Extraction and utilization of rice bran oil: A review

Umar Garba[1*], Riantong Singanusong[1,2], Sudarat Jiamyangyuen[1,2],
and Tipawan Thongsook[1,2]

[1]Department of Agro-industry, Faculty of Agriculture, Natural Resource and Environment, Naresuan University,
Muang District, Phitsanulok 65000 Thailand
[2]Centre of Excellence in Fats and Oils, Department of Agro-industry, Faculty of Agriculture, Natural Resources and
Environment, Naresuan University, Muang District, Phitsanulok 65000 Thailand

**Corresponding author: Umar Garba, Telephone: +6692704798,*

E-mail: umargarbafst@yahoo.com

ABSTRACT: Rice bran oil (RBO) is obtained through extraction of rice bran which is a by-product of the rice milling industries. There are several techniques used for the extraction of the RBO, but solvent extraction using hexane is the most popular used conventional method for commercial extraction. The use of hexane in the conventional methods has some drawbacks due to its flammability, toxicity and high temperature involved in the process resulting in some undesirable components in the oil as a result of oxidative deterioration, developments of rancid and off-flavor. Efforts were made by many researchers to explore different other nonconventional techniques for the oil extractions and utilization. Some of these methods such as supercritical carbon dioxide extraction, subcritical water extraction, enzyme-assisted, ultrasonic-assisted and microwave-assisted processes can be use produce an oil that is free from toxic residues, having high concentration of health components and a yield comparable to the conventional techniques. RBO has gained a wide popularity due to its considerable importance in the last few years for its health benefits. It has gained many applications in food, pharmaceutical, cosmetics and chemical industries because of its unique properties and medicinal value. However, the lack of widespread commercial uses of the RBO is due to the economic factor particularly the high cost of the oil as compared to other vegetable oils. This review intended to give an overview of some widely used extraction methods for the RBO as well as its existing applications in different industries.

Keywords: rice bran oil; extraction of RBO; utilization of RBO

INTRODUCTION

The RBO is known as a wonder oil for its numerous health benefits. It has a number of advantages over other edible oils because of the presence of unique antioxidant known as oryzanol [1]. It is also a good source of nutritionally important compounds such as γ-oryzanol, tocopherols, tocotrienols and sterols [2]; [3]. The crude RBO contains about 1.1-2.6% of γ-oryzanol, 0.2% of tocols, 70% of which is tocotrienol, and 3-5% of phytosterols and fatty acids steryl esters [3]. RBO is regarded as miracle product obtained from the outer layer of the brow rice [4]. The rice bran contains 10-26% oil depending on the variety, milling process, and other agro-climatic conditions [5]. After the milling process to extract the RBO, the rice bran need to undergo a process called stabilization to inactivate the enzymes and inhibit lipid oxidation. This process is essential to prevent the deterioration of fat and valuable bioactive compounds of the bran [6]. Many stabilization methods are reported from the literatures such as steaming, ohmic heating [6]; [7]; [8]; ultrasound treatment [9]; [10]; parboiling, refrigeration and pH lowering [11] and microwave radiation

[12].

India is the leading producer of RBO followed by Japan, Thailand and China. As of 2014, the global production reached up to 1.2 million tons, with India contributing about 75% (900,000 tons) of the total. The production is tremendously increasing with about 50 thousand tons yearly [1].

EXTRACTION METHODS OF RICE BRAN OIL

There are many techniques employed for the extraction of RBO which includes supercritical carbon dioxide fluid extraction [13]; [14] compressed liquefied petroleum gas [14] ultrasound-assisted aqueous extraction [15]; [13]; sub-critical water extraction techniques [16], ultrasonic enzymatic extraction [9], microwave-assisted extraction [17], subcritical carbon dioxide and soxhlet extraction [10]; [18]. Solvent extraction and soxhlet extraction techniques are widely considered as the conventional methods for extraction of RBO [19]; [20].

1. Solvent extraction process

Solvent extraction method can be used to recover oil from any materials with low oil content, or for pre-pressed oil cakes in order to obtained high oil content [21]; [22]. Hexane is the most commonly used solvent for this method, its relatively cheap ($1.15/g) and excellent for oil extraction [23]. Some short chain alcohols such as ethanol and isopropanol have also been proposed as an alternative solvent for extraction because of their greater safety [17]; [24].

