Ohmic heating as a pre-treatment in solvent extraction of rice bran

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Abstract Rice bran, which is one of the major by products of paddy contain high quality proteins and edible oil apart from fibre, ash and NFE (nitrogen free extract). The existing solvent extraction method employs n-hexane as the most viable solvent for the extraction of oil from rice bran. But the high cost and scarce availability of n-hexane resulted in uneconomical extraction of rice bran oil. In this study, rice bran was ohmically heated for different time periods (1, 2 and 3 min) with different current values (5, 15 and 20 A) and with different concentration of sodium chloride (1 M, 0.1 M and 0.01 M) as conducting medium. The ohmically heated rice bran was subjected to extraction studies. Ohmic heating of rice bran of paddy varieties Red Triveni and Basmati reduced the extraction time by nearly 75 % and 70 % respectively and gave a maximum quantity of oil extracted when compared to bran, which was not ohmically heated. From the experiments with varying concentrations, residence time of ohmic heating and currents, it was found that ohmically heating the rice bran with 1 M sodium chloride solution and with a current value of 20 A for 3 min gave maximum oil extraction with minimum extraction time.

Keywords Rice bran · Ohmic heating · N-hexane · Solvent extraction

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Introduction

Rice is a major crop which is being consumed all over the world. Apart from rice, the main by-products of rice milling industry are rice husk, rice bran, rice germ and broken. These constitute nearly 20–24 %, 5–10 %, 1–2 % and 2–3 % of the total milled rice respectively. Rice bran contains high quality proteins and edible oil apart from fibre, ash and NFE (nitrogen free extract) and it is highly nutritious containing less cholesterol (Tang et al. 2003; Mahanta, and Bhattacharya 2010). The presence of enzyme lipase is detected in rice bran which becomes active after milling. Therefore rice bran is not a stable material as the lipase enzyme converts fatty acid to free fatty acid and glycerol. This causes rancidity to the oil and produces an off flavour and odour (Prakash and Ramanatham 1995; Li et al. 2006; Arvanitoyannis and Tserkezou 2008a,b). Free fatty acid content of bran increases rapidly during storage. Therefore it is necessary that the collection and extraction processes are really quick since any delay may result in the rancidity of the oil extracted and therefore the oil obtained will not be of edible grade (Pare et al. 2012; Nguyen et al. 2012). The composition of rice bran is as follows;

Protein-6.7–11.5 %, fat-4.7–12.8 %, fibre-6.2 %, ash- 8 %, N.F.E. -33–36 % (Chen and Bergman 2005)

Llyod et al. (2000) studied the effect of commercial processing on antioxidant in rice bran. Rice bran contains high amount of beneficial antioxidants including Tocopherol and Tocotrienol.

Oil can be extracted from rice bran by mechanical expression and solvent extraction. The minimum oil content to which oil cake can be reduced by mechanical expression is about 12 %. But the solvent extraction method leaves less than 1 % oil in the extracted meal. Hence it is considered as

the most viable method for extracting oil from the rice bran (Sharma et al. 2011). Studies have proven that n-hexane is the most efficient solvent for extraction of oil from rice bran. In our experiment, we used n-hexane to compare the effect of ohmic heating with the normal extraction. But the high cost and scarce availability of n-hexane resulted in increased processing cost and therefore the extraction of rice bran becomes uneconomical (Adriaan 2006). Da Costa Rodrigues and Oliveira (2010) conducted experiments on rice bran oil extraction with ethanol as a solvent and found ethanol is economical when compared to n-hexane. Sivala et al. (1993) conducted experiments on the critical solubility temperature of rice bran oil. The aim of this investigation was to establish a suitable method for quick determination of oil content in miscella and to determine the critical solubility temperature (CST) of rice bran oil in aqueous ethanol and ethanol hexane mixtures by using solvent extraction method. When hexane was added, the critical solubility temperature value decreased.

Ohmic heating is the process in which an alternating current is passed through the food sample. In ohmic heating heat generation occurs within the medium due to its inherent electric resistance (DeAlwis and Fryer 1990; Jha et al. 2011). Lima et al. in 2001, conducted studies on ohmic heating of rice and rice by products. The objective was to evaluate unity of ohmic heating in conjunction with conventional process. It was found that the ohmic heating initiates the extraction process.

