0.0^{a}

Different superscripts in the same column are significantly different at $p<0.05$

dried by the fluidization technique under various conditions, and the hardness and stickiness values of cooked black sticky rice were found to initially be 123.9 and 0.6 N, respectively. At an initial paddy moisture of 28.3% (d.b.), the hardness and stickiness values of a sample dried at 100°C did not vary significantly from those of the ventilated sample, but, when the value of the initial moisture content of samples was increased to 33.3% (d.b.), the hardness value decreased to 118.2 N and the stickiness value increased up to 0.8 N. In addition, at the same initial moisture content, increasing the drying temperature consequently resulted in lowering the hardness value and raising the stickiness value. The hardness value was lowest and the stickiness value the highest, with significant deviation, for the paddy with initial moisture content of 33.3% (d.b.) that was dried at a temperature of 150°C, because the level of starch gelatinization was highest under such drying conditions.

The changes in the hardness and stickiness values varied directly with the level of starch gelatinization. When the structure in the starch granule was gelatinized during drying, it would also result in a loss of order in the molecules inside the grain. After being dried, the starch granule became cooler, and it then became very difficult for the disordered molecules of amylopectin to form a new gel network, because the molecules are highly branched. The structure of the gelatinized starch granule, once cooked, would be able to uptake more water than a starch that had not been gelatinized (Jaiboon *et al.*, 2011). Thus, the hardness value tends to decrease and the stickiness tends to increase with a rising level of starch gelatinization. Increasing the degree of starch gelatinization would help the texture of the cooked black sticky rice to be tender and sticky.

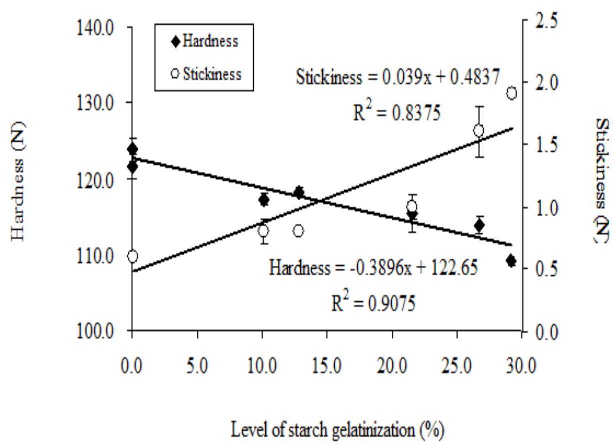

Figure 3. Correlation between level of starch gelatinization and changed of hardness and stickiness

Correlations between level of starch gelatinization and textural properties of black sticky rice

Figure 3 shows the correlation between the level of starch gelatinization at the various drying conditions that were studied and the change of the hardness and stickiness properties of cooked black sticky rice. When considering the R^2-values acquired from Figure 3, which were equal to 0.9075 and 0.8375, respectively, it was found that the change in the hardness and stickiness correlated well with increasing levels of starch gelatinization. At level of 29.2% gelation, when the 33.3% (d.b.) initial moisture content sample was dried by hot air at 150°C, the hardness value decreased while the stickiness value increased to its maximum at 14.7 and 1.3 N, respectively, when compared with the ventilated samples.

The increased level of starch gelatinization resulted in hardness values that had a linearly decreasing trend and stickiness values with a linearly increasing trend, as shown in the correlations graphs. These correlations indicate that the high temperature hot air fluidization technique could improve the textural properties of cooked black sticky rice so that it is more tender and sticky than when traditionally cooked, because the starch is gelatinized during drying.

Conclusion

Levels of gel formation in rice correlates with the initial moisture content of sample and the drying temperature used. Samples with higher initial moisture contents and that were dried at the highest drying temperatures had more gel formed from the starch than samples with lower initial moisture content and that were dried at a lower drying temperature. The changes in the hardness and stickiness values correlated highly with the level of starch gelatinization. The hardness value tended to decrease and the stickiness value tended to increase with an increase in the level of starch gelatinization. Under the drying conditions that were studied, black sticky rice samples with an initial moisture content of 33.3% (d.b.) and dried by hot air at a temperature of 150°C yielded the most tender and stickiest texture, because the level of the starch gelatinization was highest in this sample. In conclusion, the method of drying by high-temperature hot air fluidization technique could be applied for use in the improvement of the textural properties of cooked black sticky rice to make the rice more similar to the preferred taste of diverse consumers.