The yield of about 92% oil was obtained from hexane extraction of ohmic heating-stabilized rice bran [7]. Oliveira et al. [22] reported about 42.7-99.9% yield of oil from rice bran using ethanol to rice bran ratio of 2.5:1 and 4.5:1, and temperature of 60-90°C. A Study have shown that increasing the extraction temperature from 40°C to 60°C and solvent (hexane and isopropanol) to bran ratios (w/w) of 2:1 and 3:1 increased the RBO yield. Extraction at 60°C for 10 min with 3:1 solvent to bran ratio using hexane yielded about 3.6% more oil, while extraction with isopropanol produces 6.4% more oil than at 40°C [25]. The yield of liquid propane was found to yield about 22.4% of oil in kg of rice bran at 0.76 MPa and ambient temperature [23]. A RBO was also extracted with isopropanol and hexane at 40°C for 15 min. The hexane extracted almost 40% more oil than the isopropanol, while increasing the temperature up to 120°C, the yield of hexane did not increase but the isopropanol extracted 25% more RBO than hexane under similar conditions [17]. About 99– 99.5% oil was reported to be extracted by solvent extraction from oleiferous seed [26]. A preliminary data suggested an optimum of 5:1 solvent-meal ratio [27]. The crude RBO obtained from this extraction process is mostly further subjected to chemical or physical refining to meet the specifications of food grade vegetable oil [24].

The organic solvent (usually hexane) used is however, flammable, volatile, toxic and pollutes the environment [28]. Even though the use of hexane for extraction is considered efficient and most widely used, it has some undesirable as mentioned earlier [11].

2. Mechanical pressing (Cold pressing)

Mechanical pressing is traditionally the most popular oil extraction method for oilseeds globally [11]. It has been in use especially by small and medium scale oil extraction industries for commercial RBO extraction in some countries like Thailand. The process is less expensive and less labour-intensive than using solvent extraction methods [10]; [12]. The safety and simplicity of the process is an advantage over the efficient solvent extraction techniques [29]. This method does not involve heat or chemical treatment, thus making it an interesting alternative for conventional practices because of consumer concern for natural and safe product [12].

The mechanical pressing is of two types, screw and hydraulic press. The screw press is also called an expeller, it is simple, easy to maintain and operate by semi-skilled workers [10]; [30]. In comparison, the screw press is continuous and produces slightly higher yield than the hydraulic press [26]. The method involve continuous pressing using expellers (Screw press). Expellers consist of a screw rotating inside a cylindrical cage (barrel) and the material is fed between the screw and the barrel and then propelled by the rotating screw in a direction parallel to the axis. The gradual increase in pressure help to release the oil which comes out of the press through the slots provided on the periphery of the barrel and the residual pressed cake move in the direction of the shaft for discharge [8]; [10].

However, for the extraction of RBO using this method, only about 9-10% of the bran weight was found to be extracted by pressing [31]. Extraction of oleiferous seeds by this methods revealed about 80-85% [27], while it was found that 75% oil can also be recovered from algae [32]. Although mechanical pressing results in high quality oil, the yield is relatively low and its generally used for small scale extraction, specialty products or as a pre-press operation in a large scale solvent extraction plant [26]; [32]. To make this method more effective, further modification in the design is required which will help to increase the oil recovery [32].

3. Soxhlet extraction

Soxhlet based solvent extraction is a primary means of extracting vegetable oils. The oil seeds are usually crushed and put in a packed bed which is then exposed directly to the solvent, thereby leaching the oil from the solid matrix to the fluid medium [33]. The yield of 15-20% and 18.4% RBO by weight of rice bran was obtained by this method using heptane as a solvent and petroleum ether (at 40-60°C), respectively [34]; [35]. Liu et al. [27] have also obtained about 67.73% yield of RBO from soxhlet extraction using hexane. About 61.2% oil was also recovered from black date at 65°C for 8 h using this method [36]. Imsanguan et al. [37] has compared the extraction efficiency of soxhlet, supercritical CO_2 and solvent extraction. However, the highest yield was obtained using SC-CO_2 in terms of γ-oryzanol and α-tocopherol. There were no sufficient literatures indicating the used of soxhlet extraction for extraction of RBO in higher quantity. The method is mainly employed for laboratory extraction process.

4. Supercritical fluid extraction

Supercritical fluid is formed when certain fluid is subjected to a pressure and temperature higher than its critical point. Under these conditions, the fluid exhibit properties between those of a gas and liquid. However, supercritical fluid has a density like a gas and its diffusivity is intermediate [38]. Every supercritical fluid possess a specific critical point which depends on the critical temperature and pressure of that gas/liquid [39]. Supercritical fluid extraction allows for an extract free of toxic residues which can be used directly without further treatment. The extract also contains excellent features and has ultra-pure composition [40]. This methods also gives a yield which is comparable to that of hexane extraction [28]. When supercritical fluids are used for extraction, there is no risk of solvent contamination and thermolability and chemical modification problems that may exist in conventional methods [41]. Carbon dioxide (CO_2) is the most expensive supercritical solvent used in food industries [39]. The supercritical CO_2 (SC-CO_2) is an alternative to organic solvent extraction and has been shown to be ideal for extraction of many oils. The CO_2 used is changed to its supercritical fluid state beyond the supercritical point (73 atm and 31°C) [21]. Several researchers have investigated the use of SC-CO_2 for extraction of RBO [2]; [21]; [24]; [28]. A maximum RBO yield extracted by SC-CO_2 was found to range between 19.2-20.4% which represent up to 99+% recovery by hexane [42]. Balachandran et al. [35] reported a yield of 20% by weight of RBO from the SC-CO_2 at 60°C, 500 bar, for 1.5 h using a CO_2 flow rate of 40 g/min as compared to 22.5% from hexane. The oil yield can be increased by increasing the temperature of 70°C, pressure above 500 bar and extraction time. A yield of 22.2% of oil per kg rice bran was obtained by SC-CO_2 extraction at 45°C and pressure of 35 MPa [23]. However, this technology has some limitation because of its high cost of equipment.