Considering the above factors, an effort was undertaken at Kelappaji College of Agricultural Engineering and Technology, Tavanur to study extraction of rice bran oil using ohmically heated bran with the following objectives, 1) conduct studies on solvent extraction of rice bran oil using ohmically heated rice bran of paddy varieties in Kerala and 2) compare the results with extraction done without ohmic heating.

Materials and methods

The procedure for determination of the experimental procedure for ohmic heating of rice bran and extraction of rice bran oil using n-hexane as solvent is described in this section. The schematic diagram of static ohmic heating apparatus is given in Fig. 1. Ohmic heating chamber consists of a rectangular tank and two electrodes fixed on opposite sides of the rectangular tank. The material to be heated was filled in the tank in between the electrodes and when the current was applied, heating took place. The ohmic heating chamber is presented in Fig. 1. The desired tank capacity was fixed at 1 l and the electrode spacing was limited to 5 cm for the convenience of loading and unloading of the rice bran samples. With this spacing, while

Fig. 1 A schematic diagram of ohmic heating apparatus and chamber

applying a potential difference of 270 V, a voltage gradient of 54 V/cm could be achieved.

$$\text{Voltage gradient} = \frac{\text{Potential difference}}{\text{Electrode spacing}} = \frac{270}{5} = 54 \text{ V/cm}$$

Thickness of the electrode=0.25 cm

Width of the rectangular tank with two electrodes=5+(2×0.25)=5.5 cm

The height of the rectangular tank was fixed as 10 cm for the convenience of filling and emptying its contents.

$$\text{length of the tank} = \frac{1000}{5 \times 10} = 20 \text{ cm}$$

Thus the inner dimensions of the tank were fixed as 20×5×10 cm. The main criteria for the selection of the material were: It should be electrically non corrosive, it should be able to withstand the process temperature and it should not affect the quality of the product. By considering all these we selected acrylic sheet of 3 mm thickness for the construction of the chamber. The acrylic pieces were fixed with chloroform reagent to make a rectangular chamber and the outside edges were pasted with a cementing material as reinforcement. The selection of electrodes were done by considering the criteria such as it should be of good grade and non corrosive and it should be workable and should provide smooth finish. Considering the above points, stainless steel of grade SS-316 was selected as electrode material. The electrodes were made by cutting it into two rectangular pieces of 20×10 cm dimension. A hole of 2.54 cm diameter was drilled at the middle of the electrodes so as to bolt it to the sides of the rectangular tank. A variac which could vary the voltage in the range of 0–270 V was used for the experiments. In India, the voltage from domestic supply line was in between 220–227 V, with a frequency of 50 Hz. A digital thermometer with stainless steel probe was used to monitor

the temperature of various points inside the heating chamber. A V-A-W (Volt–Ampere–Watt) meter from Ztech Instruments, Gujarat, India, which could read up to 500 V, 20 A, and 2000 W was used to measure the voltage, current and power consumption simultaneously. An ammeter of 0–50 A range was used.

Experimental procedure

The rice bran obtained from the paddy variety Red Triveni and Basmati, which represents the general varieties grown in Kerala, were used for the study (Rosamma et al. 1993). Paddy varieties were bought from the local market and milled in local mill to collect the rice bran. The rice bran was used for conducting the studies within twenty four hours. Sodium chloride was selected as a conducting medium due to higher electrical conductivity. Sodium chloride solutions prepared in three concentrations, 0.01 M, 0.1 M and 1 M were used for the study. 25 g of each variety of rice bran was filled in the ohmic heating chamber and the mass was consolidated well. Then 150 ml of sodium chloride solution prepared in different concentrations was poured in to the chamber so that the pores were filled and the biological material uniformly in contact with electrodes so as to ensure the passage of electric current. To begin the ohmic heating process, power was put on and the current was set to a fixed value. The mixture began to heat up due to the passage of current and the inherent electrical resistance of the material and the values of temperature, current and power were monitored. During the process, parameters such as change in temperature with time, current and power consumption were noted. The ohmic heating was carried out by keeping the voltage at 180 V. The power was controlled throughout the ohmic heating process to maintain constant current. The rice bran obtained from Red Triveni paddy variety was ohmically heated for different intervals of time and of different molarities of sodium chloride solution with different current values as per experimental design. Then the extraction time, quantity of oil extracted, power and temperature of the rice bran were noted. The same experiments were repeated for the rice bran obtained from Basmati paddy variety. The rice bran samples were taken out from ohmic heating chamber and washed with fresh water to drain out the sodium chloride solution and then heated in hot air oven at 75 °C for 5 min. Then the samples were subjected to solvent extraction.

