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Effects atmospheric radio-frequency plasma treatment on popping characteristics of popped rice and its nutritional evaluation

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ABSTRACT

This study investigates the effects of household popping methods (using electric flying pans, kitchen ovens, and microwave ovens) on the popping characteristics percent yield and expansion volume (ml g^{-1})) and the nutritional value of popped rice. Next, an atmospheric RF plasma treatment (20 W and 40 W) was used to improve the yield, expansion volume, and content of essential amino acids in the popped rice. The effects of atmospheric RF plasma treatment on the surfaces of popped rice were examined using a microscope. The results demonstrated that the percent yield (42.2 ± 6.6%) and expansion volume (2.53 ± 0.72 ml g^{-1}) of popped rice when using an electric flying pan were approximately 4 times higher than those observed when using a kitchen oven and approximately 3 times higher than those observed when using a microwave oven. However, the crude protein and elemental composition (P, K, Mg, Ca, Zn, Na, Mn, and Fe) of popped rice using a direct heat from an electric frying pan were found to be significantly lower than obtained using other methods. Atmospheric (RF) plasma at 40 W could improve the quality of popped rice when it is popped in an electric frying pan. Higher percent yield (53.2 ± 1.6%), expansion volume (3.59 ± 0.06 ml g^{-1}), and essential amino acid content (5 mg amino acid g^{-1}protein of arginine, leucine, phenylalanine, threonine, and lysine) in the popped rice were observed after plasma treatment. In addition, a microscopic investigation confirmed that large expanded pellets were observed on the surface of the plasma treated popped rice. Without plasma treatment, a smooth surface of popped rice was observed. Therefore, plasma treatment may be an important factor in the buildup of vapor pressure inside the unhusked rice. This research suggests that a combination of an electric flying pan and atmospheric RF plasma is highly effective for increasing the producing of popped rice.

Industrial relevance: Treating unhusked rice with atmospheric RF plasma before popping has positive effects on yield and expansion volume of the popped rice. In addition, atmospheric RF plasma could be used to prevent loss of nutrition value during popping. This treatment also provides high production yields for the rice popping industries and benefits consumers by increasing the nutritional content of popped rice products.

1. Introduction

Popped rice is produced from the unhusked rice at high temperatures. It is widely known that flavor and nutritional ingredients are added to popped rice to produce ready-to-eat products such as snack bar and breakfast cereals which are suitable for human consumption (Bhattacharya, 2011). Furthermore, different rice varieties have different contents of bioactive compounds and phytonutrients (Butsat & Siriamornpun, 2010; Loypimai, Moongngarm, Chottanom, & Moontree, 2015) that may be destroyed by food processing. Swarnakar, Devi, and Das (2014) and Maisont and Narkrugsa (2010) studied various conditions, including temperature and moisture content of unhusked rice, on the quality of popped rice. Furthermore, the quality of popped rice was influenced by many other factors, such as the equilibrium moisture of unhusked rice, pericarp thickness, cracked grains, and type of starch in rice grains (Murugesan & Bhattacharya, 1991). However, the most important factors influencing the quality of popped rice are the popping methods. Although brown rice is a good source of protein, vitamin, and minerals (Suhem, Matan, Nisoa, & Matan, 2013a, 2013b), these nutrients can be destroyed due to high temperatures involved in the popping process. Electric frying pans, kitchen ovens, and microwave ovens are the three most commonly used appliances in homes and food industries (Gökmen, 2004; Sánchez-Pardo, Ortiz-Moreno, García-Zaragoza, Necoechea-Mondragón, & Chanona-Pérez, 2012). These appliances create superheat during the popping process due to a pressure vessel inside the pericarp, which produces a driving force for expanding the kernel once the pericarp ruptures (Hoseney, Zeleznak, & Abdelrahman, 1983). While heat requires to expand the volume of popped rice, heat from different conventional popping methods might also loss of nutrition value in the popped rice. However, only a small number of reports have been conducted on the effect of popping methods on the quality of popped rice;

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Table 1
Approximate composition of popped rice via different popping methods.

