

Research Article

Physico-chemical Properties and Fatty Acid Profile of Black Rice Bran Oil Extract (*Oryza sativa* L. 'Sembada Hitam')

Fifiola Aditya Ponkiyawati¹, Azzahra Mewa Kurnia¹, Zahara Indah Aulia¹, Lisna Hidayati¹, Yekti Asih Purwestri^{1,2*}

¹)Faculty of Biology, Universitas Gadjah Mada, Jl. Teknik Selatan, Sekip Utara, Yogyakarta 55281, Indonesia

²)Research Center for Biotechnology, Universitas Gadjah Mada

* Corresponding author, email: yekti@ugm.ac.id

Keywords:

Black rice
Characterization
Fatty acid
RBO
Rice Bran
Sembada Hitam

Submitted:

26 June 2023

Accepted:

25 April 2025

Published:

15 August 2025

Editors:

Miftahul Ilmi
Annisa Widayarsi

ABSTRACT

The current study highlights black rice as a nutrient-rich grain with functional properties, emphasising its relevance in advancing dietary strategies for health improvement. As a functional food, black rice contains various bioactive compounds, including anthocyanins, tocopherols, oryzanol, and essential oils, which are primarily concentrated in the bran layer of the grain. Black rice bran can be utilized as a source of rice bran oil (RBO), which enriched with nutrients, essential oils and antioxidant compounds. However, the RBO industry in Indonesia remains limited, partly due to a lack of comprehensive information on the properties of black RBO. This research aims to characterise the physico-chemical properties and fatty acid profile of black rice bran oil (*Oryza sativa* L. 'Black Sembada'), a local black rice cultivars widely cultivated in Sleman, Yogyakarta. The characterisation of RBO includes measurement of density, yield, water content, acid value, saponification value and peroxide value. Fatty acid profiles were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS). The results showed that the yield of Sembada Hitam RBO ranged from 11.537-28.887 % with a water content 0.017-0.49 %, density between 0.920-1.027 g mL⁻¹, acid value 79.203-86.427 mgKOH g⁻¹, saponification value 167.450-199.723 mg KOH g⁻¹ and peroxide value 5.953-118.233 mEq kg⁻¹. The fatty acid profile was dominated by palmitic acid (14.58 %), oleic acid (43.44 %), linoleic acid (37.52 %), and stearic acid (2.08 %).

Copyright: © 2025, J. Tropical Biodiversity Biotechnology (CC BY-SA 4.0)

How to cite:

Ponkiyawati, F.A. et al., 2025. Physico-chemical Properties and Fatty Acid Profile of Black Rice Bran Oil Extract (*Oryza sativa* L. 'Sembada Hitam'). *Journal of Tropical Biodiversity and Biotechnology*, 10(3), jtbb23808. doi: 10.22146/jtbb.23808

INTRODUCTION

Indonesia is the third-largest rice producer in Asia (Food and Agriculture Organization 2015), highlighting the country's abundance of rice crops and potential for rice-based agricultural development. According to the Ministry of Agriculture (2020), the agricultural sector, particularly food crop commodities, plays a vital role in supporting the livelihoods of the Indonesian population by ensuring economic stability and national food security. In light of this, it is important to explore innovative and sustainable diversification of rice-based products, one of which is the production of black rice bran oil.

Black rice is a unique variety distinguished by its high anthocyanin contents in the aleurone layer, in contrast to white rice and red rice (Hou et al. 2013). The content of macro and micronutrients such as protein, carbohydrates, vitamins, minerals (Zn, P, Mn, and Fe) is reported to be higher than that of commonly consumed white rice (Ichikawa et al. 2004; Kristantini et al. 2012; Apridamayanti et al. 2017). As a functional food, black rice contains a diverse range of bioactive compounds, including several flavonoids (anthocyanins, tannins, polyphenols), oryzanol, sterols, tocopherols, amino acids, and essential oils which are predominantly concentrated in the bran (Kristantini & Purwaningsih 2009; Deng et al. 2013; Banjerdpongchai et al. 2013). These bioactive compounds exhibit antioxidants, anticancer, and anti-inflammatory properties, and they contribute to the maintenance of healthy cholesterol levels in animal models (Tsuda et al. 2003; Hyun & Chung 2004; Park et al. 2008). Rice bran typically contains 18–22 % oil, which is rich in bioactive compounds such as oryzanol, policosanols, phytic acid, phytosterols, ferulic acid, tocotrienols, squalene, and inositol hexaphosphate (Khatoon & Gopalakrishna 2004; Ardiansyah et al. 2006; Saikia & Deka 2011).

