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FULL-LENGTH RESEARCH ARTICLE

Stabilization of Raw Rice Bran using Ohmic Heating

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Abstract Ohmic heating experiments for heating of raw rice bran were conducted using a Teflon cylindrical cell. Electrical conductivity (EC) values were evaluated for ohmic heating of rice bran at 20, 30, and 40 % moisture content (w.b.), by applying voltage gradients between 44 and 72 V/cm. The EC increased significantly with increase in temperature and moisture content but the variation in EC was not significant with the variation in voltage gradient. The linear temperature and moisture content-dependent EC relations were obtained. EC values for rice bran at 20 % moisture content were in the range 0.01–0.06 S/m within the entire temperature range of 25–100 °C. Whereas, they were observed to be 0.04–0.14 and 0.08–0.23 S/m, respectively, for rice bran at 30 and 40 % m.c., w.b. An ohmic heating system having a capacity of 10 kg/batch was developed and evaluated for its performance. Ten kg rice bran was hydrated and heated by flow of electric current through it. The treated sample was observed to be stable even after 75 days of storage in comparison to raw rice bran sample. The % free fatty acid (FFA) in treated (ohmically heated) bran was observed to be 4.77 % after 75 days of storage whereas it was 41.84 % in case of raw bran. The FFA concentration of the ohmically heated samples increased very slowly in comparison to raw rice bran samples during 75 days of storage. The peroxide value and acid value of ohmically heated samples after 75 days of storage were 4.7 meq/kg and 9.34 %, respectively. Results showed that ohmic heating is an effective method for rice bran stabilization.

Keywords Electrical conductivity · Voltage gradient · Free fatty acid · Peroxide value

Introduction

Rice bran obtained from milling of raw paddy is classified as full fat raw rice bran. It is light coloured oily, unstable meal of various particle sizes. The most important and crucial property of full fat raw rice bran is the instability of its oil caused by oil-splitting lipase enzymes, inherently present in it. The enzyme lipase acts as a catalyst. The fat and enzyme are spatially distributed in aleurone and testa layers, respectively, in intact rice grain. As soon as the bran surface is ruptured and separated from the brown rice in milling operations, the lipase enzymes come in contact with the oil bearing layers resulting in a very rapid rate of hydrolysis of fats into free fatty acids (FFAs). Immediately after milling the FFA content of bran is normally below 3 %. After milling the rate of increase of FFA in bran may be as high as 1 % per h under favourable conditions. Bitterness develops very soon after milling whereas soapy unpleasant taste develops during long-term storage. The higher the temperature of storage, greater is the rise in FFA. It indicates that in tropical weather the bran can undergo much more spoilage during storage than in a cool or temperate environment.

The process to produce stable rice bran by inactivating the deteriorating enzymes is called stabilization. Physical, chemical and enzymatic methods have been reported for stabilization of rice bran. Various physical stabilization

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methods, applied to protect rice bran oil degradation, have been reported such as steaming [10], extrusion [11], roasting [2] dielectric heating [28], microwave heating [13, 20] and ohmic heating [20].

Single-screw extruder, pellet cooker, pellet mill and expander cooker were evaluated for stabilization of rice bran. Extrusion and expander cooking had positive effect on rice bran stabilization in comparison to pellet cooker and pellet mill [23]. An extrusion cooking procedure was developed which produces stable rice bran which shows no significant increase in FFA content for at least 30–60 days. In the optimum process, 500 kg/h of 12–13 % moisture bran was extruded at 130 °C and held for 3 min at 97–99 °C before cooling [21].

Roasting at 190 °C temperature for 10.75 min was observed to be optimum for stabilization of rice bran. The treatment resulted in 14.45 % oil yield, 5.80 % FFA and 8.25 mEq/kg peroxide values [2]. Dielectric heating (0.5 kV/cm, 13.56 MHz) to treat rice bran (21 % moisture content) was tried. It resulted in an increase of FFA from 4.2 to 6.2 % during a 6-week cold storage period [28].