	Approximate composition (% dry matter; n = 3)			
	Electric frying pans with plasma 40 W	Electric frying pans	Kitchen oven	Microwave oven
Moisture	5.7 ± 0.1^c	7.0 ± 0.1^b	7.6 ± 0.2^a	5.6 ± 0.1^c
Ash	2.2 ± 0.1^a	1.8 ± 0.0^c	1.8 ± 0.0^c	2.0 ± 0.1^b
Crude protein	10.7 ± 0.2^a	9.3 ± 0.1^c	9.7 ± 0.2^b	9.9 ± 0.1^b
Crude fat	0.9 ± 0.2^b	1.0 ± 0.3^a	0.6 ± 0.1^b	0.5 ± 0.1^b
Fiber	2.8 ± 0.1^a	2.7 ± 0.1^a	2.0 ± 0.1^b	2.6 ± 0.1^a
Carbohydrate	83.4 ± 0.2^c	85.1 ± 0.2^b	85.9 ± 0.1^a	85.1 ± 0.1^b

[a–c]Different letters in the same row indicate a significant difference ($p < 0.05$).

therefore, this study seeks to investigate this effect. The changes in characteristic properties and nutritional value of popped rice after plasma treatment were also investigated for possible food popping applications.

Atmospheric RF plasma jets can be used to generate plasma for surface activation and decontamination by changing the gas mixture and/or excitation source (Tendero, Tixier, Tristant, Desmaison, & Leprince, 2006). These instruments are practical for industrial because they do not require expensive vacuum systems (Birer, 2015). Atmospheric RF plasma can be used to protect microbial growth on food surfaces without any effect on the nutritional value due to its low operating temperatures (Suhem et al., 2013a, 2013b; Matan, Nisoa, & Matan, 2014; Kim, Lee, Choi, & Kim, 2014; Reineke, Langer, Hertwig, Ehlbeck, & Schlüter, 2015). There have been reported for polyphenoloxidase (PPO) and peroxidase (POD) activation to avoid undesirable browning reactions and the loss of sensorial or nutritional quality of fruits and vegetables after the plasma treatment (Surowsky, Fischer, Schlueter, & Knorr, 2013). In addition, low temperature plasma was confirmed for improving cooking quality of basmati rice with no change in nutritional quality (Thirumdas, Deshmukh, & Annapure, 2015). The primary objective of our study was to investigate the effects of atmospheric RF plasma on the characteristics and nutritional value of popped rice, which, to the best of our knowledge has not been reported in the literature.

2. Materials and methods

2.1. Unhusked rice collection and preparation

Khai Mod Rin (NSRC9500113) unhusked rice, a local rice grown in the Nakhon Si Thammarat province, was obtained from the Nakhon Si Thammarat Rice Research Centre. This rice was harvested in March 2015. The 14% moisture content in the unhusked rice (100 g) was achieved by placing the rice in a stainless steel sieve inside a plastic container (120 mm wide × 150 mm long) with sterilized water. Next, the container was covered with a plastic lid to maintain moisture levels and kept at a ~30 °C to reach a moisture content of approximately 14%. Before popping, the determination of moisture content was perfomed according to the AOAC (2005).

2.2. Effect of popping methods on the characteristics of popped rice

Each unhusked rice sample was subsequently popped using three different methods; an electric frying pan (MP-16Q, Imarflex Industrial Co., Ltd., Thailand), a kitchen oven (EO-18, Sharp Thai Co., Ltd., Thailand), and a microwave oven (MW73C, Thai Samsung Electronics Co., Ltd., Thailand) in which heat conduction, heat convection and radiation, respectively, are the most dominant modes of heat transfer.

