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Influence of different moisture content on heating rate of rice during radio frequency heating

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Abstract
The purpose of this study was to investigate the influence of different moisture content on heating rate of rice during RF heating. Rice samples with different moisture content (10. 12%, 11. 06%, 12. 14%, 13%, 14. 16%, 15. 22% dry basis, db) were obtained by adding predetermined quantity of distilled water and treated in a RF heating system with 40.68 MHZ. RF treatment significantly reduced the moisture content of rice in all samples. The heating rate of the rice was found to be dependent on moisture content. Accordingly, moisture content should be taken into account as a factor in RF heating of rice. The impact of RF heating in different moisture content rice samples were studied in terms of microstructure change through SEM analysis. Results in this study suggest that moisture content of samples should be considered for attaining effective heat treatment.

Keywords: Radio frequency heating, rice, heating rate, SEM analysis and moisture content

Introduction

Radio frequency as a heating source in the food drying process is highly beneficial as it could rapidly raise the temperature of foodstuff volumetrically and significantly reduce the heating time compared to conventional heating methods (Patil, Shejale, Jabaraj, Shah, & Kumar, 2020) [8]. Radio frequency waves range from 1-300 MHZ, whereas 13.56, 27.12 and 40.68 MHz are reserved for commercial, technological and medical purposes, with a view to prevent possible interference with other spectrum users (Ozturk, Kong, Singh, Kuzy, & Li, 2017) [7]. In conventional food heating, externally generated heat is transferred to the food product via conduction, convection, or radiation (Uyar, Erdogdu, Sarghini, & Marra, 2016) [10]. RF, on the other hand, rapidly generates heat within foods due to the oscillating movement of polar dielectric molecules and the displacement of space charge caused by an externally applied AC electric field (Indumathi, Manoj, Loganathan & Shanmugasundaram, 2021) [3]. Application of RF heating in agriculture and food processing industries is versatile. RF heat treatment is one of the effective treatment to control grain-borne pathogens. Many studies have concentrated on RF heating to suppress the proliferation of insects in agriculture produce (Liu & Wang, 2019) [6]. Despite being a highly touted food processing technology and more suitable for industrial scale treatments, RF heating is quite limited due to the lack of detailed technical information on heating rate. As is well – known, the moisture content of rice is one of the important factor to economy the quality of rice. Knowledge of moisture content impact in temperature rise during RF heating is important for the prediction and control of various changes occurring in food products during RF heating treatment. To develop an effective RF treatment for food processing, an understanding of the influence of moisture content of food commodities on heating rate during RF heating is in need to be studied.

Materials and Methods

Materials

Rice was purchased from a local agriculture vendor (Thanjavur, Tamil Nadu, India). The initial moisture content of rice was found to be 11.4 ± 0.3%. Experiments were conducted in a continuous 40.68 MHz, 10 KW RF unit (Lakshmi Insta 10/4 RF dryer, Lakshmi Card Clothing Mfg. Co. Pvt. Ltd, Tamilnadu, India) that has the stable voltage of 0.5 kV voltage and the operating current load ranges from 0.4 A to 1.9 A. In this study six different moisture content samples were used. In order to study the influence of moisture content during RF heating different moisture content rice samples were prepared and subjected for RF heating at constant current load 1 A with different exposure time to RF heating.

Methods
Moisture conditioning of rice
The procured rice was cleaned by sieving and foreign particles were removed and stored in a plastic container for further research. Rice was sun dried to obtain 10% and 11% moisture content. Rice was moisture conditioned to be 12%, 13%, 14%, 15%. The formula for finding the amount of water to be added to obtain the desired moisture content (L, Theertha, Sujeetha, Abirami, & Alagusundaram, 2014) [4] is

$$Q = \frac{w_i(M_f - M_i)}{100 - M_f}$$

Where,
Q – Mass of water to be added (Kg)
W_i – Initial mass of the sample
M_i – Initial moisture content of the sample in d.b. %
M_f - Final moisture content of the sample in d.b. %

After added the required amount of water, samples were then sealed tightly in polyethylene bags and stored at 5°C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample (Guan *et al*., 2020) [2]. For RF treatment rice sample was packed in newly well stitched jute bag and was subjected for RF heating. All the jute bags used for this study were same in size. Rice packed bags were treated by applying RF heating and the treated bags were kept at ambient temperature. Due to difficult in obtaining precise moisture content, after conditioning the expected moisture of samples were approximately close to the obtained moisture content of rice samples. The moisture content of rice samples used for this study were 10. 12%, 11. 06%, 12. 14%, 13%, 14. 16% and 15. 22%.

Radio frequency heating
This study was undertaken to assess the effect of different moisture content on heating rate of rice during RF heating. In order to find the impact of moisture content on heating rate of rice, experiment was conducted with six different moisture content. Each rice bag contained 5 kg of rice and each experiment was carried out with three replications. The desired RF current load was obtained by adjusting the electrode height of the RF heating system. Experiments were conducted at 0.5 kV voltage at constant current with different exposure time.