Acknowledgments

The authors thank Assoc. Prof. Dr.Chanakan Thebault Prom-u-thai, from the Department of Plant Science and Natural Resources of Faculty of Agriculture at Chiang Mai University, Thailand, for the black sticky rice sample and the Drying Technology Research Laboratory at the School of Energy, Environment and Materials at King Mongkut's University of Technology Thonburi for the use of their equipment.

References

Babu, D. P., Subhasree, R. S., Bhakyaraj, R. and Vidhyalakshmi, R. 2009. Brown rice-beyond the color reviving a lost health food - a review. American-Eurasian Journal of Agronomy 2(2): 67-72.

Billiris, M. A., Siebenmorgen, T. J. and Wang, Y. J. 2012. Rice degree of milling effects on hydration, texture, sensory and energy characteristics: Part 2 Cooking using fixed, water-to-rice ratios. Journal of Food Engineering 113: 589-597.

Butso, O. and Isvilanonda, S. 2010. Changes in the efficiency of rice production in Thailand. Kasetsart Journal 31: 436-444.

Chen, P. N., Chu, S. C., Chiou, H. L., Kuo, W. H., Chiang, C. L. and Hsien, Y. S. 2006. Mulberry anthocyanins, cyanidin 3-rutinoside and cyaniding 3-glucoside, exhibited an inhibitory effect on the migration and invasion of a human lung cancer cell line. Cancer Letter 235: 248-259.

Donald, A. M. 2004. Understanding starch structure and functionality. In: Eliasson, A. C. (ed.). Starch in food. Woodhead Publishing Limited, Cambridge, UK.

Gamel, T. and Abdel-Aal, M. E. 2012. Phenolic acids and antioxidant properties of barley wholegrain and pearling fractions. Agricultural and food science 21: 118-131.

Heinemann, R., Fagundes, P., Pinto, E., Penteado, M. and Lanfer-Marquez, U. 2005. Comparative study of nutrient composition. Journal of Food Composition and Analysis 18: 287-296.

Jaiboon, P., Prachayawarakorn, S., Devahastin, S., Tungtrakul, P. and Soponronnarit, S. 2011. Effect of high-temperature fluidized-bed drying on cooking, textural and digestive properties of waxy rice. Journal of Food Engineering 105: 89-97.

Jaiboon, P., Prachayawarakorn, S., Devahastin, S. and Soponronnarit, S. 2010. Effects of gelatinization on textural properties of brown waxy rice. Agricultural Science Journal 41 (Suppl.): 393-396.

Jaisut, D., Prachayawarakorn, S., Varanyanond, W., Tungtrakul, P. and Soponronnarit, S. 2009. Accelerated aging of jasmine brown rice by high-temperature fluidization technique. Food Research International 42: 674-681.

Juliano, B. O. 1985. Criteria and tests for rice grain qualities. In: Juliano, B. O. (Ed). Rice chemistry and technology, p. 443-524. Minnesota: American Association of Cereal Chemists, Inc.

Juliano, B. O. 1992. Structure and function of the rice grain and its fractions. Cereal Foods World 37: 772-774.

Junka, N., Wongs-Aree, C., Rattanamechaiskul, C., Kanlayanarat, S., Boonyaritthongchai, P. and Prom-u-thai, C.T. 2015. Effect of high-temperature fluidized bed drying on quality of 'Kum Doi Saket' variety of purple rice. International Food Research Journal 22(2): 593-597.

Lai, H. M. 2001. Effects of hydrothermal treatment on the physicochemical properties of pregelatinized rice flour. Food Chemistry 72: 455-463.

Madhiyanon, T., Phila, A. and Soponronnarit, S. 2009. Models of fluidized bed drying for thin-layer chopped coconut. Applied Thermal Engineering 29: 2849-2854.

