Stabilization of rice bran milling fractions using microwave heating and its effect on storage

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Abstract Rice bran tends to become rancid during storage if it is not stabilized. In commercial rice mills, bran is removed in phases using battery of polishers and different fractions of rice bran are produced. The stabilization reduces peroxidase, lipases, lipoxygenase and auto-oxidation enzymatic activities. The bran fractions were stabilized by continuous microwave heating at different treatment combinations (850, 925 and 1000 W; 3, 4.5 and 6 min) and stability of bran fractions were analysed in terms of Free Fatty Acid (FFA), Acid value (AV) and Peroxide value (PV) for 90 days at the interval of 15 days. As power and exposure time increases the FFA, AV and PV are found to be low during storage period. The rancidity level was high in last milling bran fraction and as milling progressed, the rancidity level also increased and it was similar throughout the storage. The bran fractions processed at 925 W to 3 min found to be the suitable condition for stabilization of rice bran milling fractions.

Keywords FFA · AV · PV · Auto-oxidation · Stabilization and microwave heating

Introduction

Rice bran, a by-product of milled rice; obtained from an outer layer of brown rice kernel during milling. Milling of paddy yields 70% of rice (endosperm) as the major product

and 20% husk, 8% bran, and 2% germ as by-products (Abdul-Hamid et al. 2007). The rice bran contains an array of micronutrients like oryzanols, tocopherols, tocotrienols, phytosterols, oil (20%), protein (15%), carbohydrates (50%) majorly starch, dietary fibers like beta-glucan, pectin, and gum (Nagendra Prasad et al. 2011). Antioxidant activities reported for oryzanol and vitamin E in the rice bran, which protect cells from oxidative damage of plasma very low-density lipoprotein, cellular proteins and DNA (Xu et al. 2001; Esa et al. 2013). Rice bran protein is reported to have unique nutritional value and nutraceutical properties (Nagendra Prasad et al. 2011).

The nutrient content in bran is depended on degree of milling but degree of milling is mainly depended upon the whitening process. Whitening is the process in which brown rice is subjected to removal of bran and germ by giving shear force to grains which generates heat, cause cracking and broken which results in less head yield (Yilmaz 2016). Therefore, 3 to 4 whitening machines are provided to avoid the overheating of grains, which are collectively known as a multi-break system (Yilmaz 2016). The multi-break system will provide the resting time while milling, to avoid the reduction in the production of heat due to friction in polishing and serves as a port to the separation of the bran, which has been removed from the grain. The amount of bran removed from the whitening machine is known as bran fraction of that particular multi-break pass and mixture of outputs from these passes known as composite rice bran (Yilmaz 2016).

The application of rice bran in food industries is increasing mainly due to its dietary fiber and therapeutic potential. The bran is incorporated in many food products like bread, cakes, noodles, pasta, cookies, pizza and ice creams without significant change in their sensory and textural properties (Lavanya et al. 2017). Though the rice

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bran is rich in nutrients, it contains lipase enzyme, which causes rancidity in rice bran oil by producing Free Fatty Acid (FFA). The rate of FFA formation is highly dependent on environmental conditions. Läubli and Bruttel 1986 reported formation of 5–7% FFA per day and 70% FFA in a single month of bran storage. Bran oil with an excess of 10% FFA is unfit for human consumption and less than 5% FFA is desirable for producing rice bran oil because high FFA results in high refining loss (Tao et al. 1993; Orthoefer 2005).

Stabilization of rice bran can help to overcome these problems. Proper stabilization inactivates the enzymes and retains maximum nutrients. Thermal treatment is the most common method to stabilize rice bran. High temperatures above 120 °C denature the enzyme responsible for the oxidation of oil in RBO without destroying the nutritional value of the rice bran (Orthoefer 2005). Most of the processes involve dry or moist heat treatment. Moist heat treatment may be more effective than dry heat and few processes that use steam have achieved satisfactory results (Malekian et al. 2000). The proper stabilization will depend on the moisture content of the bran, time and temperature of the treatment.

Various stabilization techniques have been applied to avoid oxidation. Simple chemical method has been reported by Prabhakar and Venkatesh (1986), steaming (Ajmal et al. 2006), Autoclaving and parboiling (Rosniyana et al. 2009), extrusion (Sharma et al. 2004), microwave treatment (Ramezanzadeh et al. 1999), ohmic heating (Lakkakula et al. 2004; Knirsch et al. 2010), dry heat treatment (Sharma et al. 2004), gamma-irradiation (Shin et al. 1997), infrared radiation (Krishnamurthy et al. 2008) and toasting (da Silva et al. 2006).

Among all, microwave heating is one of the effective treatment showing a maximum shelf life of 60 days (Ramezanzadeh et al. 2000). Tao et al. (1993) and Malekian et al. (2000) showed that exposure of fresh rice bran samples with 21% moisture content for 3 min inactivates lipase activity (increases in % oleic acid) for 8 weeks. Ramezanzadeh et al. (1999) showed that rice bran deterioration could be effectively reduced by an initial microwave heat treatment followed by packaging of the bran in zipper-top bags and storing the bags at 4–5 °C. This method was found to be effective for at least 16 weeks of storage time. The microwave heat treated of the rice bran with 4 W/g microwave power for 5 min is sufficient to inactivate the lipase enzyme and thereby ensuring the storage of rice bran for up to 3 months (Patil 2011).

The activity of lipase enzyme was found to be more in aleurone layer of rice. As said earlier the bran layer will remove by fractions and it is necessary to know in which fraction the activity of the enzyme is maximum. In this study, we investigated to know the effect of microwave

heating on bran fractions and activity of lipase enzyme in the fractions with a change in hydrolytic rancidity during storage.