5. Sub-critical fluids extraction

The sub-critical fluid is referred to as hot liquid solvent or pressurized/accelerated liquid solvents [43], which are compressed below their critical temperatures and still maintain in the liquid state and used above their boiling point by increasing pressure. The sub-critical fluid extraction is a continuous counter-current process in which the solvent is removed after extraction using a vacuum at low temperature [44]. The sub-critical fluids extraction has the advantage of lower pressure and temperature as compared to supercritical fluids extraction which may be expensive due to the high pressure and temperature requirement. Various solvents including hexane can be used for sub-critical fluids extraction. Sub-critical propane and butane were used because of their low critical temperature and pressure, colorless and leave no toxic residue in the product. The yield of 89.11% and 91.42%, were obtained for butane and propane, respectively in comparison to hexane extraction [19]; [465.

The sub-critical water extraction (SWE) of RBO and defatted rice bran extract has been reported [16]; [46]. The SWE process involved using hot water that maintained its liquid state at temperature of between 100°C and its critical point of 374°C under a sufficient pressure of about 22 MPa to maintain the liquid state [47]; [48]; [49]. At this conditions, the water behaves like a highly hydrophobic solvents, and therefore help to extract lipophilic and hydrophobic substance [49]. The SCW is also known as superheated water or pressurized hot water [50]. Although this method gives high yield and good quality oil with high concentration of the health components [19], its application is yet not popular and the data concerning its use for extraction of RBO is not widely available.

6. Enzyme-assisted aqueous extraction

The enzyme-assisted aqueous extraction technology for RBO has been regarded as an eco-friendly process to obtain a good quality oil [51]. The use of water medium for extraction of oil from different oil seeds has been investigated by many researchers [52]; [53]; [54]. It has been reported for extraction of corn germ [55], soybean [56], peanut [57], sunflower [58] and rice bran [54]. But the method was unsuccessful in the past because of the low oil yield. However, recent development involves the use of enzymes to assist the extraction thus, resulting to a higher yield [58]. The enzymatic process helps to hydrolyze and degrade the structural polysaccharides which form the cell wall of the oils and proteins, leading to the released of both the oil and protein into the aqueous system [6]; [59].

A yield of 92.63% RBO was obtained by enzymatic extraction with ultrasonic treatments. The enzymatic hydrolysis was performed using enzyme (cellulose 1.2%, protease 0.6% and amylase 0.3%) at 55°C, 4.5 pH and hydrolysis time of 5.5 h [9]. A maximum of 87.25% of total oil from sunflower seed was also extracted using a viscozymes L enzyme from Novozymes (Bagsvaerd, Denmark) incubated at 45°C for 2 h [58]. For an enzymes-assisted extraction of wheat germ, barley germ and rice bran, different enzymes (Protex 6 L, Protex 7L, Alcalase, Fermgen, Lysomax and G-zyme 999) were tested. The combination of four enzymes gave an oil yield of about 70%, while combination of 5% fermgen (protease) and 5% spezymes (cellulase) gave the highest yield of 73.1% using 2:1 of raw material to water ratio, pH of 5, hydrolysis temperature of 50°C and 5% enzyme (V/W) for 20 h, respectively [54].

The enzyme-assisted extraction of RBO from full fat rice bran was reported by many researchers using different enzymes; mixture of enzymes protease, α-amylase and cellulese [60], neutrase and cellulese [51], mixture of protease, amylase and cellulose [9]. This method is better than the traditional process because it produces oil of good quality attributes such as color, free fatty acids, peroxide value, and phosphorus contents [60]; [57].

UTILIZATION OF RICE BRAN OIL

RBO is widely used in food, pharmaceutical and chemical industry because of its unique properties and high medicinal value [11]. The desirable health benefits and functional attribute of cold pressed of RBO make it useful for foods, cosmetics and pharmaceutical [3]. There is an increasing interest in the use of RBO in a wide variety of health products because of consumer's demand for natural products [61]. It is a healthy source of PUFA (polyunsaturated fatty acid) which give a potential nutraceutical properties.

Recently, several nanoencapsulation and microencapsulation studies of RBO both in food and pharmaceuticals has been conducted to increase its stability and control release of the bioactive compounds in RBO [62]; [63]. The uses of RBO are discussed here in terms of food, pharmaceutical, cosmetics, feed and other uses.