Rice bran stabilised by microwave heating at 2,450 MHz for 3 min was found to be stable for up to 4 weeks in storage. FFA content of microwave stabilised bran increased from 4 to 4.9 % in long grain rice bran and from 4.6 to 6.25 % in medium grain rice bran, even when stored under unfavourable conditions (33 ± 2 °C, 75 ± 5 % RH). In contrast, increase in FFA in the untreated bran ranged from 4 to 68.3 % and 4.6 to 56.8 % in long grain and medium grain bran, respectively [30]. Rice bran adjusted to 21 % moisture content wet basis was stabilized satisfactorily with ohmic heating and microwave heating. The FFA content of treated rice bran samples after 6 weeks of storage (at 4 °C) was observed to be 3.89 and 5.47 % for microwave heated and ohmic heated samples, respectively [13]. The effect of ohmic heating on lipase activity, bioactive compounds and antioxidants of rice bran, at electric field strengths in the range of 140–225 V/cm was studied [12]. Chemical composition of rice milling fractions stabilised by microwave heating have been studied [2].

Addition of anti-lipase enzyme along with water and heat for stabilizing of rice bran has been reported [7]. Addition of edible acid (0.10–2.0 %) having anti-oxidative properties to parboiled rice bran has been reported [29]. Hydrochloric acid at 40 l/ton of bran for lowering the pH of rice bran from 6.9–6.0 to 4.0 has been tried to inactivate the lipase enzymes [18].

Ohmic heating is based on the passage of alternating electric current through a food product that serves as an electrical resistance and thereby heat is generated instantly inside the food [22]. The amount of heat generated is directly related to the current induced by voltage gradient applied and electrical conductivity (EC) of the food [26]. This technology provides rapid and uniform heating whereas the absence of a hot surface in ohmic heating reduces fouling problems and thermal damage to a product [25]. The EC of foods is a key parameter of the electrical properties due to its potential influence on ohmic heating [5]. The effects of insoluble solids and applied voltage on EC of pre-pasteurised carrot and tomato juices during ohmic heating have been studied [16]. Evaluation of EC of blanched 2 cm cubic particles (carrot, potato, radish, beef muscle, pork muscle and commercial ham) dispersed in carrier fluid (5 % w/w starch–water solution with 0.15–1.5 % w/w/salt concentrations) has been reported. EC was observed to be highly co-related to sample temperature and salt concentration [35]. EC of a two-phase food system comprising a liquid phase using 4 % w/w starch solution with 0.5 % w/w salt and a solid phase containing carrot puree and cubes of different sizes (6 and 13 mm) in different concentrations (30 and 50 % w/w) ranged from 0.2 to 1.8 S/m. The EC increased with the process temperature from 20 to 80 °C [33]. Ohmic heating rates are critically dependent on the EC of the foods [6].

The main factors affecting the EC of minced beef-fat blends having different fat level (2, 9 and 15 %) and full meat-fat samples were the temperature and the composition of the blends. The EC of the samples increased with increasing temperature up to 60–70 °C temperature. The determination of EC is crucial to characterise the ohmic cooking of meat products and design of ohmic systems [8]. Performance evaluation of an ohmic heating unit for liquid foods was studied and it was reported that temperature affected EC values of fresh orange juice [19]. Electrical conductivities of six different fruits and three types of meat were determined from room temperature through to the sterilisation temperature (25–140 °C) range [24]. Linear temperature-dependent EC relations were obtained for ohmic heating of fruit purees under voltage gradients in the range of 20–70 V/cm [9].

The effect of ohmic heating on lipase activity, bioactive compounds and antioxidants of rice bran, at electric field strengths in the range of 140–225 V/cm has been studied [15]. It is very expensive to achieve such high electrical field strength for small scale system. The aim of this study was to investigate EC of full-fat raw rice bran to design and evaluate an ohmic heating system for its stabilisation on small scale. The present study was thus undertaken with the following objectives:

(i) In order to determine the EC of raw rice bran at different moisture contents, temperatures and applied voltage gradients.
(ii) In order to study the effect of ohmic heating on stabilization of rice bran with respect to FFA formation.

Materials and Methods

Rice (Var; PR 110) was milled in a local rice mill to obtain rice bran for conducting the experiments. Freshly milled rice bran was passed through a B S sieve no. 20 (750 micron aperture) to remove foreign material and then used for ohmic heating experiments. The initial moisture content of bran samples was determined by AOAC 1984 method (Oven dry method) and was adjusted to moisture content of 20, 30 and 40 % wet basis for the EC studies.