Batch solvent extraction methods are found to be exclusively suitable for rice bran oil extraction (Sivala et al. 1993). Solvent extraction using a soxhlet apparatus is the most commonly adopted batch method. Rice bran was cleaned and shaken to separate it from stones; broken rice etc. 25 g of sample was taken for conducting the extraction process. The extraction as conducted as per standard method

by soxhlet apparatus by using n-hexane as the solvent. The temperature of extraction was 72 °C. The oil was collected in the extraction chamber of the batch soxhlet apparatus which contained n-hexane. The n-hexane traces were removed by heating the oil samples at 70 °C to evaporate n-hexane which has a boiling point of 65 °C.

The experimental design for both the rice varieties are as follows. The experimental design contains 3 factors with 3 levels. Those are, molarity of ohmic heating solvent (levels- 1 M, 0.1 M and 0.01 M), ohmic heating current (levels- 5 A, 10 A and 20 A) and time of ohmic heating (levels- 1 min, 2 min and 3 min).

Results and discussion

Extraction without ohmic heating (control)

Twenty-five grams of rice bran was taken and oil extraction was conducted in the soxhlet apparatus. The volume of n-Hexane used for the extraction was 200 ml. The quantity of rice bran oil extracted for the variety Red Triveni was 0.83 ml with an extraction time of 183 min. The variety Basmati took an average extraction time of 185 min with the oil yield of 0.53 ml. So these results show that the oil yield of the variety Red Triveni was higher than that of Basmati. But the time of extraction and consumption of energy were more in solvent extraction without ohmic heating.

Extraction after ohmic heating

Ohmic heating was introduced as a pre-treatment before solvent extraction with different molarity of solvent, time of ohmic heating and current applied and is considered as an effective pre-treatment before extraction (Lima 2008).

Red Triveni

The result obtained from the extraction of rice bran oil after ohmically heating the rice bran of paddy variety Red Triveni under different treatment conditions are furnished in Table 1.

The extraction was carried out by ohmically heated rice bran under various conditions. The temperature of ohmic heating is directly proportional to the current supplied for ohmic heating for all the ohmic heating time. The temperature of the bran also increased with increase in time of ohmic heating. This is due to the heat generation due to the resistance offered by the bran samples (Table 1). Molarity of sodium chloride was inversely proportional to the time of ohmic heating for same current and ohmic heating time. Ohmic heating current was directly proportional to the bran

Table 1 Extraction after ohmic heating (Red Triveni)

Molarity (M)	Heating time (min)	Current (A)	Time of extraction (min)	Quantity of oil extracted (ml)	Initial power (Watts)	Bran temperature (°C)
1	1	20	63	1	480	65
		15	72	1	240	54
		5	78	0.9	80	51
	2	20	60	1	480	74
		15	70	1	240	69
		5	76	0.9	80	64
	3	20	48	1	480	81
		15	56	1	240	71
		5	67	1	80	66
0.1	1	20	88	1	480	60
		15	95	1	240	51
		5	108	1	80	47
	2	20	82	1	480	70
		15	91	1	240	62
		5	99	1	80	51
	3	20	72	1	480	60
		15	84	1	240	51
		5	96	0.9	80	47
0.01	1	20	108	1	480	44
		15	117	1	240	37
		5	129	1	80	32
	2	20	102	1	480	54
		15	109	1	240	49
		5	114	1	80	38
	3	20	87	1	480	66
		15	99	1	240	60
		5	113	0.9	80	52

temperature and inversely proportional to the solvent extraction time. When ohmic heating time of bran increased, the time of extraction of rice bran oil decreased. But the extraction time also dependent on the molarity of the conducting solution and the current applied for ohmic heating. The concentration of NaCl decreased, the extraction time increased for both Red Triveni and Basmati. Current applied for ohmic heating was also a factor which affects the extraction time. For the rice bran variety Red Triveni, 3 min of ohmic heating with 1 M conducting solution (NaCl) resulted extraction time of 48, 56 and 67 min when current applied for ohmic heating changed as 20 A, 15 A and 5 A.