1. Food uses

RBO is used extensively as a premium edible oil in many Asian counties like Japan, Korea, China, Taiwan and Thailand. In Japan, it is popularly known as 'Heart Oil' [1]; [64]. It is generally considered as the highest quality vegetable oil for cooking in terms of its fatty acid profile, cooking quality and shelf life [65]; [66]. It is more stable at higher temperature, gives better taste and flavour to foods. When use for frying, takes less time and food absorbed 15% less oil leading to its economy [67]. The RBO has very high smoke point of 254°C and mild flavour, making it suitable for high temperature cooking such as deep frying and stir frying [68].

The oil is currently used commercially in snacks food industries and restaurants due to its stability at high cooking temperatures and better flavour characteristics. About one-thirds of all Japanese restaurants in US have shifted to the RBO in the last decades [68].

Efforts have been made to use RBO as an alternative shortening for bakery products. A replacement of conventional shortening with up to 50% RBO was found to give superior quality bread in terms of baking and organoleptic properties [65]. The RBO was reported to be used as a healthy fat alternative in Shrikhand (sweetened concentrated curd) premix with better organoleptic acceptability [69]. It was also reported to be used as replacement for bakery shortening in bread preparation [65]; muffins [70] and mayonnaise and salad dressing [71].

2. Cosmetics uses

RBO is growing much stronger for specialty ingredients in the cosmetic or personal care market. In cosmetics industry, it is used to produce sunscreen lotions, nail polishes, lipsticks and hair conditioners [72]. This is because of its γ-oryzanol content that acts as protective agent against the lipid peroxidation cause by UV light, and the ferulic acid and its esters present in the γ-oryzanol also stimulates hair growth and prevent aging [73]. The γ-oryzanol concentration of 1-2% w/w can serve as natural antioxidants in protecting skin from free radicals [62]. The squalene and tocotrienols in the RBO are important for skin softening and repair [24]. The undiluted form of RBO was reported to be safe cosmetic ingredient [74]. In an *in vivo* assessment of nanoemulsions developed using 10% RBO, it was found to have good potential for use in cosmetic products due to its improved skin moisture, low irritation potential, and maintained normal skin pH when applied to human skin [73]. An encapsulated RBO in solid lipid nanoparticle (SLN) (1.28% w/w RBO) has shown a higher skin hydration than a cream base when applied for 7, 14, and 28 days. The skin viscoelasticity has also increased significantly in a range of 4-5% for 7, 14 and 28 days [62]. However, the information regarding the application of RBO as active ingredients for cosmetic formulation has been limited [62].

3. Pharmaceutical uses

RBO was found to be in used in pharmaceutical, food and chemical industries because of its unique properties and medicinal values [11]. The significant level of its micronutrients make it unique and suitable for use in nutraceutical and pharmaceutical products [19]; [34]; [75]. The RBO is used as supplement for body builders and athletes for muscle developments [1]. Studies have shown that administration of RBO to both human and animals lowers the cholesterol level to an appreciable level. Consumption of diet containing RBO was also found to lower LDL cholesterol by 7%. This activity was believed to be as a result of γ-oryzanol present [3]; [76]. The tocols (tocopherols and tocotrienols) present in RBO possess antioxidants and anti-tumor properties [3]. It was reported that RBO can reduce the risk of low density lipoprotein (LDP) which is a bad cholesterol by about 6-75% [73]; [77]. It was also reported to reduce bad cholesterol (LDL) by 3-10% [24] and have anti-inflammatory properties in several rodents, primate and human models. In an animal's study in which hamsters were treated with RBO, an early atherosclerosis was found to be reduced by 48% with refine RBO relative to canola and coconut oil [78].

4. Feed and other uses

The soapstock and deoiled RBO were reported to be used as animal feed [79]. Unprocessed gum obtained during degumming are also added to animal meals and pellets to increase their nutritive value [80] or used as emulsifier in many industries [81].

The RBO have been used for the extraction of γ-oryzanol, tocopherol and tocotrienols for nutraceutical applications [3]; [21]; [28]; [37]. A high amount of γ-oryzanol can be separated from soapstock by-product of RBO processing [81]. The soapstock is also used as a source of glycerides containing mono- and diglycerides that are used as emulsifiers in food, pharmaceuticals and cosmetic industries [75]; [35]. A food grade wax have can also be extracted from RBO [3].

CONCLUSION

Rice bran is the raw material used for the production of RBO which accounts to about 8.0 % of the total milled rice. The RBO is extracted from the bran through various existing methods, and many more are continuously investigated. However, methods like subcritical water extraction has not yet been sufficiently investigated for RBO extraction. The phytochemicals content of the RBO are highly associated with its health benefits, which then leads a high demand for its extraction and application in various products. The by-product of the RBO refining are also used for many purposes such as extraction of the bioactive components present, lecithin, etc. There is also a growing interest in encapsulation technology to protect the bioactive compounds in the RBO in cosmetics and pharmaceutical products from the thermal degradation during processing and increase its stability and control release. However, the application in other industries like biodiesel has not been fully successful and well recognized because of the economic reasons.