Materials and methods

Materials

Freshly milled rice bran was collected from Modern Rice Mill, Sitharkkadu, Mayiladuthurai, Tamil Nadu. Bran was collected from polisher (1–3) and from a composite bran stream. Samples were immediately transported to the laboratory, sieved using 500 µm sieve and separated husk and broken. The collected bran fractions from polishers pass 1, pass 2 and pass 3 having an initial moisture content of 9.21, 9.86 and 9.83 respectively while composite bran is having 10.01 (w.b). The moisture content of all bran fractions was increased to 21% for proper stabilization by microwave heating.

Stabilization

Microwave dryer (Enerzi microwave system, model No-PTF-2515) was used for conducting the experiment. By using control panel, the following parameters: belt speed, microwave power level, heater temperature, and hot air temperature were controlled.

The bran fractions (BF1- Bran fraction 1, BF2- Bran fraction 2 and BF3- Bran fraction 3) was exposed to different microwave powers at 850, 925 and 1000 W; exposure time was 3, 4.5 and 6 min; hot air temperature was maintained constantly at 70 °C and belt speed (10 mm/s) was maintained according to the exposure time. The capacity of microwave treatment of rice bran to inactivate lipases was determined by measuring the Free Fatty Acid (FFA) and Peroxide Value (PV) of the samples.

Storage of stabilized rice bran milled fractions

The stabilized bran fractions were packed in LDPE (25 gauge) packaging materials and stored in ambient conditions (37–42 °C; RH 70–80% in Thanjavur, Tamil Nadu) for 90 days. Rancidity test (FFA, AV, and PV) were conducted every 15 days' interval.

Rancidity analysis

The Free fatty acid and acid value was determined by directly titrating the oil in an alcoholic medium against standard potassium hydroxide solution as explained in IUPAC 2201 (1979). Peroxide value was calculated according to AOAC, 965.33.

Statistical analysis

The effects of factors (microwave power and storage times on FFA, AV and PVs) were evaluated individually for each bran fractions in triplicate on the measured parameters at 95% confidence level ($p < 0.005$). The differences among means were separated using Least Significance Differences (LSD) procedure. The statistical analysis was run using IBM SPSS software Version 20.0 (Armonk, NY: IBM Corp 2011).

Results and discussions

The rancidity level in fresh rice bran fractions

The bran was measured initially for its rancidity level before treatment. The lipase enzyme activates at 30–40 °C (Qingci et al. 1999). The rancidity levels were significantly different in all bran fractions and FFA, AV, and PV were significantly increased from the first fraction to the third fraction. The composite bran showed quite higher values of FFA, AV and PV compared to 1st bran fraction but not significantly different from 2nd and 3rd fraction. FFA values of 1.098, 1.24, 1.57 and 1.41% oleic acid; AV of 5.82, 6.83, 7.42 and 7.93 mg KOH/g oil and PV of 2.77, 2.82, 3.94 and 3.87 mg Eqv/kg oil for BF1, BF2, BF3 and total bran respectively. The heat produced by friction due to physical interaction of grain-to-grain and to the polisher during polishing that causes an increase in temperature during milling step (Yilmaz et al. 2014). It may have favored the lipolytic enzyme activity, which causes increasing FFA, AV, and PV from bran fraction 1 to bran fraction 3.

Free fatty acid content

FFA content of unstabilized bran increased within 30 days and off-flavor developed. Prabhakar and Venkatesh (1986), showed similar results for unstabilized bran samples which degraded quickly. The deterioration was due to the oxidation of oil to FFA in the presence of water and the reaction is generally catalyzed by enzyme lipase in the rice bran. The FFA content of all stabilized bran fractions was significantly different (< 0.05), notably fast for the first 30 days while the increase was gradual for the later stages of storage showed in Table 1. Due to auto-oxidation, which may be attributed to the reversible inactivation or regeneration of enzyme activity (Pourali et al. 2009), which causes the increase in FFA during 30 days of storage.

The minimum and maximum FFA values were 4.29 and 5.52% respectively for the first fraction, 4.41 and 5.83% respectively for the second fraction, 4.96 and 6.19%

respectively for the third fraction and 4.51 and 5.86% respectively for composite bran. FFAs content in the first fraction was significantly higher than other fractions this may be due to initial FFAs, which were higher in rest of the fractions except first. The bran fractions which exposed to different power levels for varying exposure time showed a significant difference ($p < 0.05$).

In other words, the FFA content of rice bran fractions that were stabilized with microwave treatment continued to increase gradually, with varying degrees, throughout the storage period. Similarly, slow and steady FFAs increase in stabilized rice bran samples was observed in many studies employing infrared, microwave and extrusion stabilization procedures (Shin et al. 1997; Ramezanzadeh et al. 1999; Yilmaz et al. 2014). Generally, acceleration in FFAs increase was observed in the first month of the storage in most of the processed bran samples likewise the crude ones which may be attributed to the reversible inactivation or regeneration of enzyme activity (Yilmaz 2016). However, FFA increase was notably retarded with microwave treatment at specific conditions. Therefore, it can be suggested that short process times at a high dose of microwave treatment was sufficient to inhibit the enzyme activity, the storage temperature also will influence the FFA content, so the bran should store in low temperature.

Acid value content

Acid value of all stabilized bran fractions increased significantly in a lower rate during storage. As like in FFAs value, the AV also developed rapidly till 30 days and becomes slow and steady at the end of the storage period of 90 days (Table 2). AVs was more in third bran fraction compared to the first fraction, the increased values were significantly different from each other. AVs for same power levels and same exposure time for different storage periods were significantly different (< 0.05). The AVs between the treatments was significantly different over a period of 90 days.

AVs development was slow as power levels and exposure time increased. The obtained results were in agreement with Dhingra et al. (2012) who stabilized the bran by using ohmic heating. The results also revealed that the lipase inactivation by microwave treatment was an irreversible process which leads to the conclusion that lipase enzyme completely inactivated. In fact, the combined effects of temperature, exposure time, and microwave dosage in microwave treatment can provide very suitable conditions for inactivation of lipase enzyme. On the other hand, increasing in AVs might be attributed to the oxidative rancidity during storage of stabilized bran in LDPE packaging material over a period of 90 days.