Moisture content determination
The moisture content of the rice was assessed by hot air oven technique (AOAC, 2019) [1]. In a silver dish which was previously dried at 98 - 100 °C, 2 g of well mixed rice was taken. In a hot air furnace, rice awas set to 130 ± 3 °C for 1 hour and was moved to desiccator to drain to ambient condition. Then the sample along the dish was weighed soon after reaching the ambient temperature. The weight loss was noted as moisture content (%) in wet basis.

Temperature measurement
The temperature of the rice samples was measured by using lazer – sighted infrared gun-style thermometer having accuracy of ±2 °C. The gun thermometer having the spot ratio is 12:1, response time is 500 ms and low battery indicator. The gun thermometer measures temperature in degree Celsius or Farenheit.

Scanning electron microscope (SEM)
SEM analysis was performed to know the effect of RF heating in different moisture content rice sample using Tescan Vega 3, which has LaB6 filament with resolution of 2 nm at 30 kV in high - vacuum mode and 2.5 nm at 30 kV in low - vacuum mode.

Results and Discussion
Effect of RF heating on heating rate and moisture reduction in different moisture content rice samples
The temperature of the rice was increased with an increase in exposure time in all moisture content samples as shown in Fig. 1. At the same time, it was found that the moisture content of rice samples was decreased with increased exposure time as shown in Fig. 2. From the graph (Fig.1.) the rate of heating was found to be increased with moisture content increase. Thus the relation between temperature and moisture content of sample was inverse during RF heating (Xu *et al*., 2018) [11]. The increase in temperature was exponential till 12.13% rice sample and the temperature increase was found to be low in the high moisture samples of 13%, 14.16% and 15.22%. Thus the heating rate was not found to be same in all samples and it was dependent on moisture content. If moisture content is beyond 13% the heating rate was little lesser. The moisture content was found to be reduced from initial moisture content with respect to increase in exposure time in all rice samples (Yu, Shrestha, & Baik, 2017) [12].

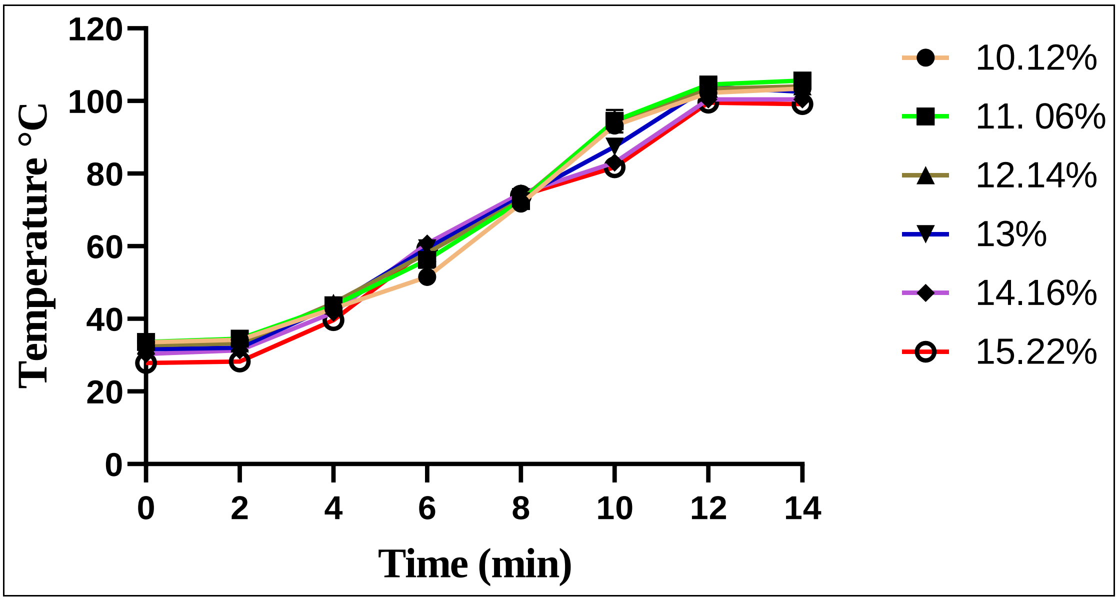

Fig 1: Temperature curves of rice at controlled moisture levels during RF heating.

