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Optimization of operating process parameters for instant brown rice production with microwave-followed by convective hot air drying

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ABSTRACT

Nowadays, instant or quick cooking brown rice is a food product that has marketing potential due to the life style of new generation. This research mainly aimed to characterize, model and optimize the key processing conditions including water-rice ratio (WRR), microwave power level (MWL) and hot air temperature (HAT) for producing instant brown rice by applying Box-Behnken technique. The process responses comprised with color, rehydration ratio and textural qualities of products. The microscopic images of products were also determined. The result indicated that MWL caused the most intense effect on the rehydration ratio and textural qualities. Furthermore, the MWL and HAT influenced on the lightness while the WRR affected on the hardness of rehydrated samples. All three processing parameters significantly affected on the color intensity and stickiness of rehydrated rice. The optimal processing conditions for WRR, MWL and HAT were 1.44, 499.8 W and 89.99 °C respectively with 88% overall desirability.

1. Introduction

Nowadays, the instant products seem to be preferred to deal with the modern lifestyle. It is well-known that brown rice is deemed as a good source of nutritional values for human. However, brown rice normally requires long cooking time of about forty-five minutes and the texture tends to be gummy (Bardet et al., 1961). Furthermore, some compounds inside brown layer cause undesirable odors, which are so-called old rice odor leading to unpleasant feeling of consumer especially when the brown rice is stored for long period (Sun, 2008). Due to the mentioned reasons, it would be interesting to process the brown rice to be a more convenient and preferable product, namely instant brown rice or quick cooking brown rice.

Generally, the production of instant rice includes several basic steps such as pretreatment, cooking, and drying process (Rewthong et al., 2011; Sripinyowanich and Noomhorm, 2013). The operating conditions for each step should be properly selected depending on the forms of rice and warming method prior to serving. For the brown rice, such process might be more complicate in comparison with that of white rice to facilitate rehydration time and eating qualities, which have been concerned as important attributes for instant product. Therefore, the initial moisture content before drying process, degree of gelatinization and drying techniques were considered as the most important key factors in instant rice production (Prasert and Suwannaporn, 2009; Rewthong et al., 2011).

There have been a number of studies about the production techniques for improving the instant rice quality. Leelayuthsoontorn and Thipayarat (2006) and Prasert and Suwannaporn (2009) claimed that high pressure cooking helped increasing the degree of gelatinization and decrease the percentage of broken rice. Luangmalawat et al. (2008) and Le and Jittanit (2012) found that the higher initial moisture content of cooked rice before drying related to the appearance and characteristics of dried-cooked rice, e.g., percentage of broken rice grain and protruded endosperm after being cooked. Moreover, they pointed out that higher drying rate could result in desired porous or sponge-like structure in dried rice kernel while low drying rate when using hot air drying at low temperature resulted in the dense structure. Ramesh and Srinivasa Rao (1996) stated that the porous structure

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leaded to the better rehydration quality. In some works, the high drying rate by applying vibro-fluidized-bed dryer (Ramesh and Srinivasa Rao, 1996) and high temperature of tray dryer (Ramesh, 2003; Prasert and Suwannaporn, 2009) were conducted for cooked rice drying. These researchers mentioned to the puffing phenomena when explaining the volume expansion and porous structure of their dried products. Apart from its high drying rate, the vibro-fluidized bed dryer could reduce the sticky problem of cooked rice during drying. Interestingly, Rewthong et al. (2011) and Sripinyowanich and Noomhorm (2013) proposed the idea to apply the freezing step prior to drying in order to raise the porous structure of instant rice.

Microwave drying is an interesting alternative for removing moisture from the cooked brown rice due to its fast drying rate. For the microwave drying, heat is generated within the material especially at the moist zone; as a consequence, the moisture transport from the inner to the surface of material would be accelerated by the vapor pressure inside the material. This phenomenon is so-called pumping effect. As a result of pumping effect, the required porous structure of cooked brown rice could be created (Krokida and Maroulis, 1999; Sharma and Prasad, 2005; Le and Jittanit, 2012). Although microwave drying has some advantages as previously described, the application of microwave drying for the whole process of food drying is deemed as non-economical practice compared to hot air drying (Feng and Tang, 1998). Furthermore, Clark (1996) and Nijhuis et al. (1998) suggested that excessive temperatures along the edges and corners of dried sample during microwave drying might lead to overheating resulting in possible scorching and subsequently lower quality of final product. In this case, the application of tempering treatment after microwave drying in the first stage followed by low temperature hot air drying might help maintaining the high quality of dried product and save energy cost. Robert (1952) and Weibye (1983) proposed that after the proper degree of porosity of instant rice is reached, the drying should be finished by conventional drying method with lower drying rate in order to reduce burning of dried cooked rice and economize the energy consumption.