Table 1 Variation of free fatty acid content (% oleic acid) of bran fractions throughout 90 days of storage at ambient temperature

Rice Bran fraction	Microwave power (W)	Process time (min)	Storage time (days)					
			15	30	45	60	75	90
BF1	850	3.0	2.8 ± 0.10 ^{a,B}	2.95 ± 0.36 ^{a,C}	3.46 ± 0.29 ^{a,D}	3.88 ± 0.48 ^{a,E}	4.57 ± 0.45 ^{a,F}	5.52 ± 0.21 ^{a,G}
		4.5	2.71 ± 0.07 ^{b,B}	2.82 ± 0.22 ^{a,C}	3.14 ± 0.33 ^{a,D}	3.62 ± 0.45 ^{b,E}	4.26 ± 0.50 ^{b,F}	4.98 ± 0.23 ^{b,G}
		6.0	2.56 ± 0.12 ^{c,B}	2.73 ± 0.18 ^{b,B}	2.99 ± 0.15 ^{a,C}	3.21 ± 0.96 ^{c,D}	4.58 ± 0.03 ^{c,D}	4.63 ± 0.07 ^{c,E}
	925	3.0	2.69 ± 0.24 ^{d,B}	2.76 ± 0.38 ^{c,B}	3.31 ± 0.23 ^{a,C}	3.64 ± 0.74 ^{d,D}	4.7 ± 0.53 ^{d,E}	5.46 ± 0.16 ^{d,F}
		4.5	2.54 ± 0.39 ^{e,B}	2.68 ± 0.13 ^{a,C}	2.94 ± 0.38 ^{a,D}	3.48 ± 0.50 ^{e,E}	4.2 ± 0.14 ^{e,F}	4.94 ± 0.20 ^{e,F}
		6.0	2.38 ± 0.09 ^{f,B}	2.51 ± 0.15 ^{a,C}	2.73 ± 0.44 ^{b,D}	3.36 ± 0.53 ^{f,E}	4.12 ± 0.36 ^{f,F}	4.63 ± 0.45 ^{f,G}
	1000	3.0	2.55 ± 0.17 ^{g,B}	2.66 ± 0.09 ^{d,B}	2.8 ± 0.50 ^{e,B}	3.51 ± 0.33 ^{g,C}	3.98 ± 0.41 ^{g,D}	4.57 ± 0.43 ^{g,G}
		4.5	2.43 ± 0.05 ^{h,B}	2.51 ± 0.14 ^{e,B}	2.72 ± 0.38 ^{a,D}	3.26 ± 0.39 ^{h,D}	3.82 ± 0.34 ^{h,D}	4.31 ± 0.08 ^{h,E}
		6.0	2.21 ± 0.16 ^{i,B}	2.45 ± 0.16 ^{f,B}	2.69 ± 0.28 ^{d,D}	3.1 ± 0.36 ^{i,E}	3.62 ± 0.47 ^{i,F}	4.29 ± 0.21 ^{i,G}
BF2	850	3.0	3.2 ± 0.15 ^{a,B}	3.68 ± 0.33 ^{a,C}	3.96 ± 0.06 ^{a,D}	4.53 ± 0.43 ^{a,E}	4.98 ± 0.60 ^{a,F}	5.83 ± 0.25 ^{a,G}
		4.5	2.91 ± 0.11 ^{b,B}	3.02 ± 0.07 ^{b,B}	3.47 ± 0.08 ^{b,B}	3.91 ± 0.64 ^{b,D}	4.56 ± 0.53 ^{b,E}	5.31 ± 0.30 ^{b,F}
		6.0	2.72 ± 0.15 ^{c,A}	2.99 ± 0.19 ^{c,B}	3.23 ± 0.49 ^{c,C}	3.57 ± 0.61 ^{c,D}	3.83 ± 0.60 ^{c,E}	4.69 ± 0.55 ^{c,F}
	925	3.0	3.01 ± 0.17 ^{a,B}	3.34 ± 0.23 ^{d,B}	3.75 ± 0.09 ^{d,C}	4.31 ± 0.41 ^{d,D}	4.79 ± 0.54 ^{d,E}	5.56 ± 0.17 ^{d,F}
		4.5	2.83 ± 0.10 ^{d,B}	3.18 ± 0.24 ^{e,B}	3.31 ± 0.13 ^{e,B}	3.86 ± 0.49 ^{e,C}	4.53 ± 0.45 ^{e,D}	5.18 ± 0.31 ^{e,E}
		6.0	2.54 ± 0.07 ^{e,B}	2.87 ± 0.23 ^{f,C}	3.06 ± 0.07 ^{f,D}	3.48 ± 0.50 ^{f,E}	3.75 ± 0.41 ^{f,F}	4.34 ± 0.59 ^{f,G}
	1000	3.0	2.97 ± 0.11 ^{f,B}	3.13 ± 0.11 ^{g,B}	3.54 ± 0.14 ^{g,C}	4.03 ± 0.38 ^{g,D}	4.63 ± 0.10 ^{g,E}	5.21 ± 0.23 ^{g,F}
		4.5	2.61 ± 0.08 ^{g,B}	2.94 ± 0.23 ^{h,B}	3.36 ± 0.13 ^{h,C}	3.64 ± 0.50 ^{h,C}	4.17 ± 0.53 ^{h,D}	4.92 ± 0.25 ^{h,E}