REFERENCES

1. Nayik, A.G., Majid, I., Gull, A., and Muzaffar, K. 2015. Rice bran oil, the future edible oil of India: A mini Review. Rice Research: Open Access. 3(4): 4–6.
2. Dunford, N.T., and King, J.W. 2000. Phytosterol enrichment of rice bran oil by a supercritical carbon dioxide fractionation technique. Journal of Food Science. 65(8): 1395–1399
3. Ju, Y.H., and Vali, S.R. 2005. Rice bran oil as a potential resource for biodiesel: A review. Journal of Scientific and Industrial Research. 64(11): 866 –882.
4. Marshall, W.E., & Wadsworth, J.I. 1993. Rice Science and Technology. Taylor & Francis. Retrieved from https://books.google.co.th/books?id=O- 9VHHMAVAoC
5. Chatha, S.A.S., Hussain, A.I., Zubair, M., and Khosa, M.K. 2011. Analytical characterization of rice (*oryza sativa*) bran and bran oil from different agro-

ecological regions. Pakistan Journal of Agricultural Sciences. 48(3): 243–249.

6. Loypimai, P., Moongngarm, A., and Chottanom, P. 2015. Impact of stabilization and extraction methods on chemical quality and bioactive compounds of rice bran oil. Emirates Journal of Food and Agriculture. 27(11): 849–856.
7. Lakkakula, N.R., Lima, M., and Walker, T. 2004. Rice bran stabilization and rice bran oil extraction using ohmic heating. Bioresource Technology. 92(2): 157–161.
8. Matouk A.M., El-Kholy, M.M., El-Sadany, M. and Hendawy, Y.T. 2009. Rice bran oil extraction using an expeller machine. Misr Journal of Agricultural Engineering. 26(1): 324–342.
9. Huang, W.W., Wang, W., Li, J. lie, and Li, Z.H. 2013. Study on the preparation process of rice bran oil by the ultrasonic enzymatic extraction. Advance Journal of Food Science and Technology. 5(2): 213–216.
10. Sayasoonthorn, S., Kaewrueng, S., and Patharasathapornkul, P. 2012. Rice bran oil extraction by screw press method: Optimum operating settings, oil extraction level and press cake appearance. Rice Science. 19(1): 75–78.
11. Amarasinghe, B.M.W.P.K., Kumarasiri, M.P.M., and Gangodavilage, N.C. 2009. Effect of method of stabilization on aqueous extraction of rice bran oil. Food and Bioproducts Processing. 87(2): 108–114.
12. Uquiche, E., Jerez, M., and Ortiz, J. 2008. Effect of pretreatment with microwaves on mechanical extraction yield and quality of vegetable oil from Chilean hazelnuts (*Gevuina avellana Mol*). Innovative Food Science and Emerging Technologies. 9(4): 495–500.
13. Khoei, M., and Chekin, F. 2016. The ultrasound-assisted aqueous extraction of rice bran oil. Food Chemistry. 194: 503–507.
14. Soares, J.F., Dal Prá, V., De Souza, M., Lunelli, F.C., Abaide, E., Da Silva, J.R.F., Kuhn, R.C.; Martinez, J., and Mazutti, M.A. 2016. Extraction of rice bran oil using supercritical CO_2 and compressed liquefied petroleum gas. Journal of Food Engineering, 170: 58–63.
15. Krishnan, VCA., Kuriakose S, and Rawson, A. 2015. Ultrasound assisted extraction of oil from rice bran: A response surface methodology approach. Journal of Food Processing & Technology. 6(6): 454.
16. Pourali, O., Salak Asghari, F., and Yoshida, H. 2009. Simultaneous rice bran oil stabilization and extraction using sub-critical water medium. Journal of Food Engineering. 95(3): 510–516.
17. Zigoneanu, I.G., Williams, L., Xu, Z., and Sabliov, C.M. 2008. Determination of antioxidant components in rice bran oil extracted by microwave-assisted method. Bioresource Technology. 99(11): 4910–4918.
18. Chia, S.L., Boo, H.C., Muhamad, K., Sulaiman, R., Umanan, F., and Chong, G.H. 2015. Effect of

subcritical carbon dioxide extraction and bran stabilization methods on rice bran oil. Journal of the American Oil Chemists' Society. 92(3): 393–402.