The results on analysis revealed that when extraction was carried out with sodium chloride solution of 1 M and ohmic heating time of 1 min (minimum) and with varying current, the extraction time was found to be minimal for 20 A current range (Fig. 2). Also with this current value, maximum oil could be extracted as compared with other current values. The changes of extraction times with the variation in ohmic

heating time and current during ohmic heating for variety Red Triveni with 1 M NaCl are shown in Fig. 3. Also it was found that when current rating of above 20 A were used, the power requirement was extremely high and process could not be economically viable.

Basmati

For the variety Red Triveni, the time of extraction without and with ohmic heating was 183 and 48 min respectively and the oil yield without and with ohmic heating was 0.83 and 1 ml respectively. Similarly, for Basmati, the time of extraction without and with ohmic heating was 185 and 54 min respectively and the oil yield without and with ohmic heating was 0.53 and 0.8 ml respectively. The changes of extraction times with the variation in ohmic heating time and current during ohmic heating for variety Basmati with 1 M NaCl are shown in Fig. 4. It was also clearly revealed from compared the result with the result of control that ohmically heating the bran reduces the extraction time by 75 % for the same quality of oil extracted. Thus it was established that ohmically heating the bran would increase the oil extraction and make the process economical.

Ohmic heating as a pre-treatment in extraction

The experiment was conducted using the bran with 1 M sodium chloride concentration and 20 A current but heating times of 1, 2 and 3 min. From this result, it was concluded that the heating time of 3 min gave a maximum quantity of oil (1 ml) and minimum extraction time (48 min) as shown in Fig. 2. Therefore 20 A current and 3 min of ohmic heating were taken as optimum values for conducting further studies. When the residence time for ohmic heating was further increased, the temperature of the bran raised up to 95 °C which caused off-flavour and odour (Zhong and Lima 2003). The experiments were continued by varying the molarity of sodium chloride solution to 0.1 M and 0.01 M and the results of the experiments are shown in the Table 1. From the results, it was found that with decrease in concentration of sodium chloride of the rice bran, the extraction time increased (Fig. 2). It was noted that when the concentration of sodium chloride was above 1 M, white solids of sodium chloride were found in the oil which would become non edible. From the above studies, it was concluded that, ohmically heating paddy variety of Red Triveni reduced the extraction time by about 75 % and gave maximum quantity of oil extracted when compared to the control. From our research, it was found that ohmically heating rice bran with 1 M sodium chloride solution and with a current value of 20 A for 3 min gave maximum oil extraction with a minimum extraction time of 48 min and this condition was found to be optimum for the above varieties. The temperature of

Fig. 2 Relation between the factors current, time of extraction, time of ohmic heating and molarity

the bran in this condition was 81 ° C. The biological and chemical changes like dehydration, cell rupture, tissue shrinkage, loss of air bubbles, melting changes in membrane permeability etc were happened in ohmic heating, and those should be the reason for increased oil yield in ohmically heated rice bran oil. Lakkakula et al. in 2004, conducted studies on effect of ohmic heating in rice bran stabilization and rice bran extraction with various parameters such as 60, 100 and 140 V/cm field strengths, 10.5, 21 and 30 % moisture, with 2 frequencies of 1 Hz and 60 Hz. He concluded that lowering the frequency increased the oil yield and ohmic heating improves the rice bran stabilization. In this

experiment, our parameters were molarity of the solvent, electric current and time of ohmic heating. The results of the extraction studies conducted with ohmically heated Basmati bran also showed similar trends as that observed for ohmically heated Red Triveni bran (Table 2). The experiments were optimized as described for the variety Red Triveni, and arrived at a conclusion that ohmically heating the rice bran of variety Basmati reduced the extraction time by about 70 % and gave maximum quantity of oil extracted when compared to the bran which was not ohmically treated. It was also found that ohmically heating the rice bran with 1 M sodium chloride solution and with a current value of 20 A for 3 min gave maximum oil extraction with a minimum

Fig. 3 Changes of extraction time with current of ohmic heating and time of ohmic heating for Red Triveni at 1 M conducting (NaCl) solution