		6.0	2.44 ± 0.05 ^{h,B}	2.71 ± 0.19 ^{i,B}	3.08 ± 0.09 ^{i,C}	3.31 ± 0.47 ^{i,D}	3.96 ± 0.31 ^{i,E}	4.41 ± 0.38 ^{i,F}
BF3	850	3.0	3.42 ± 0.3 ^{a,B}	3.87 ± 0.62 ^{a,C}	4.67 ± 0.21 ^{a,D}	5.14 ± 0.33 ^{a,E}	5.58 ± 0.62 ^{a,F}	6.19 ± 0.23 ^{a,G}
		4.5	3.07 ± 0.3 ^{b,B}	3.59 ± 0.58 ^{a,C}	4.29 ± 0.26 ^{b,D}	4.82 ± 0.31 ^{b,E}	5.26 ± 0.32 ^{b,F}	5.74 ± 0.09 ^{a,G}
		6.0	2.94 ± 0.43 ^{c,B}	3.23 ± 0.46 ^{b,B}	3.84 ± 0.29 ^{c,C}	4.44 ± 0.26 ^{c,E}	4.81 ± 0.67 ^{c,F}	5.48 ± 0.16 ^{b,G}
	925	3.0	3.26 ± 0.39 ^{d,B}	3.62 ± 0.52 ^{a,C}	4.35 ± 0.21 ^{d,D}	4.89 ± 0.28 ^{d,E}	5.29 ± 0.19 ^{d,F}	5.81 ± 0.26 ^{a,G}
		4.5	2.98 ± 0.4 ^{e,B}	3.48 ± 0.31 ^{a,C}	3.76 ± 0.07 ^{e,D}	4.56 ± 0.26 ^{e,E}	4.93 ± 0.17 ^{e,F}	5.63 ± 0.50 ^{c,G}
		6.0	2.65 ± 0.45 ^{f,B}	3.05 ± 0.24 ^{c,C}	3.31 ± 0.09 ^{f,D}	4.19 ± 0.31 ^{f,E}	4.64 ± 0.28 ^{f,F}	5.18 ± 0.42 ^{d,G}
	1000	3.0	3.13 ± 0.62 ^{g,B}	3.35 ± 0.42 ^{a,C}	4.07 ± 0.07 ^{g,D}	4.57 ± 0.22 ^{g,E}	4.97 ± 0.07 ^{g,F}	5.54 ± 0.29 ^{e,G}
		4.5	2.73 ± 0.36 ^{h,B}	3.17 ± 0.072 ^{a,C}	3.93 ± 0.28 ^{h,C}	4.36 ± 0.28 ^{h,C}	4.76 ± 0.24 ^{h,D}	5.28 ± 0.18 ^{f,D}
		6.0	2.52 ± 0.33 ^{i,B}	2.94 ± 0.50 ^{d,C}	3.46 ± 0.13 ^{i,D}	3.98 ± 0.36 ^{i,E}	4.49 ± 0.28 ^{i,F}	4.96 ± 0.31 ^{g,G}
Total Bran	850	3.0	3.36 ± 0.70 ^{a,B}	3.78 ± 0.54 ^{a,C}	4.36 ± 0.41 ^{a,D}	4.81 ± 0.31 ^{a,E}	5.21 ± 0.28 ^{a,F}	5.21 ± 0.70 ^{a,G}
		4.5	3.1 ± 0.054 ^{b,B}	3.46 ± 0.35 ^{b,C}	3.87 ± 0.8 ^{b,D}	4.58 ± 0.50 ^{b,E}	4.93 ± 0.74 ^{b,F}	4.93 ± 0.50 ^{b,G}
		6.0	2.86 ± 0.47 ^{c,B}	3.18 ± 0.25 ^{c,C}	3.53 ± 0.24 ^{c,D}	3.96 ± 0.30 ^{c,E}	4.56 ± 0.26 ^{c,F}	4.56 ± 0.96 ^{c,G}
	925	3.0	3.24 ± 0.57 ^{d,B}	3.61 ± 0.17 ^{d,B}	4.05 ± 0.31 ^{d,B}	4.69 ± 0.45 ^{d,B}	5.01 ± 0.56 ^{d,C}	5.01 ± 0.19 ^{d,D}
		4.5	2.93 ± 0.58 ^{e,B}	3.32 ± 0.16 ^{e,C}	3.66 ± 0.24 ^{e,C}	4.26 ± 0.42 ^{e,D}	4.68 ± 0.42 ^{e,E}	4.68 ± 0.10 ^{e,E}
		6.0	2.62 ± 0.58 ^{f,B}	2.96 ± 0.36 ^{f,C}	3.45 ± 0.34 ^{f,D}	3.81 ± 0.5 ^{f,E}	4.24 ± 0.68 ^{f,F}	4.24 ± 0.48 ^{f,G}
	1000	3.0	3.01 ± 0.67 ^{g,B}	3.47 ± 0.39 ^{g,C}	3.97 ± 0.35 ^{g,D}	4.27 ± 0.21 ^{g,E}	4.87 ± 0.44 ^{g,F}	4.87 ± 0.31 ^{g,G}
		4.5	2.58 ± 0.71 ^{h,B}	2.91 ± 0.22 ^{h,C}	3.53 ± 0.43 ^{h,D}	3.83 ± 0.28 ^{h,E}	4.42 ± 0.06 ^{h,F}	4.42 ± 0.41 ^{h,G}
		6.0	2.32 ± 0.17 ^{i,B}	2.74 ± 0.27 ^{i,C}	3.27 ± 0.37 ^{i,D}	3.59 ± 0.22 ^{i,E}	4.08 ± 0.29 ^{i,F}	4.08 ± 0.33 ^{i,G}