19. Liu, H.M., Wang, F.Y., Li, H.Y., Wang, X.D.M and Qin, G.Y. 2015. Subcritical butane and propane extraction of oil from rice bran. Bioresources. 10(3): 4652–4662.
20. Pourali, O., Asghari, F.S., Yoshida, H. and Francisco, S. 2009b. A rapid and ecofriendlytreatment Technique for rice bran oil stabilization and extraction under sub-critical water condition. Proceeding of the World Congress on Engineering and Computer Science, October, I, 20–22, San Francisco, USA.
21. Xu, Z. and Godber, J.S. 2000. Comparison of supercritical fluid and solvent extraction methods in extracting γ-oryzanol from rice bran. Journal of the American Oil Chemists' Society. 77(5): 547–551.
22. Oliveira, R., Oliveira, V., Aracava, K.K., and Rodrigues, C.E.D.C. 2012. Effects of the extraction conditions on the yield and composition of rice bran oil extracted with ethanol - A response surface approach. Food and Bioproducts Processing. 90(1): 22–31.
23. Sparks, D., Hernandez, R., Zappi, M., Blackwell, D. and Fleming, T. 2006. Extraction of rice bran oil using supercritical carbon dioxide and propane. Journal of the American Oil Chemists' Society. 83(10): 10–16.
24. Patel, M., and Naik, S.N. 2004. Gamma-oryzanol from rice bran oil - A review. Journal of Scientific and Industrial Research. 63(7): 569–578.
25. Hu, W., Wells, J.H., Shin, T.S., and Godber, J.S. 1996. Comparison of isopropanol and hexane for extraction of vitamin E and oryzanols from stabilized rice bran. Journal of the American Oil Chemists' Society. 73(12): 1653–1656.
26. Arisanu, A.O. 2013. Mechanical continuous oil expression from oilseeds: Oil yield and press capacity. 5TH International Conference of Computational Mechanics and Virtual Engineering, pp. 347–352. October 24-25, 2013, Braşov, Romania.
27. Liu, S.X., and Mamidipally, P.K. 2005. Quality comparison of rice bran oil extracted with d-limonene and hexane. Cereal Chemistry. 82(2): 209–215.
28. Balachandran, C., Mayamol, P.N., Thomas, S., Sukumar, D., Sundaresan, A., and Arumughan, C. 2008. An ecofriendly approach to process rice bran for high quality rice bran oil using supercritical carbon dioxide for nutraceutical applications. Bioresource Technology. 99(8): 2905–2912.
29. Thanonkaew, A., Wongyai, S., Decker, E.A., and McClements, D.J. 2015. Formation, antioxidant property and oxidative stability of cold pressed rice bran oil emulsion. Journal of Food Science and Technology.

52(10): 6520– 6528.

30. Omobuwajo, T.O., Ige, M.T., and Ajayi, A.O. 1998. Theoretical prediction of extrusion pressure and oil flow rate during screw expeller processing of palm kernel seeds. Journal of Food Engineering. 38(4): 469–485.
31. Nakagawa, K. 1983. Apparatus for pretreatment for extracing crude oil from rice bran. United States Patent. 4,384,837. p.1-8.
32. Topare, N.S., Raut, S.J., Renge, V.C., Khedkar, S.V., Chavan, Y.P., and Bhagat, S.L. 2011. Extraction of oil from algae by solvent extraction and oil expeller method. International Journal of Chemical Sciences. 9(4): 1746–1750.
33. Dutta, R., Sarkar, U., and Mukherjee, A. 2015. Soxhlet extraction of Crotalaria Juncea oil using cylindrical and annular packed beds. International Journal of Chemical Engineering and Applications. 6(2): 130–133.
34. Al-Okbi, S.Y., Mohamed, D.A., Hamed, T.E., and Esmail, R.S.H. 2014. Rice bran oil and pumpkin seed oil alleviate oxidative injury and fatty liver in rats fed high fructose diet. Polish Journal of Food and Nutrition Sciences. 64(2): 127–133.
35. Zaccheria, F., Mariani, M., and Ravasio, N. 2015. The use of rice bran oil within a biorefinery concept. Chemical and Biological Technologies in Agriculture. 2(1): 23.
36. Aji, M.M., Gutti, B., Highina, B.K., and Kyari, S.A. 2015. Soxhlet extraction and characterization of oil from Schweinfurthii (Black Date) fruits for domestic purpose. Applied Research Journal. 1(2): 41–45.
37. Imsanguan, P., Roaysubtawee, A., Borirak, R., Pongamphai, S., Douglas, S., and Douglas, P. L. 2008. Extraction of α-tocopherol and γ-oryzanol from rice bran. LWT - Food Science and Technology. 41(8): 1417–1424.
38. Miguel Herrero, Alejandro Cifuentes, E.I. 2006. Sub- and supercritical fluid extraction of functional ingredients from different natural sources: plants, food-by-products, algae and microalgae: A review. Food Chemistry. 98 (1): 136–148.
39. Sohail, M., Rakha, A., Butt, M.S., Iqbal, M.J., and Rashid, S. 2016. Rice bran nutraceutics: A comprehensive review. Critical Reviews in Food Science and Nutrition. 57(17): 3771–3780.
40. Straccia, M.C., Siano, F., Coppola, R., La Cara, F., and Volpe, M.G. 2012. Extraction and characterization of vegetable oils from cherry seed by different extraction processes. Chemical Engineering Transactions. 27: 391–396.
41. Sarmento, C.M.P., Ferreira, S.R.S., and Hense, H. 2006. Supercritical fluid extraction (SFE) of rice bran oil to obtain fractions enriched with tocopherols and tocotrienols. Brazilian Journal of Chemical Engineering. 23(2): 243–249.
42. Kuk, M. S., & Dowd, M. K. (1998). Supercritical CO_2 extraction of rice bran. Journal of the American Oil Chemists' Society. 75(5): 623–628.
43. Liang, X., and Fan, Q. 2013.