Mapan, P., Suphannika, T., Prom-u-thai, C. T., Kaladee, D. and Jamjod, S. 2014. Early generation selection for high anthocyanin and photoperiod insensitivity in F2 population between Kumdoisaket and Pathumthani 1. Naresuan Phayao Journal 7: 160-171.

Mohapatra, D. and Bal, S. 2006. Cooking quality and instrumental textural attributes of cooked rice for different milling fractions. Journal of Food Engineering 73: 253-259.

Moreira, R., Chenlo, F., Torres, M. D., Rama, B., Arufe, S. 2015. Air drying of chopped chestnuts at several conditions: Effect on colour and chemical characteristics of chestnut flour. International Food Research Journal 22(1): 407-413.

Netzel, M., Netzel, G., Kammerer, D. R., Schieber, Carle, A. R., Simons, L., Bitsch, I., Bitsch, R. and Konczak, I. 2007. Cancer cell antiproliferation activity and metabolism of black carrot anthocyanins. Innovative Food Science and Emerging Technologies 8: 365-372.

Normand, F. L. and Mashall, W. E. 1989. Differential scanning calorimetry of whole grain milled rice and milled rice and milled rice flour. Cereal Chemistry 66: 317-320.

Poomsa-ad, N., Soponronnarit, S., Prachayawarakorn, S. and Terdyothin, A. 2002. Effect of tempering on subsequent drying of paddy using fluidization technique. Drying Technology 20: 195-210.

Pääkkönen, K. 2002. A combined infrared/heat pump drying technology applied to a rotary dryer. Agricultural and Food Science 11: 209-218.

Rattanamechaiskul, C., Soponronnarit, S. and Prachayawarakorn, S. 2014. Glycemic response to brown rice treated by different drying media. Journal of Food Engineering 122: 48-55.

Rattanamechaiskul, C., Soponronnarit, S., Prachayawarakorn, S. and Tungtrakul, P. 2013. Optimal operating conditions to produce nutritious partially parboiled brown rice in a humidified hot air fluidized bed dryer. Drying Technology 31: 368-377.

Salmenkallio-Marttlia, M., Heiniö, R-L. and Myllymäki, O. 2004. Relating microstructure, sensory and instrumental texture of processed oat. Agricultural and food science 13: 124-137.

Saxena, J. and Dash, K. K. 2015. Drying kinetics and moisture diffusivity study of ripe jackfruit. International Food Research Journal 22(1): 414-420.

Singh, N., Kaur, L. Sodhi, N.S. and Sekhon, K.S. 2005. Physicochemical, cooking and textural properties of milled rice from different Indian rice cultivars. Food Chemistry 89: 253-259.

Soponronnarit, S., Yapha, M. and Prachayawarakorn, S. 1995. Cross-flow fluidized bed paddy dryer: prototype and commercialization. Drying Technology 13: 2207-2216.

Soponronnarit, S. and Prachayawarakorn, S. 1994. Optimum strategy for fluidized bed paddy drying. Drying Technology 12: 1667-1686.

Suwannaporn, P., Pitiphunpong, S. and Champangern, S. 2007. Classification of rice amylose content by discriminant analysis of physicochemical properties. Starch 59: 171-177.

Thuwapanichayanan, R., Prachayawarakorn, S., Kunwisawa, J. and Soponronnarit, S. 2011. Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying. LWT - Food Science and Technology 44: 1502-1510.

Tirawanichakul, S., Prachayawarakorn, S., Varanyanond, W., Tungtrakul, P. and Soponronnarit, S. 2004. Effect of fluidized bed drying temperature on various quality attributes of paddy. Drying Technology 22: 1731-1754.

Zavareze, E., Mello El Halal, S. L., de los Santos, D. G., Helbig, E., Pereira, J. M. and Guerra Dias, A. R. 2012. Resistant starch and thermal, morphological and textural properties of heat-moisture treated rice starches with high-, medium- and low-amylose content. Starch 64: 45-54.