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Ohmic heating for cooking rice: Electrical conductivity measurements, textural quality determination and energy analysis

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ABSTRACT

In this study, an innovative technique, namely ohmic heating was applied in rice cooking and compared with conventional method using electric rice cooker. Four types of rice samples including white rice of two varieties (KDML105 and Sao Hai), brown rice and germinated brown rice of one variety (KDML105) were used. Electrical conductivities of mixtures between rice samples and 0.1 M salt solution at various ratios were measured. Empirical models were developed for predicting electrical conductivities of rice samples as a function of temperatures. Textural properties of cooked rice samples and energy consumption were compared between ohmic and conventional cooking methods. The purposes of this work were to (1) study the possibility of applying ohmic method in rice cooking and (2) compare between cooking rice by ohmic and conventional method. The results revealed that it is possible to apply ohmic method for cooking all rice samples by using 0.1 M salt solution in the mixtures. The electrical conductivities of white rice (KDML105), white rice (Sao Hai), brown rice and germinated brown rice (KDML105) mixtures were 0.246–0.900, 0.375–1.005, 0.617–1.370 and 0.485–1.182 S/m respectively. The rice cooked by ohmic method had significantly different textural properties from that cooked by electric rice cooker. The magnitude of difference depended on the rice types. The electrical energy consumption of ohmic cooking system was approximately 73–90% of energy required for conventional rice cooker.

1. Introduction

Rice is one of the most important staple food for the world population. Asian people consume cooked rice for almost every meal. Hundreds of rice varieties are grown in Thailand (Wiboonpongse & Chaovanapoonphol, 2001); however, KDML105 (jasmine rice) is the most internationally-recognized variety. Apart from consuming cooked rice in the form of white rice (WR), so far brown rice (BR) and germinated brown rice (GBR) have gained an increasing popularity especially for the health lovers group. Although, BR is more nutritious than WR, its consumption is slightly limited due to its chewy texture and reduced digestibility. This problem can be overcome by subjecting BR to partial germination. GBR can be produced by soaking the whole kernel of BR in water until its germ begins to bud. The outer bran layer becomes soft and more prone to water absorption, making it easier to cook (Musa, Umar, & Ismail, 2011). Moreover, it has been already proved that the levels of some nutrients and bioactive compounds such as gamma aminobutyric acid (GABA), dietary fibers, magnesium, potassium, zinc, ascorbic acid, tocopherols, tocotrienols and phenolic compounds increase during germination process of BR (Fernandez-Orozco et al., 2008; Frias, Miranda, Doblado, & Vidal-Valverde, 2005; Latifah et al., 2010; Ohtsubo, Suzuki, Yasui, & Kasumi, 2005).

Generally, rice must be cooked prior to consumption. The amylose content of rice is deemed as one of the most important factors influencing to the cooking characteristics of rice (Delwiche, McKenzie, Webb, & Williams, 1995; Webb, 1991). According to Juliano (1992), rice can be categorized by its amylose content to be five groups comprising with waxy (0 to 5% amylose), very low (5 to 12% amylose), low (12 to 20% amylose), intermediate (20 to 25% amylose) and high (25 to 33% amylose) amylose rice. After cooking, the rice with high amylose content would be dry, less tender and become hard when cooling. Dissimilarly, the cooked low-amylose rice would be moist and sticky (Mutters & Thompson, 2009). Apart from the amylose content of rice, Roy et al. (2010) pointed out that the cooking properties of rice depended on the forms of rice, the water-rice ratio and the preset cooking mode. It is well known that the BR requires much longer cooking time

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and water-rice ratio than WR; as a result, it is inconvenient and not compatible with the modern lifestyle that do not want to spend long time for preparing food.

There are various methods to cook rice depending on rice type and culture of people in each region (Daomukda, Moongngarm, Payakapol, & Noisuwan, 2011). The cooking methods and utensils significantly affected on the chemical compositions, physicochemical properties and eating quality of cooked rice. In general, the tools for cooking rice are electric rice cooker, microwave oven, steamer, gas stove and charcoal brazier. However, nowadays the most common appliance for rice cooking is the electric rice cooker. For the electrical rice cooker, the heat is generated by converting electrical energy to be thermal energy at the heating plate and then the heat will be transferred to the pot and the water-rice mixture respectively by the heat conduction and convection mechanisms. The thermal efficiency of the electric rice cooker is limited due to its technically conceptual design which is indirect heating.