*Means followed by different small letters for the different treatments are significantly different ($p < 0.05$)

*Means followed by different capital letters for the different treatments and the same storage period are significantly different ($p < 0.05$)

Peroxide value content

The peroxide value (PV) measures the quantity of peroxides in the oil; these are important intermediates of oxidative reaction since they decompose via transition metal irradiation and elevated temperatures to form free

radicals. The lipoygenase and peroxidase enzymes also have a negative impact on the oxidative state of the bran. All peroxidase activity of microwave heated bran milling fractions was lower than that of the control samples. Less peroxide value reflects the inactivation of the enzyme. The

Table 2 Variation of acid value (mg KOH/g oil) of bran fractions throughout 90 days of storage at ambient temperature

Rice Bran fraction	Microwave power (W)	Process time (min)	Storage time (days)					
			15	30	45	60	75	90
BF1	850	3.0	6.78 ± 0.5 ^{a,A}	8.42 ± 0.14 ^{a,B}	9.16 ± 0.24 ^{a,C}	9.83 ± 0.19 ^{a,D}	10.73 ± 0.42 ^{a,E}	12.41 ± 0.49 ^{a,F}
		4.5	6.42 ± 0.22 ^{b,A}	7.98 ± 0.88 ^{b,B}	8.02 ± 0.4 ^{b,C}	8.95 ± 0.13 ^{b,D}	9.82 ± 0.46 ^{b,E}	11.33 ± 0.48 ^{b,F}
		6.0	6.38 ± 0.62 ^{c,A}	7.46 ± 0.35 ^{c,B}	7.93 ± 0.34 ^{c,C}	8.47 ± 0.19 ^{c,D}	9.16 ± 0.45 ^{c,E}	10.52 ± 0.93 ^{c,F}
	925	3.0	6.66 ± 0.41 ^{d,A}	7.83 ± 0.37 ^{d,B}	8.62 ± 0.23 ^{d,C}	9.26 ± 0.01 ^{d,D}	10.06 ± 0.89 ^{d,E}	11.24 ± 0.12 ^{d,F}
		4.5	6.33 ± 0.33 ^{e,A}	7.52 ± 0.4 ^{e,B}	7.74 ± 0.46 ^{e,C}	8.91 ± 0.21 ^{e,D}	9.82 ± 0.61 ^{e,E}	10.84 ± 0.53 ^{e,F}
		6.0	6.41 ± 0.56 ^{f,A}	7.28 ± 0.65 ^{f,B}	7.43 ± 0.14 ^{f,C}	8.52 ± 0.6 ^{f,D}	9.61 ± 0.42 ^{f,E}	10.18 ± 0.84 ^{f,F}
	1000	3.0	6.54 ± 0.48 ^{g,A}	8.16 ± 0.25 ^{g,B}	8.58 ± 0.51 ^{g,C}	8.78 ± 0.36 ^{g,D}	9.73 ± 0.92 ^{g,E}	10.42 ± 0.44 ^{g,F}
		4.5	6.24 ± 0.36 ^{h,A}	7.28 ± 0.26 ^{h,B}	7.61 ± 0.33 ^{h,C}	8.09 ± 0.6 ^{h,D}	8.66 ± 0.37 ^{h,E}	9.63 ± 0.77 ^{h,F}
		6.0	6.16 ± 0.33 ^{i,A}	6.99 ± 0.57 ^{i,B}	7.38 ± 0.36 ^{i,C}	7.98 ± 0.7 ^{i,D}	8.18 ± 0.62 ^{i,E}	9.92 ± 0.67 ^{i,F}
BF2	850	3.0	7.83 ± 0.74 ^{a,A}	9.45 ± 0.15 ^{a,B}	10.18 ± 0.12 ^{a,C}	11.52 ± 0.52 ^{a,D}	12.78 ± 1.09 ^{a,E}	13.63 ± 0.86 ^{a,F}
		4.5	7.67 ± 0.88 ^{b,A}	8.13 ± 0.26 ^{b,B}	8.64 ± 0.41 ^{b,C}	9.36 ± 0.09 ^{b,D}	10.43 ± 0.41 ^{b,E}	12.62 ± 0.91 ^{b,F}
		6.0	7.41 ± 0.72 ^{c,A}	7.84 ± 1.11 ^{c,B}	8.23 ± 0.01 ^{c,C}	9.02 ± 0.57 ^{c,D}	10.18 ± 0.44 ^{c,E}	11.57 ± 0.74 ^{c,F}
	925	3.0	7.55 ± 0.62 ^{d,A}	8.08 ± 1.11 ^{d,B}	8.88 ± 0.28 ^{d,C}	10.58 ± 1.30 ^{d,D}	11.27 ± 1.22 ^{d,E}	12.14 ± 0.63 ^{d,F}
		4.5	7.49 ± 0.82 ^{e,A}	7.77 ± 0.33 ^{e,B}	8.15 ± .66 ^{e,C}	9.13 ± 0.57 ^{e,D}	9.93 ± 0.97 ^{e,E}	10.28 ± 0.49 ^{e,F}