Application of sub- critical water extraction in pharmaceutical industry. Journal of Materials Science and Chemical Engineering. 1: 1–6.

44. Miao, J., Che, K., Xi, R., He, L., Chen, X., Guan, X., Zhuang, X., Wen, X. and Cao, Y. 2013. Characterization and Benzo[a]pyrene content analysis of camellia seed oil extracted by a novel subcritical fluid extraction. Journal of the American Oil Chemists' Society. 90(10): 1503–1508.
45. Liu, Z., Mei, L., Wang, Q., Shao, Y., and Tao, Y. 2014. Optimization of subcritical fluid extraction of seed oil from *Nitraria tangutorum* using response surface methodology. LWT - Food Science and Technology. 56(1): 168–174.
46. Chiou, T.Y., Neoh, T.L., Kobayashi, T., and Adachi, S. 2011. Antioxidative ability of defatted rice bran extract obtained by subcritical water extraction in bulk oil and aqueous dispersion systems. Japan Journal of Food Engineering. 12(4): 147–154.
47. Yoshida, H., Izhar, S., Nishio, E., Utsumi, Y., Kakimori, N., and Asghari Feridoun, S. 2014. Recovery of indium from TFT and CF glasses in LCD panel wastes using sub-critical water. Solar Energy Materials and Solar Cells. 125: 14–19.
48. Tahir, A.S I.T.M. 2015. Sub-critical water as a green solvent for production of valuable materials from agricultural waste biomass : A review of recent work. Global Journal of Environmental Science Management. 1(3): 255–264.
49. Ea, S., and Sardarodiyan, M. 2016. Biochemistry : An Indian Journal Bioactive Phytochemicals in Rice Bran : Processing and Functional Properties. 10(3): 1–10.
50. Yoswathana, N., and Eshtiaghi, M.N. 2013. Optimization for subcritical water extraction of phenolic compounds from Rambutan peels. World Academy of Science, Engineering and Technology. 7(6): 122–126.
51. Nandi, S. and Bhattacharyya, R. 2015. A parametric study for the enzymatic extraction of rice bran oil and its optimization. International Journal on Recent and Innovation Trends in Computing and Communication. (2): 21–25.
52. Cater, C.M., Rhee, K.C., Hagenmaier, R.D., and Mattil, K.F. 1974. Aqueous extraction-An alternative oilseed milling process. Journal of the American Oil Chemists Society. 51(4): 137–141.
53. Seung Ho, K.I.M. 1989. Aqueous extraction of oil from palm kernel. Journal of Food Science. 54(2): 491– 492.
54. Fang, X., and Moreau, R.A. 2014. Extraction and demulsification of oil from wheat germ, barley germ, and rice bran using an aqueous enzymatic method. Journal of the American Oil Chemists' Society. 91(7): 1261–1268.
55. Moreau, R.A., Dickey, L.C., Johnston, D.B., and Hicks, K.B. 2009. A process for the aqueous

enzymatic extraction of corn oil from dry milled corn germ and enzymatic wet milled corn germ (E-Germ). Journal of the American Oil Chemists' Society. 86(5): 469–474.