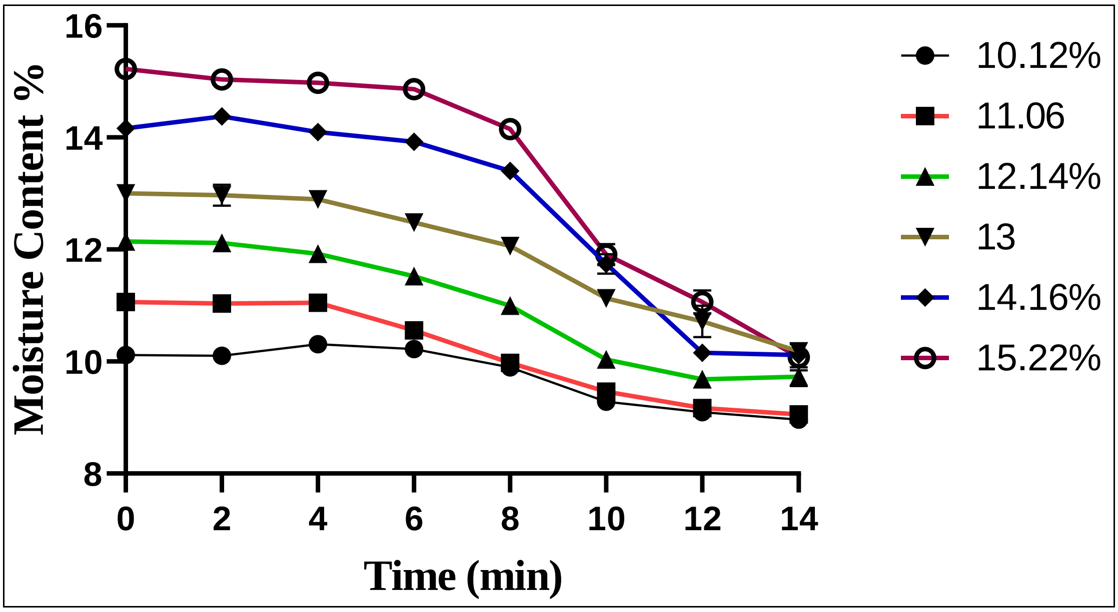

Fig 2: Moisture content profile of RF treated rice samples

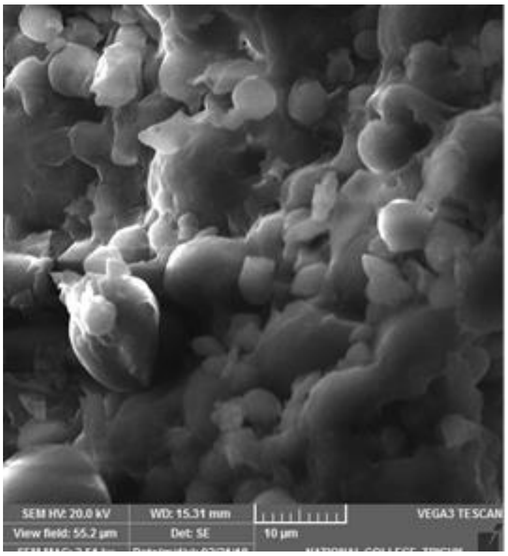

Fig 2a: SEM image of 10.12% M.C. RF treated rice sample

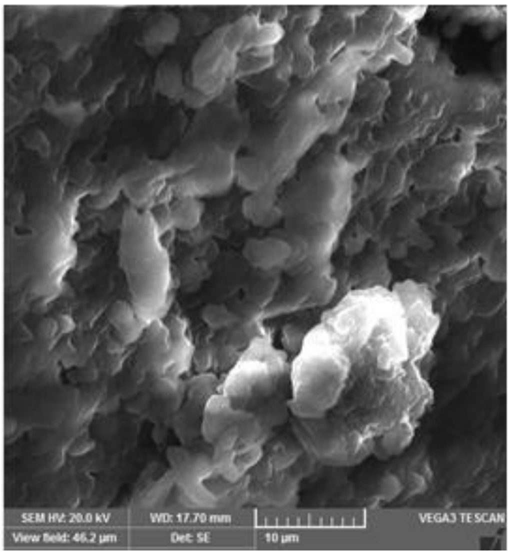

Fig. 2b. SEM image of 11.06% M.C. RF treated rice sample

SEM analysis of RF treated rice samples

The SEM images of different moisture content RF heated rice were shown in Fig. 2. In all the SEM images honey comb like granular appearance was found. Many granules with different sizes and clear visible outlines were tightly packed in the microstructure of 10.12% (Fig. 2a) and 11.06% (Fig. 2b) (Liao *et al*., 2020) [5]. During the RF heating as heat is produced internally, it causes the starch of rice to enlarge. Thus, in SEM images of 10.12% (Fig. 2a) and 11.06% (Fig. 2b) the starch granules were appeared as tightly packed than the remained moisture content samples. Due to the presence of more water molecules in high moisture content samples the collision of water molecule with starch granule will be more that cause disruption in starch granule appearance that observed in rice samples of 12.14%, 13%, 14.16%, 15.22% (Fig. 2c, Fig. 2d, Fig. 2e and Fig. 2f) (Zhou, Robards, Helliwell, & Blanchard, 2010) [13]. If starch is more gelatinized it may affect the cooking property of rice. Study of literature showed (Russo and Doe, 1970) [9] that the heating of rice to high temperature began to lose its crystalline character and in this present study, we also found the same where crystalline structure was very clear in low moisture content samples than the high moisture rice samples.

Conclusion

The perusal of the results revealed that moisture content of rice is the vital factor in attaining desired heating rate without affecting its microstructure during RF heating. And this study suggests that if the moisture content is higher, preheat treatment such as solar drying can be applied before RF heating. Hence the desired quality of rice or any other food products can be retained followed by RF heating. However, there is need to conduct more studies on RF heating to analyse minutely its effect on grain quality. By considering moisture content as one of the primary factor, would be of tremendous benefit in RF heating application on rice such as disinfestation of rice, ageing of rice, etc.,

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