Ohmic heating is a novel thermal processing that applies electrical current into the food sample in order to directly generate heat inside the food (Knirsch, Alves dos Santos, Martins de Oliveira Soares Vicente, & Vessoni Penna, 2010, Palaniappan & Sastry, 1991; Reznick, 1996). The amount of heat produced by this technique depends on the applied electrical field strength and the electrical conductivity of sample (Icier & Ilicali, 2005). As a result, the foods which have lower electrical conductivities will be heated slower than those of higher electrical conductivities if the identical electrical field strength is used. Referring to Lyng and McKenna (2007), the food materials with electrical conductivities in the range of 0.01–10 S/m are considered proper for ohmic heating. The electrical conductivities of food products usually depend on their temperatures and constituents (Shirsat, Lyng, Brunton, & McKenna, 2004; Sarang, Sastry, & Knipe, 2008;). Shirsat et al. (2004) pointed out that the foods with high salt or acid contents would have high electrical conductivities and subsequent ohmic heating rates; in contrast, an increase in fat content resulted in the opposite effect. Zhang (2007) and Srivastav and Roy (2014) claimed that the electrical conductivity of food is strongly related to its ionic content, moisture mobility, and physical structure. The addition of ionic substances such as acids and salts into food material could raise its conductivity (Sakr & Liu, 2014). Wang and Sastry (1997) added sodium chloride (1% w/w water) to starch suspension in order to escalate the electrical conductivity to be suitable for ohmic heating. Zareifard, Ramaswamy, Trigui, and Marcott (2003) claimed that the solid phase could be heated quicker than the liquid phase if ohmic heating method was applied. However, it depended on several factors such as electrical conductivity of each phase, particle size and particle orientation in the ohmic heating cell. According to the direct heating concept of ohmic heating, it is considered as an innovative cooking method that have the potential to improve the efficiency of rice cooking procedure and replace the conventional household and industrial-scale electric rice cookers. Nevertheless, so far there has been limited amount of published researches in the area of cooking rice by ohmic method and the invention of ohmic rice cooker.

In this work, the ohmic heating technique was utilized for measuring the electrical conductivities and cooking of WR, BR and GBR. After that, the textural properties of ohmically-cooked rice samples were compared with those of samples cooked by conventional electric rice cooker. In addition, the energy utilized for both cooking methods were evaluated. The aims of this work were to (1) study the possibility of applying ohmic heating technique for the cooking of WR, BR and GBR and (2) compare between cooking rice by ohmic heating technique and conventional method using electric rice cooker.

2. Materials and methods

2.1. Raw materials

Four types of rice samples were used in this study including WR of two varieties viz. KDML105 and Sao Hai (Sandee Rice Co. Ltd., Bangkok, Thailand), brown rice of one variety of KDML105 (Patum Rice Mill and Granary Public Co. Ltd., Bangkok, Thailand) and germinated brown rice of one variety of KDML105 (Chiameng Co. Ltd., Nonthaburi, Thailand). The KDML105 and Sao Hai were popular rice varieties in Thailand and categorized as the low and high amylose content rice varieties respectively. While measuring the electrical conductivity or cooking rice by ohmic heating, the rice samples were mixed with water that was added with "Prung Thip" iodized table salt (Thai Refined Salt Co. Ltd., Nakorn Ratchasima, Thailand) at the concentration of 0.1 M in order to raise its electrical conductivity and subsequent ohmic heating rate. If the water was used without adding salt, the rice could not be cooked by ohmic heating due to its too low electrical conductivity of rice-water mixture. The water for cooking rice was the water that passed through a water filtering system consisting of three columns, namely polypropylene 0.3 μm, activated carbon and resin filters respectively. The electrical conductivity of this filtered water was very low and undetectable. The 0.1 M concentration of salt was selected because it provided the proper heating rate for monitoring and measuring the electrical conductivities along the heating period without noticeable effect on the taste of cooked rice samples.

2.2. Ohmic heating apparatus

There were two sets of ohmic heating devices applied in this work comprising with the system for measuring electrical conductivity and that for cooking the rice samples as the schematic diagrams shown in Fig. 1 (a) and (b) respectively. For the electrical conductivity measurement, the ohmic cell was made from an acrylic cylindrical tube. The diameter of electrodes was 43.55 mm and the distance between electrodes was 42.2 mm. The pattern of this ohmic cell for electrical conductivity measurement was similar to those of Sarkis, Mercali, Tessaro, and Marczak (2013), Engchuan, Jittanit, and Garnjanagoonchorn (2014) and Darvishi, Hosainpour, Nargesi, and Fadavi (2015). Differently, for the ohmic cooking system the cooking chamber was made of glass with the inside diameter of 195 mm and height of 300 mm. The electrodes were rectangular shape with the width and height of 70 and 240 mm respectively. The electrodes were slightly bended to be parallel with the perimeter of the glass chamber. The distance between the centers of electrodes was 95 mm. This cooking chamber was analogous to that of Pham, Jittanit, and Sajjaanantakul (2014). The stainless steel was used as electrode material for ohmic heating apparatus in many researches such as Pataro et al. (2014), Engchuan et al. (2014), Darvishi et al. (2015), Moreno et al. (2016), Lascorz, Torella, Lyng, and Arroyo (2016) and Gally et al. (2017); therefore, in this study, the material used for all electrodes was stainless steel grade 316 L.

2.3. Electrical conductivity measurement

As previously mentioned, rice samples were added with 0.1 M salt solution prior to the electrical conductivity measurement. The volume ratios between each sort of rice sample and solution applied in this study were shown in Fig. 2. These volume ratios were specified by considering the recommended water ratio for rice cooking presented on the packaging of each rice sample. The electrical voltage applied between electrodes was 50 V with a frequency of 50 Hz for both varieties of WR, while for BR and GBR the applied voltage was 45 V with a frequency of 50 Hz corresponding to electrical field strengths of 11.8 V/cm and 10.7 V/cm respectively. The applied voltage for BR and GBR was lower than WR because the electrical conductivity values of BR and GBR were greater than those of WR. The lessening of applied voltage for