EC Measurement

A cylindrical test cell having internal diameter 20 mm, outer diameter 25 mm and 40 mm length was used for measurement of EC of rice bran samples at known moisture contents. A cylindrical test cell was chosen because of its symmetrical nature. The diameter of the stainless steel electrodes was 20 mm. The thickness of the sample was 30 mm. The temperature was monitored using a K-type thermocouple (diameter 1.5 mm), which was inserted into the centre of the cell as the temperature was uniform throughout the test cell. Voltage and alternating current (50 Hz) were supplied using an isolation transformer, variable transformer, a digital voltmeter, a digital ammeter, relays and fuses (Meco Instruments Pvt Ltd. Mumbai India). The test cell was packed with rice bran sample of predetermined moisture content and was sealed by pressing in the electrodes on either side of the cell and care was taken to ensure excellent contact between sample and electrode surface. Electrical supply at 132, 150, 168, 189 and 216 V and 50 Hz was supplied across the test sample. It resulted in electric field strengths of 44, 50, 56, 63 and 72 V/cm. The voltage, current and temperature were recorded at every 10 s interval with the assumption that there was no voltage drop across the wiring and connectors in the circuit. All the experiments were carried out in triplicate.

The EC (S/m) of rice bran was calculated using Eq. (1) [17].

$$\text{EC} = (I \times L)/(V \times A) \tag{1}$$

where L is gap between electrodes, V is voltage being applied, I is current being drawn and A is the cross-sectional surface area of the electrode. The heating rate of the sample was expressed as temperature increase per unit time (°C/s). The resistance of the sample (R, ohms) was calculated from voltage (V) and current (I) data as $R = V/I$. Time–temperature data were plotted to obtain ohmic heating curves for rice bran. EC was plotted against the corresponding temperature to obtain EC curves. The results were evaluated statistically and linear regression and ANOVA were performed using SIGMA Plot, Version 11. The data points obtained from the observations were used to develop and validate the empirical model for EC of rice bran as a function of temperature, moisture content and applied voltage gradient. The statistical criteria used to discriminate among the variables were R^2 for each coefficient and confidence limits to determine statistical significance were 95 and 99 %.

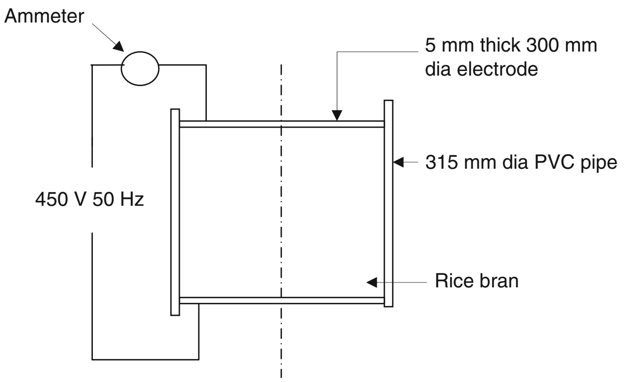

Fig. 1 Schematic of an ohmic heating system for rice bran

Ohmic Heating System

An ohmic heating system having a capacity of 10 kg/batch was fabricated. The schematic of the system is presented in Fig. 1. The bottom electrode was fixed and the upper electrode was placed on top of the material after filling the cylindrical chamber. The electrodes were made of stainless steel. A step-up isolation transformer having a rating of 10 kW and output of 450 V, 50 Hz AC was used to supply electrical power to the system. The complete system was enclosed in a wooden frame and mounted on a MS stand. The various parameters were recorded using digital ammeter, voltmeter and multifunction meter (Meco Instruments Pvt Ltd. Mumbai India).

Ohmic Heating of Raw Rice Bran

Moisture content of raw rice bran was determined by hot air oven method. The amount of water required to increase the moisture content to 30 % (w.b.) was calculated using mass balance on moisture. The hydrated rice bran was filled in the ohmic heating system and the upper electrode was placed on the top of free surface of rice bran. Then the system was connected to electricity for ohmic heating of rice bran. After ohmic heating the bran was dried. The treated bran was then stored and per cent FFA was calculated as oleic acid and expressed as per cent of the total lipids.

Results and Discussion

Effect of Temperature on EC

Changes in EC of rice bran at 20, 30 and 40 m.c. % w.b. with variations in temperature, during ohmic heating, were

Table 1 EC–temperature relationships at different moisture contents

Moisture content (%)	EC–temperature relation	Regression coefficient (R^2)
20	EC = −8.17E−03 + 5.58E−04 (*T*)	0.93
30	EC = 0.0169 + 1.28E−03 (*T*)	0.93
40	EC = 0.039 + 1.69E−03 (*T*)	0.90

obtained in a band shape as depicted in Fig. 1a–c. EC was observed to vary linearly with increase in temperature for all the three moisture contents used in the study. The linear relationship between EC and temperature (with R^2 ranging from 0.90 to 0.92) is also presented in Table 1. These findings were observed to be in agreement with the reported observations for ohmic processing of lean beef, strawberry products, chicken breast, peach/apricot purees and for fresh fruits, respectively [4, 9, 16, 24, 31]. The observed increase of EC at high temperature could be attributed to the ionic mobility [16].