In this study, the instant or quick cooking brown rice was produced under various conditions. Then, the qualities of instant rice products in aspects of color, rehydration ratio and textural qualities were determined. The main objectives were to characterize, model and optimize the key processing conditions including water-rice ratio (WRR), microwave power level (MWL) and hot air temperature (HAT) for instant brown rice production. Furthermore, the microscopic images of products were captured. The outcome of this research would be beneficial for both researchers and food industry that intend to process their rice to be value-added products.

2. Materials and methods

2.1. Sample preparation and pretreatment processes

The rice seeds (*Oryza sativa* L.) of the KDML105 variety (Jasmine rice) were dehusked to be brown rice using a laboratory dehusker (motor 0.5 HP/220 V/50 Hz, Ngek Seng Huat Part., Ltd., Bangkok, Thailand). After removing the husk and broken rice out, 500 g of jasmine brown rice was washed by tap water and then cooked in a "Zebra" digital pressure cooker (ZB-DEP2200, Satien Stainless Steel Public Company Limited, Bangkok, Thailand) with the operating pressure range of 40–70 kPa for 18 min with the specified ratio of water to rice. After the cooking period of 18 min, the rice was warmed in the cooker at a temperature range of 60–80 °C for 15 min to increase the degree of gelatinization. Then, the cooked brown rice was then exposed to few pretreatments prior to drying. The pretreatments consisted of (1) freezing the cooked brown rice in the chest freezer setting temperature at -18 ± 2 °C for 90 min by placing cooked rice as a thin layer on trays and (2) thawing the frozen cooked brown rice by two stages. The first stage of thawing was conducted in the refrigerator at temperature about 6 ± 2 °C for 40 min and followed by the second stage at room temperature for 20 min. The thawing was divided to be 2 steps so that the drip loss was minimized because the thawed moisture was reabsorbed into cooked rice. After final stage of thawing, the sample was sprayed with cold water at temperature of 8 °C in order to separate the cooked rice that attached together. The moisture content of brown rice sample before drying was approximately 68–70% wet basis (wb).

2.2. Experimental design

Three levels of water-rice ratio (1.3:1, 1.5:1, and 1.7:1), microwave power levels (595, 425, and 255 W) and hot air drying temperatures (50, 70 and 90 °C) were applied in this study. The experiments were designed by Box-Behnken technique for optimization purpose. The rehydration ratio, color and textural qualities of rehydrated samples were determined for the instance rice samples of all experiments. These measured values were used for plotting the response surfaces.

The code values and real values of the factors are shown in Table 1. The design consists of 13 experimental conditions. Five replications were carried out for the experimental condition at the center point (0, 0, 0) whereas the remaining experimental conditions were repeated in triplicate.

2.3. Bulk density measurement

Thirty grams of dried cooked brown rice was put in 100-ml cylinder and tapped 25–30 times to allow uniform compacting of grains (Prasert and Suwannaporn, 2009). Then the volume and the weight of samples in the cylinder were recorded. Bulk density of quick cooking brown rice was calculated by equation (1).

$$\text{Bulk density} = \frac{\text{Weight of dried cooked brown rice (g)}}{\text{Volume of dried cooked brown rice (ml)}} \quad (1)$$

2.4. Texture measurement

Twenty grams of dried cooked brown rice were rehydrated by microwave oven for 5 min. After draining excess water for 5 min, six kernels were randomly selected and separately placed on the straight line of basement for texture analysis by using texture analyzer (TA.XT Plus, Stable Micro System Ltd., UK). A cylindrical probe of 25 mm diameter was used to compress the kernels to 85% deformation at the pre-test speed of 1 mm/s and post-test speed of 10 mm/s. This method was modified from Rewthong et al. (2011). The force-deformation data of samples obtained from each experimental run were determined in eight replications and interpreted

Table 1
Code values and real values of water-rice ratio (WRR), microwave power level (MWL) and hot air temperature (HAT) applied in the Box-Behnken design.

Ratio of water to rice	Microwave power level (Watt)	Hot air temperature (°C)
−1 (1.3:1)	−1 (255)	−1 (50)
0 (1.5:1)	0 (425)	0 (70)
+1 (1.7:1)	+1 (595)	+1 (90)