Unhusked rice samples were popped with an electric frying pan at a temperature of approximately 200 °C. Surface temperature was measured using an infrared thermometer (UT301A, UNI-T Technology (China) Co., Ltd., China). A popping time of 90 s was used. For the kitchen oven, the oven was preheated to 200 °C. The power control was set to maintain the surface temperature of the oven constant during popping. Oven popping was carried out for 150 s. Microwave popping was performed using a microwave oven at 800 W for 120 s. Preliminary studies have been performed to obtain the suitable popping time that provided the highest yield and did not damage the rice grains for each method. The temperature of the popped rice from the microwave was measured using an infrared thermometer.

2.3. Effect of atmospheric RF plasma on the popped rice

The atmospheric RF plasma used in this study was developed by the Plasma Agricultural Application Laboratory, the Green Innovation in Physics for Agro-industry Research Center of Excellence, Walailak University. The discharge tube consists of pyrex glass tube and floated copper coil winding outside the tube. The glass tube has 6 mm outside diameter and 2 mm thickness. Argon was selected for gas discharge and the gas flow rate was controlled by a gas flow meter. The RF power and frequency are adjustable between from 20 W to 40 W and 20 kHz to 600 kHz, respectively.

Before popping, unhusked rice was placed in a glass container and exposed to atmospheric RF plasma at 20 W and 40 W for 90 s. Five replicates were prepared for each treatment. After the plasma treatment, unhusked rice was popped with an electric frying pan as described in the previous section. Control was done without plasma.

2.4. Determination of popping characteristics

After popping, the weight of fully popped grains (W_1), semi-popped grains (W_2), and unpopped grains (W_3) were recorded. Popping yield (as a percentage) was determined according to Eq.(1) (Mishra, Joshi, Mohapatra, & Babu, 2015).

$$\text{Yield}(\%) = \frac{W_1+W_2}{W_1+W_2+W_3} \tag{1}$$

The expansion volume (EV) of the popped rice was determined by the method described in Dofing, Thomas-Compton, and Buck (1990) using Eq. ((2):

$$\text{EV}(\text{ml}\cdot\text{g}^{-1}) = \frac{V}{W} \tag{2}$$

where, V is the popped rice volume (ml) and.
W is the sample weight (g).

2.5. Determination of approximate composition

The official methods of the Association of Official Analytical Chemistry (AOAC, 2005) were employed to determine the moisture, ash, crude protein, crude fat, and fiber contents of the popped rice samples.

Table 2
Elemental composition of popped rice via different popping methods.

Content of elements (mg 100 g^{-1} dry matter; n = 3)	Electric frying pans with plasma 40 W	Electric frying pans	Kitchen oven	Microwave oven
Phosphorus (P)	365.4 ± 10.6^b	361.7 ± 14.6^b	435.2 ± 4.7^{ab}	477.8 ± 71.71^a
Potassium (K)	300.2 ± 5.0^b	308.0 ± 7.0^b	346.7 ± 4.9^{ab}	376 ± 38.5^a
Magnesium (Mg)	188.8 ± 5.5^a	133.9 ± 9.0^d	154.9 ± 3.6^c	171.8 ± 8.5^b
Calcium (Ca)	101.3 ± 13.8^a	67.9 ± 8.1^c	63.6 ± 3.6^c	90.6 ± 16.8^b
Zinc (Zn)	4.1 ± 1.0^b	4.0 ± 1.1^b	7.3 ± 1.0^a	8.4 ± 2.1^a
Sodium (Na)	4.8 ± 0.1^b	4.9 ± 0.1^b	5.3 ± 0.1^b	7.1 ± 0.9^a
Manganese (Mn)	2.0 ± 0.1^b	2.1 ± 0.1^b	2.3 ± 0.1^{ab}	2.6 ± 0.3^a
Iron (Fe)	0.6 ± 0.0^b	0.6 ± 0.0^b	0.5 ± 0.0^c	1.3 ± 0.0^a
Copper (Cu)	0.1 ± 0.0^a	0.1 ± 0.0^a	0.1 ± 0.0^a	0.1 ± 0.0^a

[a–d]Different letters in the same row indicate a significant difference ($p < 0.05$) P, K, Zn, Na, Mn, and Fe.