Variation of EC with temperature necessitates its quantification at all temperatures beginning with room temperature [32]. In our experiments, the EC of rice bran increased till 95–100 °C and later on decreased at the critical temperature of 101, 100 and 98 °C for rice bran at 20, 30 and 40 m.c. % w.b., respectively. While the critical temperature decreased with the increasing moisture content, the applied voltage gradient did not have any effect on the critical temperature at $p > 0.05$. However, steam formation at the boiling point of water posed a difficulty to measure EC of rice bran after critical temperature. This is in accordance with the earlier observations of Zhao et al. [34] where localised water boiling during ohmic heating led to bubbling. Similar results have also been reported during ohmic heating of apricot puree where heating could not be carried out after 60 °C [9].

Effect of Moisture Content on EC

Ohmic heating has not been found to be suitable for EC values less than 0.01 S/m and above 10 S/m because very large voltages or very large amperage values, respectively, would be needed to generate the amount of heat required for raising temperature substantially by the Joule effect [12]. In our experiments, the observed EC values for rice bran at 20 % moisture content were in the range 0.01–0.06 S/m within the entire temperature range of 25–100 °C. Whereas, they were observed to be 0.04–0.14 and 0.08–0.23 S/m, respectively, for rice bran at 30 and 40 % m.c. (w.b.). Generally, EC increased with increase in moisture content for the range of temperature from 25 to 100 °C and voltage gradients from 44 to 72 V/cm, respectively (Fig. 1a–c). Within the test temperature range of 25–100 °C, EC values for the least moisture content was also at the lower limit and as the moisture content was increased the EC also increased significantly ($p < 0.05$). This means that the presence of moisture in rice bran has a critical importance to obtain an efficient heating process as an increase in water molecules resulted in proportional increase in ion solvation and thus higher ionic mobility and higher flow of electric current. A previous study reported that increase in EC with increase of moisture content of surimi paste during ohmic heating was significantly greater as compared to change in EC values due to voltage gradient [32].

Effect of Voltage Gradient

The effect of applied voltage gradient on the EC of rice bran samples during ohmic heating was not observed to be statistically significant ($p > 0.05$) during application of voltage gradient in the range of 44, 50, 56, 63 and 72 V/cm (Table 2). The observed variation in EC could be expressed in terms of variation up to 98 % w.r.t. temperature and 2 % due to voltage gradient, respectively. It could be largely due to cell disruption during ohmic heating and further electrical breakdown during application of different voltage gradients did not affect EC significantly. However, higher voltage gradients were seen to be beneficial to achieve faster heating of rice bran at all the moisture contents used in the study (Fig. 3). At all the three moisture contents used in this study, EC of rice bran varied in a narrow band in the temperature range 20–100 °C, as the voltage gradient increased from 44 to 72 V/cm (Fig. 1a–c). These findings were in commensuration with the observations where the effect of voltage gradient was not significant from 20–30, 20–40 and 30–40 V/cm for variation in EC during ohmic heating of orange juice concentrates [9]. Further findings of another researcher [32] stated that change in voltage gradient had little or no effect on EC during ohmic heating of surimi paste,

Table 2 ANOVA for effect of voltage gradient on electrical conductivity

Source of variation	SS	*df*	MS	*F*	*P* value	*F* crit
Temperature	0.030508	7	0.004358	166.7477	5.98E−17	3.63959
Voltage gradient	0.000144	3	4.8E−05	1.838078	0.171183	4.874046
Error	0.000549	21	2.61E−05			
Total	0.031201	31				