		6.0	7.23 ± 0.57 ^{f,A}	7.53 ± 0.14 ^{f,B}	7.81 ± 0.18 ^{f,C}	8.42 ± 0.66 ^{f,D}	9.41 ± 0.35 ^{f,E}	10.98 ± 0.54 ^{f,F}
	1000	3.0	7.34 ± 0.56 ^{g,A}	7.71 ± 0.28 ^{g,B}	8.38 ± 0.15 ^{g,C}	8.91 ± 0.91 ^{g,D}	9.85 ± 0.73 ^{g,E}	10.79 ± 0.92 ^{g,F}
		4.5	6.71 ± 0.65 ^{h,A}	7.16 ± 0.67 ^{h,B}	7.58 ± 1.23 ^{h,C}	7.98 ± 0.14 ^{h,D}	8.51 ± 0.06 ^{h,E}	9.32 ± 0.41 ^{h,F}
		6.0	6.38 ± 0.54 ^{i,A}	6.99 ± 0.23 ^{i,B}	7.24 ± 0.72 ^{i,C}	7.56 ± 0.45 ^{i,D}	8.33 ± 0.16 ^{i,E}	9.25 ± 0.15 ^{i,F}
BF3	850	3.0	8.13 ± 0.021 ^{a,A}	9.23 ± 0.15 ^{a,B}	10.25 ± 0.04 ^{a,C}	10.92 ± 0.64 ^{a,D}	11.84 ± 0.7 ^{a,E}	12.62 ± 0.7 ^{a,F}
		4.5	7.96 ± 0.2 ^{b,A}	8.88 ± 0.5 ^{b,B}	9.39 ± 0.5 ^{b,C}	10.47 ± 0.8 ^{b,D}	11.31 ± 1.47 ^{b,E}	12.48 ± 0.09 ^{b,F}
		6.0	7.88 ± 0.33 ^{c,A}	8.65 ± 0.57 ^{c,B}	9.14 ± 0.96 ^{c,C}	9.82 ± 1.11 ^{c,D}	10.97 ± 1.95 ^{c,E}	11.53 ± 0.08 ^{c,F}
	925	3.0	7.94 ± 0.27 ^{d,A}	8.42 ± 0.26 ^{d,B}	9.53 ± 0.54 ^{d,C}	10.31 ± 0.72 ^{d,D}	11.32 ± 1.94 ^{d,E}	12.18 ± 0.028 ^{d,F}
		4.5	7.77 ± 0.19 ^{e,A}	8.13 ± 0.25 ^{e,B}	9.15 ± 0.7 ^{e,C}	9.74 ± 1.73 ^{e,D}	10.82 ± 0.68 ^{e,E}	11.86 ± 1.11 ^{e,F}
		6.0	7.64 ± 0.28 ^{f,A}	7.94 ± 0.28 ^{f,B}	8.82 ± 0.71 ^{f,C}	9.45 ± 1.42 ^{f,D}	10.14 ± 0.63 ^{f,E}	10.97 ± 0.06 ^{f,F}
	1000	3.0	7.79 ± 0.31 ^{g,A}	8.08 ± 0.26 ^{g,B}	8.56 ± 0.56 ^{g,C}	9.63 ± 1.14 ^{g,D}	10.82 ± 0.86 ^{g,E}	11.83 ± 0.73 ^{g,F}
		4.5	7.49 ± 0.23 ^{h,A}	7.74 ± 0.11 ^{h,B}	8.16 ± 0.12 ^{h,C}	9.23 ± 0.54 ^{h,D}	10.02 ± 1.9 ^{h,E}	11.08 ± 0.6 ^{h,F}
		6.0	7.17 ± 0.12 ^{i,A}	7.52 ± 0.19 ^{i,B}	8.03 ± 0.55 ^{i,C}	8.73 ± 1.17 ^{i,D}	9.74 ± 0.4 ^{i,E}	10.51 ± 0.27 ^{i,F}
Total Bran	850	3.0	8.93 ± 0.56 ^{a,A}	9.73 ± 0.35 ^{a,B}	10.45 ± 0.14 ^{a,C}	11.24 ± 0.22 ^{a,D}	12.16 ± 0.33 ^{a,E}	12.98 ± 0.25 ^{a,F}
		4.5	8.54 ± 0.41 ^{b,A}	9.56 ± 0.48 ^{b,B}	10.13 ± 0.52 ^{b,C}	10.92 ± 0.39 ^{b,D}	11.81 ± 0.35 ^{b,E}	12.14 ± 0.24 ^{b,F}
		6.0	8.17 ± 0.22 ^{c,A}	9.31 ± 0.46 ^{c,B}	9.74 ± 0.34 ^{c,C}	10.56 ± 0.52 ^{c,D}	11.5 ± 0.39 ^{c,E}	11.97 ± 0.32 ^{c,F}
	925	3.0	8.62 ± 0.48 ^{d,A}	9.57 ± 0.83 ^{d,B}	10.28 ± 0.53 ^{d,C}	10.77 ± 0.32 ^{d,D}	11.92 ± 0.43 ^{d,E}	12.74 ± 0.99 ^{d,F}
		4.5	8.31 ± 0.38 ^{e,A}	9.24 ± 0.89 ^{e,B}	9.96 ± 0.57 ^{e,C}	10.68 ± 0.66 ^{e,D}	11.64 ± 0.67 ^{e,E}	12.25 ± 0.34 ^{e,F}
		6.0	8.04 ± 0.67 ^{f,A}	9.14 ± 0.84 ^{f,B}	9.61 ± 0.66 ^{f,C}	10.39 ± 0.6 ^{f,D}	11.32 ± 0.87 ^{f,E}	11.82 ± 0.6 ^{f,F}
	1000	3.0	8.28 ± 0.34 ^{g,A}	8.84 ± 0.53 ^{g,B}	9.82 ± 0.89 ^{g,C}	10.28 ± 0.45 ^{g,D}	10.91 ± 0.03 ^{g,E}	11.47 ± 0.25 ^{g,F}
		4.5	7.97 ± 0.33 ^{h,A}	8.57 ± 0.58 ^{h,B}	9.47 ± 0.92 ^{h,C}	9.87 ± 0.43 ^{h,D}	10.57 ± 0.44 ^{h,E}	11.03 ± 0.03 ^{h,F}
		6.0	7.75 ± 0.41 ^{i,A}	8.46 ± 0.66 ^{i,B}	9.21 ± 0.83 ^{i,C}	9.51 ± 0.55 ^{i,D}	9.98 ± 0.16 ^{i,E}	10.72 ± 0.14 ^{i,F}