56. Campbell, K.A., and Glatz, C.E. 2010. Protein recovery from enzyme-assisted aqueous extraction of soybean. Biotechnology Progress. 26(2): 488–495.
57. Zhang, S.B., Lu, Q.Y., Yang, H., Li, Y., and Wang, S. 2011. Aqueous enzymatic extraction of oil and protein hydrolysates from roasted peanut seeds. Journal of the American Oil Chemists' Society. 88(5): 727–732.
58. Latif, S., and Anwar, F. 2009. Effect of aqueous enzymatic processes on sunflower oil quality. Journal of the American Oil Chemists' Society. 86(4): 393–400.
59. Hernandez, N., Rodriguez-Alegría, M.E., Gonzalez, F., and Lopez-Munguia, A. 2000. Enzymatic treatment of rice bran to improve processing. Journal of the American Oil Chemists' Society. 77(2): 177–180.
60. Sharma, A., Khare, S.K., and Gupta, M.N. 2001. Enzyme-assisted aqueous extraction of rice bran oil. Journal of the American Oil Chemists' Society. 78(9): 949–951.
61. Dominguez, H., Nlikz, M.J., and Lema, J.M. 1995. Aqueous processing of sunflower kernels with enzymatic technology. Food Chemistry. 53(4): 427–434.
62. Moreau, R.A., Kamal-Elddin, A. 2008. Introduction. In: Moreau RA, Kamal-Elddin A (eds) Gourmet and health-promoting specialty oils. Association of Chemical Society Press, Illinois, pp 1–32.
63. Yingngam, B., Phimpanit, Y., Wongkasemchai, N., Sila-On, W., and Rungseevijitprapa, W. 2008. Encapsulation of rice bran oil in solid lipid nanoparticles (SLN) for skin hydration and viscoelasticity. International Journal of Pharmaceutical Science. 3(2): 9-22.
64. Rigo, L.A., Da Silva, C.R., De Oliveira, S.M., Cabreira, T.N., Da Silva, C.B., Ferreira, J., and Beck, R.C.R. 2015. Nanoencapsulation of rice bran oil increases its protective effects against UVB radiation-induced skin injury in mice. European Journal of Pharmaceutics and Biopharmaceutics. 93(November): 11–17.
65. Orthoefer, F.T. 2005. Rice bran oil. Bailey's industrial oil and fat products. 2(7): 465–489.
66. Kaur, A., Jassal, V., Thind, S.S., and Aggarwal, P. 2012. Rice bran oil an alternate bakery shortening. Journal of Food Science and Technology. 49(1):110–114.
67. Fan, H.Y., Sharifudin, M.S., Hasmadi, M., and Chew, H.M. 2013. Frying stability of rice bran oil and palm olein. International Food Research Journal. 20(1): 403–407.
68. Sharma A. R. 2002. Edible rice bran oil consumer awareness programme. Rice bran oil promotion committee. Solvent Extractors Association of India, Mumbai.
69. Domis, G. 2003. Health benefits strengthen rice bran oil use. Chemical Market Reporter, 263(19): ABI/INFORM

Collection p.c12.

70. Gupta, S., and Ghosh, M. 2015. Formulation development and process parameter optimization of lipid nanoemulsions using an alginate-protein stabilizer. Journal of Food Science and Technology. 52(5): 2544–2557.
71. Kaur, A. Jassal, V., and Bhise, S.R. 2014. Replacemnt of bakery shortening with rice bran oil in the preparation of muffins. African Journal of Biochemistry Research. 8(7): 141–146
72. Swern, O. 1972. Bailey's industrial oil and fat products. 3rd ed. International Science Publication Technology. p. 196-225.
73. Bernardi, D.S., Pereira, T.A., Maciel, N.R., Bortoloto, J., Viera, G.S., Oliveira, G.C., and Rocha-Filho, P.A. 2011. Formation and stability of oil-in- water nanoemulsions containing rice bran oil: in vitro and in vivo assessments. Journal of Nanobiotechnology. 9: 44.
74. Nagendra Prasad MN, N.P., Kr, S., and Khatokar M.S. 2011. Health Benefits of Rice Bran - A Review. Journal of Nutrition & Food Sciences. 1(3): 1–7.
75. Cosmetic Ingredient Review Expert Panel. 2006. Amended final report on the safety assessment of *oryza sativa* (Rice) bran oil, *Oryza Sativa* (Rice) germ oil, rice bran acid, *Oryza Sativa* (Rice) bran wax, hydrogenated rice bran wax, *Oryza Sativa* (Rice) bran extract, *Oryza Sativa* (Rice) extract, Oryza Sat. International Journal of Toxicology. 25(2): 91–120.
76. Sharma, R., Srivastava, T., and Saxena, D.C. 2015. Studies on Rice Bran and its benefits-A Review. Journal of Engineering Research and Applications. 5(5). 107–112.
77. Most, M.M., Tulley, R., Morales, S., and Lefevre, M. 2005. Rice bran oil, not fiber, lowers cholesterol in humans. American Journal of Clinical Nutrition. 81(1). 64–68.
78. Sugano, M., and Tsuji, E. 1996. Rice bran oil and human health. Biomedical and Environmental Sciences. 9 (2–3): 242–246.
79. Kaewboonnum, W., Wachararuji, K., and Shotipruk, A. 2005. Value added products from by-products of rice bran oil processing. Chiang Mai Journal of Science. 35(1): 2–3.
80. Ceci, L.N., Constenla, D.T., and Crapiste, G.H. 2008. Oil recovery and lecithin production using water degumming sludge of crude soybean oils. Journal of the Science of Food and Agriculture. 88(14): 2460–2466.
81. Narayan, A.V., Barhate, R.S., and Raghavarao, K.S.M.S. 2006. Extraction and purification of oryzanol from rice bran oil and rice bran oil soapstock. Journal of the American Oil Chemists' Society. 83(8): 663–670.