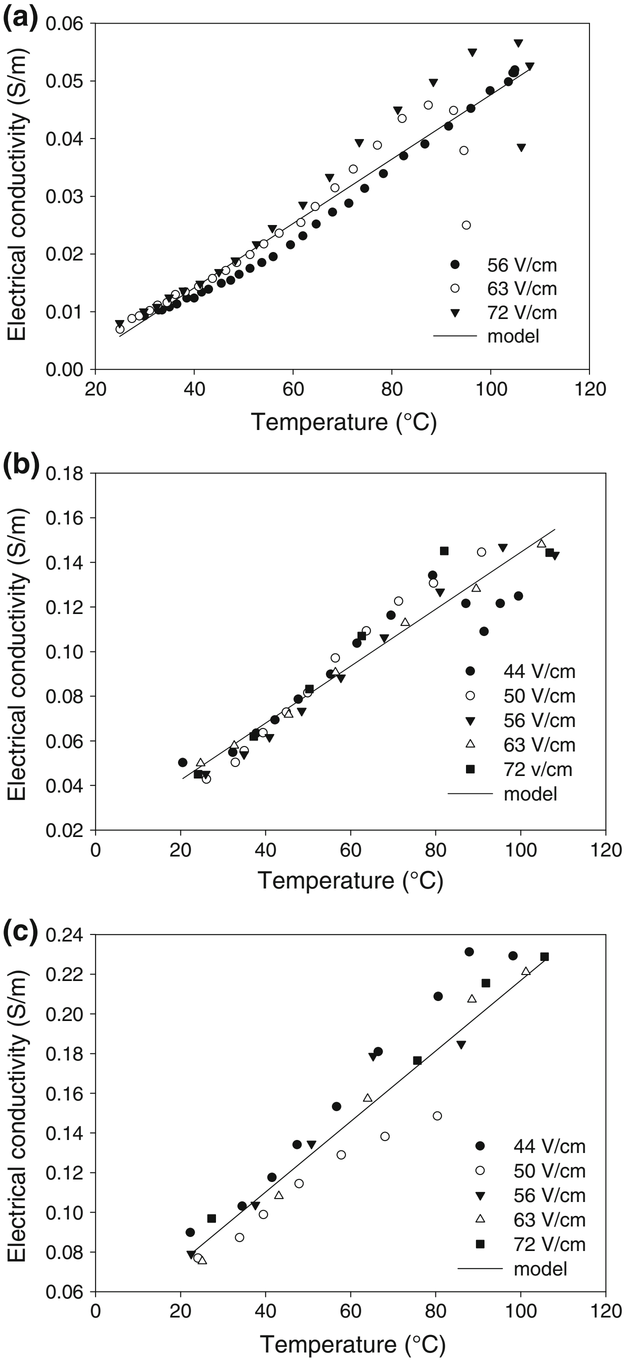

Fig. 2 Electrical conductivity of rice bran at **a** 20 % **b** 30 % and **c** 40 % moisture content during ohmic heating at different voltage gradients

as well. Electric field strengths in the range of 140–225 V/cm have been reported [15]. A 30 cm rice bran column in a prototype designed to provide electric field strength in the range of 140–225 V/cm will require voltage gradient in the range of 4,200–6,750 V. A high voltage source is expensive and also there is more chance of fatal electric shock. Lower electric field strengths (44–72 V/cm) were thus chosen for