*Means followed by different small letters for the different treatments are significantly different ($p < 0.05$)

*Means followed by different capital letters for the different treatments and the same storage period are significantly different ($p < 0.05$)

peroxide values were significantly increased in lower rate during a storage period of 90 days.

The peroxide value increased rapidly during first 30 days and became slower at the end of storage period (Table 3). The bran fractions which treated at a same power level and same exposure time have a significant

difference (< 0.05). The slower and steady increase in PVs shown that the inactivation of lipase and peroxidase enzyme and there were no longer free radicals are available for further deterioration (Orthoefer 2005). Therefore, the development of peroxide was reduced.

Table 3 Variation of Peroxide value (mg eq/kg oil) of bran fractions throughout 90 days of storage at ambient temperature

Rice Bran fraction	Microwave power (W)	Process time (min)	Storage time (days)					
			15	30	45	60	75	90
BF1	850	3.0	3.96 ± 0.36 ^{a,A}	5.01 ± 0.14 ^{a,B}	5.86 ± 0.24 ^{a,C}	6.93 ± 0.19 ^{a,D}	7.72 ± 0.42 ^{a,E}	8.62 ± 0.49 ^{a,F}
		4.5	3.48 ± 0.53 ^{a,A}	4.53 ± 0.8 ^{b,B}	5.32 ± 0.4 ^{b,C}	6.56 ± 0.31 ^{b,D}	7.46 ± 0.46 ^{b,E}	7.94 ± 0.48 ^{b,F}
		6.0	3.01 ± .22 ^{b,A}	4.62 ± 0.3 ^{c,B}	5.13 ± 0.24 ^{c,C}	5.98 ± 0.19 ^{c,D}	7.18 ± 0.45 ^{c,E}	7.53 ± 0.93 ^{c,F}
	925	3.0	3.62 ± 0.62 ^{a,A}	4.86 ± 0.37 ^{d,B}	5.45 ± 0.23 ^{d,C}	6.66 ± 1.01 ^{d,D}	7.58 ± 0.89 ^{d,E}	8.16 ± 0.12 ^{d,F}
		4.5	3.6 ± 0.17 ^{a,A}	4.44 ± 0.4 ^{e,B}	4.98 ± 0.46 ^{e,C}	6.27 ± 0.21 ^{e,D}	7.24 ± 0.73 ^{e,E}	7.62 ± 0.52 ^{e,F}
		6.0	3.21 ± 0.17 ^{c,A}	4.28 ± 0.65 ^{f,B}	4.67 ± 0.14 ^{f,C}	5.71 ± 0.06 ^{f,D}	6.98 ± 0.42 ^{f,E}	7.19 ± 0.84 ^{f,F}
	1000	3.0	3.18 ± 0.36 ^{d,A}	4.63 ± 0.25 ^{g,B}	5.18 ± 0.51 ^{g,C}	5.83 ± 0.36 ^{g,D}	6.63 ± 0.92 ^{g,E}	7.96 ± 0.44 ^{g,F}
		4.5	3.4 ± 0.56 ^{e,A}	4.18 ± 0.26 ^{c,B}	4.78 ± 0.33 ^{h,C}	5.54 ± 0.06 ^{h,D}	6.47 ± 0.37 ^{h,E}	7.41 ± 0.77 ^{h,F}
		6.0	3.29 ± 0.33 ^{f,A}	4.51 ± 0.57 ^{h,B}	4.57 ± 0.36 ^{i,C}	5.19 ± 0.76 ^{i,D}	5.98 ± 0.6 ^{i,E}	6.18 ± 0.67 ^{i,F}
BF2	850	3.0	3.53 ± 0.23 ^{a,A}	5.15 ± 0.69 ^{a,B}	5.42 ± 0.55 ^{a,C}	6.81 ± 0.98 ^{a,D}	7.47 ± 0.4 ^{a,E}	8.92 ± 0.20 ^{a,F}
		4.5	3.86 ± 0.24 ^{b,A}	4.89 ± 0.69 ^{b,B}	5.63 ± 0.43 ^{b,C}	6.31 ± 0.48 ^{b,D}	7.93 ± 1.14 ^{b,E}	8.57 ± 1.2 ^{b,F}
		6.0	3.44 ± 0.37 ^{c,A}	4.72 ± 0.73 ^{c,B}	5.42 ± 0.47 ^{c,C}	6.28 ± 0.6 ^{c,D}	7.67 ± 0.98 ^{c,E}	8.14 ± .12 ^{c,F}
	925	3.0	3.98 ± 0.54 ^{d,A}	4.94 ± 0.7 ^{d,B}	5.81 ± 0.70 ^{d,C}	6.98 ± 0.82 ^{d,D}	7.78 ± 0.56 ^{d,E}	8.15 ± 0.38 ^{c,F}
		4.5	3.45 ± 0.38 ^{c,A}	4.26 ± 0.66 ^{e,B}	5.73 ± 0.5 ^{c,C}	6.52 ± 0.55 ^{e,D}	7.52 ± 0.7 ^{e,E}	7.42 ± 0.16 ^{d,F}
		6.0	3.63 ± 0.43 ^{e,A}	4.75 ± 0.19 ^{f,B}	5.72 ± 0.57 ^{e,C}	6.63 ± 0.64 ^{f,D}	7.13 ± 0.35 ^{f,E}	7.63 ± 0.13 ^{e,F}
	1000	3.0	3.57 ± 0.20 ^{f,A}	4.91 ± 0.18 ^{g,B}	5.94 ± 0.39 ^{f,C}	7.01 ± 0.76 ^{g,D}	7.18 ± 0.12 ^{g,E}	7.78 ± 0.66 ^{f,F}
		4.5	3.71 ± 0.22 ^{g,A}	4.51 ± 0.18 ^{h,B}	5.45 ± 0.37 ^{g,C}	6.47 ± 0.72 ^{h,D}	6.83 ± 0.25 ^{h,E}	7.26 ± 0.67 ^{g,F}
		6.0	3.93 ± 0.38 ^{h,A}	4.66 ± 0.73 ^{i,B}	4.98 ± 0.65 ^{h,C}	6.18 ± 0.84 ^{i,D}	6.26 ± 0.05 ^{i,E}	7.18 ± 0.76 ^{h,F}
BF3	850	3.0	4.12 ± 0.18 ^{a,A}	4.89 ± 0.37 ^{a,B}	5.53 ± 0.08 ^{a,C}	6.47 ± 0.74 ^{a,D}	7.81 ± 0.24 ^{a,E}	8.73 ± 0.13 ^{a,F}