Fig. 4 Changes of extraction time with current of ohmic heating and time of ohmic heating for Basmati at 1 M conducting (NaCl) solution

Table 2 Extraction after ohmic heating (Variety Basmati)

Molarity (M)	Heating time (min)	Current (A)	Time of extraction (min)	Quantity of oil extracted (ml)	Initial power (Watts)	Bran temperature (°C)
1	1	20	66	0.7	480	62
		15	69	0.6	240	57
		5	84	0.6	80	51
	2	20	65	0.8	480	72
		15	72	0.7	240	67
		5	79	0.7	80	62
	3	20	54	0.8	480	78
		15	58	0.8	240	65
		5	67	0.7	80	56
0.1	1	20	86	0.7	480	65
		15	97	0.7	240	54
		5	111	0.6	80	44
	2	20	79	0.7	480	74
		15	90	0.7	240	65
		5	98	0.7	80	49
	3	20	71	0.8	480	79
		15	81	0.7	240	73
		5	94	0.7	80	62
0.01	1	20	107	0.7	480	48
		15	113	0.7	240	42
		5	131	0.7	80	32
	2	20	99	0.7	480	52
		15	108	0.7	240	47
		5	116	0.7	80	36
	3	20	90	0.7	480	54
		15	101	0.7	240	47
		5	115	0.7	80	40

extraction time of 54 min. The temperature of the bran at that condition was only 78 °C.

Ohmic heating temperature and extraction

Temperature of bran during the pre-treatment affects the final quality of the extracted oil. Oil extracted with bran of high temperature after pre-treatment had off-flavour and odour according to Zheong in 2003. The maximum temperature of rice bran varieties of Red Triveni and Basmati during ohmic heating are shown in Tables 1 and 2. The factors affecting the temperature of bran during ohmic heating are, time of ohmic heating, current, conductivity of the bran and sodium chloride solution (Varghese et al. 2012). In this experiment, we kept frequency and voltage constant throughout the experiment, so that there was no effect of frequency and voltage of alternating current in the ohmic heating of the samples. The bran temperature was increased with the time of ohmic heating for all the experiments (Sastry 2008). As per the results obtained, the ohmic heating

current increased with increase in the current applied (Demirdöven and Baysal 2012). Similar trend was observed in the case of molarity of sodium chloride solution. Rice bran with 1 M sodium chloride attained the maximum temperature of 81 °C for Red Triveni and 78 °C for Basmati at 20 A current and 3 min of ohmic heating time when compared to 0.1 and 0.01 M sodium chloride solution. The molarity of the conducting solution showed a direct effect on the temperature of the ohmic heating of rice bran (Wei-Chi Wang and Sastry 1997)

Electrical effect of ohmic heating

The yield of oil after extraction was more in ohmically heated rice bran when compared to the control. This is due to the effect of ohmic heating. The thermal effect of ohmic heating was only one of the reasons for the oil yield, and the other reason was the effect of electric field applied to the sample. In ohmic heating, naturally porous cell walls allowed cell membrane to build up charges which formed disruptive pores which resulted in electroporation (Cho et al. 1996). Electroporation is a significant increase in the electrical conductivity and permeability of the cell plasma membrane caused by an externally applied electrical field. Electroporation occurred, because the cell membrane had a specific dielectric strength, which could be exceeded by the electric field (Knirsch et al. 2010). The electric energy applied between the electrodes was responsible for breakdown of the rice bran cell membranes, which enabled the extraction much easier when compared to the extraction with rice bran without ohmic heating (Uemura et al. 2010).

Conclusion

From the studies, it was concluded that ohmic heating of rice bran of paddy varieties Red Triveni and Basmati reduced the extraction time by about 75 % and 70 % respectively and gave maximum quantity of oil extracted when compared to bran, which was not ohmically heated. The amount of the electric current in Amperes, molarity of the conducting solution and time of ohmic heating were inversely proportional to the time of extraction. Also it was found that ohmically heating the rice bran with 1 M sodium chloride solution and with a current value of 20 A for 3 min gave a maximum oil extraction time for both the varieties of paddy. Ohmic heating was proved as an efficient way to minimize the solvent extraction time and energy consumption for the rice varieties Red Triveni and Basmati.

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