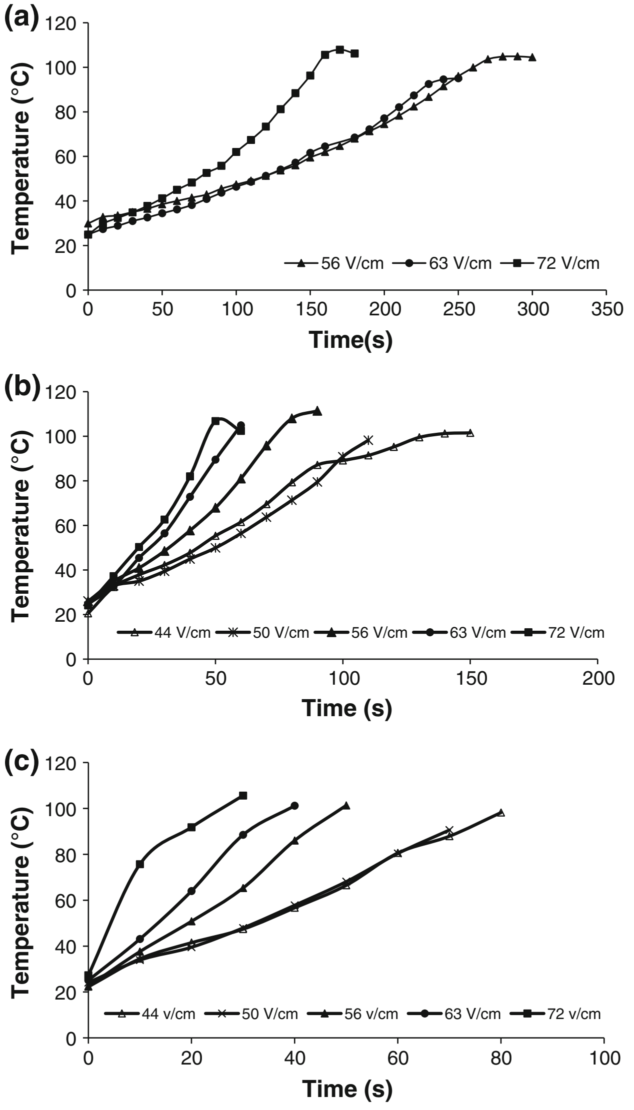

Fig. 3 Ohmic heating curves of rice bran having moisture content **a** 20 % **b** 30 % **c** 40 % at different voltage gradients

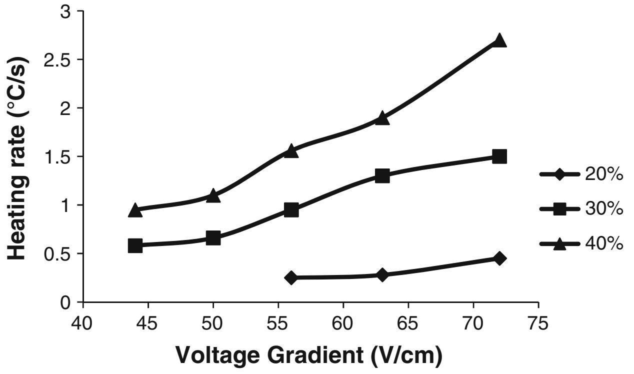

Fig. 4 Heating rate during ohmic heating of rice bran at 20, 30 and 40 % moisture contents

the present study to design a cost effective and safe ohmic heating system for rice bran.

The experimental data in this research indicated that EC of rice bran was largely influenced by temperature (T) and moisture content (M) and slightly by voltage gradient (V_g). It is represented in terms of a multiple linear regression equation (Eq. 2) as follows:

$$\mathrm{EC} = -0.165 + 0.000964(T) + 0.00619(M) + 0.000151(V_g),\ R^2 = 0.90 \tag{2}$$

The EC, T, M and V_g were measured in S/m, °C, % w.b. and V/cm, respectively.

The constant term, coefficients of temperature and moisture content were observed to be significant at 1 % (p value <0.001); whereas the coefficient of voltage gradient was non-significant with p value of 0.0438, which led to the conclusion that EC can be estimated from a linear combination of moisture content and temperature alone (Eq. 3) as follows:

$$\mathrm{EC} = -0.155 + 0.000968(T) + 0.00613(M),\ R^2 = 0.90 \tag{3}$$

The EC, T and M were measured in S/m, °C and % w.b., respectively

Heating Rate during Ohmic Heating

The rate of change of temperature of rice bran at 10, 20 and 30 % m.c. (w.b.) is presented in Fig. 2a–c. As is apparent from Fig. 2 as the applied voltage gradient was reduced from 72 to 44 V/cm for rice bran at 30 and 40 % m.c., the time required to reach the desired temperature of 100 °C increased approximately by 2.3 and 2.7 times, respectively. Also at particular moisture content, as voltage gradient increased, a significant decrease in ohmic heating time was observed. This was largely due to impact of amount of heat generated during ohmic heating, which was directly related to current induced by the voltage gradient in the applied electric field as reported earlier by different researchers [3, 16, 26]. Further, our findings are also in commensuration with several researchers that higher voltage gradients cause a decrease in ohmic heating time of the product [9, 17, 27, 32].

At moisture content of 20 % (w.b.) the low EC of rice bran did not allow the temperature of sample to rise at voltage gradients of 44 and 50 V/cm (Fig. 3). Heating rate varied between 0.5–1.5 and 0.95–2.6 °C/s for rice bran having moisture content 30 and 40 %, respectively, as voltage gradient increased from 44 to 72 V/cm; however it varied from 0.25 to 0.45 °C/s for rice bran at 20 % moisture content as voltage gradient varied between 50 to 72 V/cm (Fig. 3). This was mainly due to the increase in the current flow through the material at higher voltage gradient. Ohmic heating rate of meat batter has been reported to be in the range of 4.66–25 °C/min [27]. These results are also comparable to the conclusions [14], wherein heating rates were said to be 1 °C/s for ohmic heating of liquids and mixture of liquids and solids. Further, it is apparent from Fig. 3 that the heating rate was faster in rice bran at higher moisture content. While rice bran at 40 % m.c. reached 100 °C in 30 s at a voltage gradient of 44 V/cm, the heating time for samples at 20 % m.c. to the similar level was 340 s. Higher EC of rice bran at 40 % m.c. allowed an increased flow of current which resulted in higher rate of rise of temperature (Fig. 4).