		4.5	4.44 ± 0.16 ^{b,A}	4.63 ± 0.7 ^{b,B}	5.31 ± 0.05 ^{b,C}	5.75 ± 0.08 ^{b,D}	6.36 ± 1.11 ^{b,E}	8.42 ± 0.1 ^{b,F}
		6.0	4.15 ± 0.12 ^{c,A}	4.47 ± 0.76 ^{c,B}	5.19 ± 0.82 ^{c,C}	5.52 ± 0.07 ^{c,D}	5.87 ± 1.27 ^{c,E}	7.93 ± 0.14 ^{c,F}
	925	3.0	4.28 ± 0.6 ^{d,A}	4.68 ± 0.7 ^{d,B}	5.36 ± 0.8 ^{d,C}	6.2 ± 0.27 ^{d,D}	7.25 ± 0.37 ^{d,E}	8.47 ± 0.22 ^{d,F}
		4.5	4.13 ± 0.09 ^{a,A}	4.4 ± 0.94 ^{c,A}	5.27 ± 0.89 ^{e,B}	5.81 ± 0.05 ^{e,C}	6.62 ± 0.63 ^{e,D}	7.53 ± 0.07 ^{e,E}
		6.0	4.08 ± 0.7 ^{e,A}	4.27 ± 1.02 ^{f,B}	4.84 ± 0.2 ^{e,C}	5.47 ± 0.17 ^{f,D}	6.26 ± 0.61 ^{f,E}	718 ± 0.2 ^{f,F}
	1000	3.0	4.06 ± 0.13 ^{f,A}	4.54 ± 0.98 ^{g,B}	5.04 ± 0.33 ^{f,C}	5.72 ± 0.15 ^{g,D}	6.87 ± 0.21 ^{g,E}	7.48 ± 0.31 ^{g,F}
		4.5	3.87 ± 0.10 ^{g,A}	4.26 ± 0.84 ^{f,B}	4.75 ± 0.33 ^{g,C}	5.47 ± 0.14 ^{f,D}	5.78 ± 0.74 ^{h,E}	6.91 ± 0.12 ^{h,F}
		6.0	3.63 ± 0.6 ^{h,A}	4.1 ± 0.62 ^{h,B}	4.52 ± 0.83 ^{h,C}	4.95 ± 0.14 ^{h,D}	5.23 ± 0.73 ^{i,E}	6.48 ± 0.24 ^{i,F}
Total Bran	850	3.0	4.82 ± 0.48 ^{a,A}	5.63 ± 0.52 ^{a,B}	6.53 ± 0.04 ^{a,C}	7.68 ± 0.14 ^{a,D}	8.83 ± 0.07 ^{a,E}	9.32 ± 0.49 ^{a,F}
		4.5	4.57 ± 0.09 ^{b,A}	5.14 ± 0.36 ^{b,B}	6.02 ± 0.19 ^{b,C}	7.41 ± 0.3 ^{b,D}	8.17 ± 0.17 ^{b,E}	8.58 ± 0.28 ^{b,F}
		6.0	4.23 ± 0.05 ^{c,A}	4.92 ± 0.31 ^{c,B}	5.94 ± 0.29 ^{c,C}	6.99 ± 0.48 ^{c,D}	7.72 ± 0.14 ^{c,E}	8.18 ± 0.01 ^{c,F}
	925	3.0	4.73 ± 0.31 ^{d,A}	5.26 ± 0.41 ^{d,B}	6.13 ± 0.05 ^{d,C}	7.48 ± 0.21 ^{d,D}	8.19 ± 0.18 ^{d,E}	8.96 ± 0.02 ^{d,F}
		4.5	4.54 ± 0.28 ^{e,A}	4.97 ± 0.4 ^{e,B}	5.98 ± 0.12 ^{e,C}	7.03 ± 0.34 ^{e,D}	7.57 ± 0.02 ^{e,E}	7.74 ± 0.57 ^{e,F}
		6.0	4.15 ± 0.04 ^{f,A}	4.47 ± 0.14 ^{f,B}	5.54 ± 0.04 ^{f,C}	6.74 ± 0.28 ^{f,D}	7.19 ± 0.01 ^{f,E}	7.47 ± 0.22 ^{f,F}
	1000	3.0	4.36 ± 0.21 ^{g,A}	5.02 ± 0.33 ^{g,B}	5.74 ± 0.01 ^{g,C}	6.46 ± 0.5 ^{g,D}	7.72 ± 0.16 ^{g,E}	8.68 ± 0.11 ^{g,F}
		4.5	4.13 ± 0.18 ^{h,A}	4.82 ± 0.39 ^{h,B}	5.32 ± 0.1 ^{h,C}	5.97 ± 0.6 ^{h,D}	6.86 ± 0.03 ^{c,E}	7.72 ± 0.63 ^{h,F}
		6.0	3.98 ± 0.24 ^{i,A}	4.36 ± 0.18 ^{i,B}	4.97 ± 0.01 ^{i,C}	5.47 ± 0.55 ^{i,D}	6.47 ± 0.01 ^{h,E}	7.31 ± 0.32 ^{i,F}

*Means followed by different small letters for the different treatments are significantly different ($p < 0.05$)

*Means followed by different capital letters for the different treatments and the same storage period are significantly different ($p < 0.05$)

The minimum PVs values of 6.18% were observed in first milling fraction which stored for 90 days which was stabilized with high microwave power and exposed to longer time. The variations in the PVs of bran fractions was may be due to the initial values of bran before treatment and the lipase enzyme is depending on the power levels,

exposure time and temperature (Malekian et al. 2000). Therefore, the bran fractions, which exposed for a longer time with high power levels, the enzymes are completely inactivated compare to the bran fractions that are exposed to lesser time.

Conclusion

The third rice bran milling fraction showed higher rancidity in terms of FFA, AV, and PV initially followed by composite bran. Therefore, it can be suggested to exclude this bran fraction from composite bran, which can avoid the increase in rancidity level in composite bran. It was found that the higher microwave power for longer time exposure can inactivate lipase enzyme effectively. The bran fractions, which processed under 925 W for 3 min found the lesser content of rancidity, which was within the prescribed level.

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