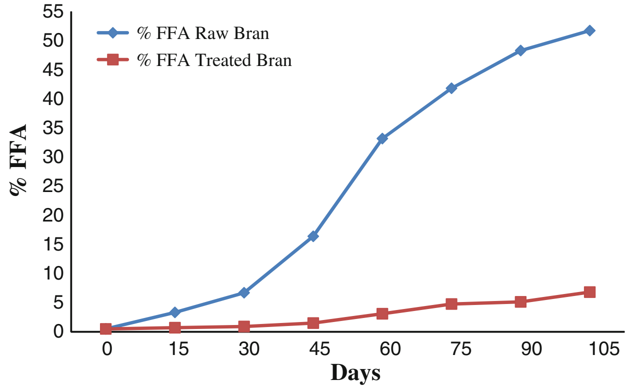

Fig. 5 FFA (%) of treated and raw rice bran with storage

Ohmic Heating of Raw Rice Bran

The hydrated rice bran was filled in the ohmic heating system as described in Fig. 1. The upper electrode was placed on the top of free surface of rice bran. Then the system was connected to electricity. The electrical field strength of 45 V/cm was applied. Initially the current flow was observed to be very small (around 1–2 A), because the temperature of the hydrated rice bran was low. As the temperature increased, the EC increased, and the current flow increased to around 16 A. The current flow was continued till steam started emanating. It took around 5 min to heat 10 kg rice bran from 20 to 100 °C. At this point electrical current was switched off. The heated rice bran was taken out from the system and dried. The FFA of treated and raw rice bran was measured at regular intervals. The variation in % FFA is presented in Fig. 5. The % FFA in treated (ohmically heated) bran was observed to be 4.77 % after 75 days of storage whereas it was 41.84 % in case of raw bran. The FFA concentration of the ohmically heated samples increased very slowly in comparison to raw rice bran samples during 75 days of storage. Ohmic heating effectively checked the development of FFA in rice bran. The peroxide value and acid value of ohmically heated samples after 75 days of storage were 4.7 meq/kg and

9.34 %, respectively. Ohmic heating was observed to be an effective method for rice bran stabilization.

Conclusions

EC was highly dependent on temperature and slightly dependent on moisture content during ohmic heating of rice bran. The effect of applied voltage was insignificant. The multiple linear regression equation was estimated to adequately predict the EC of rice bran based on temperature and moisture content. A significant decrease in ohmic heating time and increase in heating rate was observed with the increase in applied voltage gradient. The developed system was observed to be successful and is practically working in industry.

References

1. Abdul-Hamid Azizah, Raja Sulaiman RR, Osman A, Saari N (2007) Preliminary study of the chemical composition of rice milling fractions stabilized by microwave heating. J Food Compos Anal 20:627–637
2. Akinso R, Adeyanju JA (2010) Optimisation of edible oil extraction from ofada rice bran using response surface methodology. Food Bioprocess Technol. doi:10.1007/s11947-010-456-8
3. Bozkurt H, Icier F (2009) Rheological characteristics of quince nectar during ohmic heating. Int J Food Prop 12(4):844–859
4. Castro I, Teixeira JA, Salengke S, Sastry SK, Vicente AA (2003) The influence of field strength, sugar and solid content on electrical conductivity of strawberry products. J Food Process Eng 26(1):17–30
5. de Alwis AAP, Fryer PJ (1990) The use of direct resistance heating in the food industry. J Food Eng 11:3–27
6. Halden K, de Alwis AAP, Fryer PJ (1990) Changes in the electrical conductivity of foods during ohmic heating. Int J Food Sci Technol 25(1):9–25
7. Hammond NA (1994) Method for stabilizing rice bran and bran products. US Patent 5, 292, 537, 8 March 1994
8. Hayriye B, Icier F (2010) Electrical conductivity of minced beef-fat blends during ohmic cooking. J Food Eng 96:86–92
9. Icier F, Ilicali C (2005) Temperature dependent electrical conductivities of fruit purees during ohmic heating. Food Res Int 38(10):1135–1142
10. Juliano B (1985) Rice bran. In: Juliano B (ed) Rice chemistry and technology. The American Association of Cereal Chemist, St. Paul, p 659
11. Kim CJ, Byun SM, Cheigh HS, Kwon TW (1987) Optimization of extrusion rice bran stabilization process. J Food Sci 52(5):1355–1357
12. Knirsch MC, Santos AS, Antonio AM, Vicente OS, Penna TCV (2010) Ohmic heating: a review. Trends Food Sci Technol 21:436–441
13. Lakkakula NR, Lima M, Walker T (2004) Rice bran stabilisation and rice bran oil extraction using ohmic heating. Bioresour Technol 92:157–161
14. Lewis M, Heppell N (2000) Continuous thermal processing of foods: pasteurisation and UHT stabilisation. An Aspen Publication, Gaithersburg
15. Loypimai P, Moonggarm A, Chottanom P (2009) Effects of ohmic heating on lipase activity, bioactive compounds and antioxidant activity of rice bran. Aust J Basic Appl Sci 3(4):3642–3652
16. Palaniappan S, Sastry SK (1991) Electrical conductivity of selected juices: influences of temperature, solids content, applied voltage, and particle size. J Food Process Eng 14(4):247–260
17. Piette G, Buteau ML, de Halleux D, Chiu L, Raymond Y, Ramaswamy HS (2004) Ohmic cooking of processed meats and its effects on product quality. J Food Sci 69:E71–E78
18. Prabhakar J, Venkatesh K (1986) A simple chemical method for stabilization of rice bran. J Am Oil Chem Soc 63(5):644–646
19. Qihua T, Jindal VK, van Winden J (1993) Design and performance evaluation of an ohmic heating unit for liquid foods. Comput Electron Agric 9:243–253
20. Ramezanzadeh FM, Rao RM, Prinwiwaykul W, Marshell WE, Windhauser M (2000) Effect of microwave heat, packaging and storage temperature on fatty acid and proximate composition in rice bran. J Agric Food Chem 48(2):464–467
21. Randall JM, Sayre RN, Schultz WG, Fong RY, Mossman AP, Tribelhorn RE, Saunders RM (1985) Rice bran stabilization by extrusion cooking for extraction of edible oil. J Food Sci 50:361–364. doi:10.1111/j.1365-2621.1985.tb13402.x
22. Reznick D (1996) Ohmic heating of fluid foods: ohmic heating for thermal processing of foods: government, industry, and academic perspectives. Food Technol 50(5):250–251
23. Riaz MN, Asif M, Plattner B, Rokey G (2010) Comparison of different methods for rice bran stabilization and their impact on oil extraction and nutrient destruction. Cereal Foods World 55(1):35–40
24. Sarang S, Sastry SK, Knipe L (2008) Electrical conductivity of fruits and meats during ohmic heating. J Food Eng 87(3):351–356
25. Sastry SK, Barach JT (2000) Ohmic and inductive heating. J Food Sci 65:42–46
26. Sastry SK, Li Q (1996) Modeling the ohmic heating of foods. Food Technol 50(5):246–248
27. Shirsat N, Lyng JG, Brunton NP, McKenna B (2004) Ohmic processing: electrical conductivities of pork cuts. Meat Sci 67(3):507–514
28. Sreenarayanan VV, Chattopadhyay PK (1986) Rice bran stabilisation by dielectric heating. J Food Proc Preserv 10:89–98
29. Tao J (2001) Method of stabilizing rice bran by acid treatment and composition of the same. US Patent 6,245,377 B1, 12 June 2001
30. Tao J, Rao R, Liuzzo J (1993) Microwave heating for rice bran stabilization. J Microw Power Electromagn Energy 28(3):156–164
31. Tulsiyan P, Sarang S, Sastry SK (2008) Electrical conductivity of multicomponent systems during ohmic heating. Int J Food Prop 11(1):233–241
32. Yongsawatdigul J, Park JW, Kolbe E (1995) Electrical conductivity of pacific whiting surimi paste during ohmic heating. J Food Sci 60(5):922–935
33. Zareifard MR, Ramaswamy HS, Trigui M, Marcotte M (2003) Ohmic heating behaviour and electrical conductivity of two-phase food systems. Innov Food Sci Emerg Technol 4:45–55
34. Zhao Y, Kolbe E, Flugstad B (1999) A method to characterise electrode corrosion during ohmic heating. J Food Process Eng 22:81–89
35. Zhu SM, Zareifard MR, Chen CR, Marcotte M, Grabowski S (2010) Electrical conductivity of particle-fluid mixtures in ohmic heating: measurement and simulation. Food Res Int 43:1666–1672