Black rice bran, therefore serves as a valuable source for producing rice bran oil (RBO) which enriched with nutrients, essential oils and antioxidant properties. Studies have shown that dietary intake of unsaturated fatty acids from vegetable oils plays a protective role against chronic diseases such as heart disease, cancer, type 2 diabetes and hypertension (Caterina et al. 2000; Abedi & Sahari 2014). Additionally, RBO consumption is known to help lower LDL (Low Density Lipoprotein) cholesterol due to its beneficial fatty acid composition (Wilson et al. 2000). The development of black rice bran oil production is essential for obtaining high quality vegetable oil while also promoting the diversification of rice-based products to maximize the potential of Indonesia's rice agricultural sector. Despite its potential, industrial development of rice bran oil in Indonesia is still in its early stages and has not been widely optimised (Etiasih et al. 2021). The application of black rice bran oil in the industrial sector requires reliable scientific data, particularly regarding its physico-chemical properties and fatty acid profile. Such data are critical for authenticating black RBO, ensuring product quality and safety, and supporting its optimal utilization. Physico-chemical characterisation provides specific information on the identity and quality of RBO, including measurements of viscosity, specific gravity, odor, and visual color. Meanwhile, chemical properties such as acid value, saponification value, peroxide value, and fatty acid composition are essential indicators of oil quality (Rohman & Windarsih 2018). The limited information on the nutritional and chemical characteristics of black rice bran oil has constrained its utilization, emphasizing the need for further research.

In response to this need, the present study aimed to characterize the physico-chemical properties and fatty acid profile of *Oryza sativa* L. 'Black Sembada' rice bran oil, a locally cultivated black rice variety originating from Sleman, Yogyakarta.

MATERIALS AND METHODS

Materials

The materials used in this research included black rice (*Oryza sativa* L.'Sembada Hitam'), collected from a rice farming area in Pakem, Sleman, Yogyakarta. Additional chemicals and reagents used in the extraction and characterisation processes were n-hexane, methanol, seal, aluminium foil, distilled water, oxalic acid, KOH, phenolphthalein, 96% ethanol, HCl, potassium dichromate, Na₂S₂O₃, chloroform, glacial acetic acid, starch, and KI.

Methods

Sample preparation

Black rice (*Oryza sativa* L. 'Sembada Hitam') was collected from Pakem, Sleman, Yogyakarta. The grains (250g) were milled using rice whitener (Satake) for 30 seconds to remove the outer black layer, producing white (polished) rice. The removed black layer was collected as black rice bran. Prior to oil extraction, the rice bran was stabilized by drying 100 g of the sample in an oven (Memmert) at 105 °C for 10 minutes. This step was performed to inactivate lipase enzymes and prevent rancidity during oil extraction.

Bran Oil Extraction

Rice bran oil extracted using a Soxhlet extractor (Iwaki Soxh-Set-200) with n-hexane and methanol as solvents at a bran-to-solvent ratio of 1:3. Extraction was performed at 65–70 °C for 8 hours with 10 cycles. The solvent was then evaporated using a rotary vacuum evaporator (40 °C, 22 in Hg) until no more solvent dripped. The crude extract was stored in a fume cupboard for 1–3 days to ensure complete evaporation of residual solvent.

Physico-chemical Characterisation and Fatty Acid Profile of Oil Extract

The physical characteristics of the oil can be determined by determining the viscosity, specific gravity, odour, and visual colour produced. The chemical character can be done by determining the acid value, saponification value, peroxide value and fatty acid profile. Fatty acid profile of black rice bran oil was analysed by Gas Chromatography-Mass Spectrometry (GCMS-QP2010S SHIMADZU). The oil samples were esterified prior to injection at a column oven temperature of 70 °C, injection temperature of 300 °C, with split injection mode and pressure of 17.8 kPa with a linear velocity of 26.9 cm sec⁻¹. Total flow 33.0 mL min⁻¹ and column flow 0.54 mL min⁻¹. Purge flow 3.5 mL min⁻¹ with split ratio 54.0. The MS data were then analysed to determine the identity of the target compounds being read. Name identification of fatty acid compound in the extract is done by comparing the mass spectra and retention time of the target compound with the standard of each fatty acid in Library. Physico-chemical characters of crude rice bran oil were determined according to SNI 01-3555-1998 (BSN n.d.). Physico-chemical characterisation obtained from testing the acid, saponification, and peroxide value by the titration method were analysed volumetrically.

Data analysis

Physico-chemical characterization data obtained from testing the acid number, saponification number, peroxide number, yield, water content, and density with three repetitions of measurements were analysed by SPSS. The data obtained is averaged for each group and the values are compared with other treatment groups. T-Test was used to statistically examine group mean differences in order to determine whether treatment effects were significant. The aim of statistical tests in this research is to compare and to see significant differences in results for each treatment.

RESULTS AND DISCUSSION

Yield

CRBO from Sembada Hitam rice bran was isolated through an extraction process involving the use of n-hexane and methanol which are shown in Figure 1, with 83.33 grams of dry sample produced an average yield for about 24.47 grams with methanol solvent and 9.62 grams with n-hexane solvent. Figure 2. show that methanol produced higher yield of CRBO than n-hexane for about 28 % and 11 % respectively.

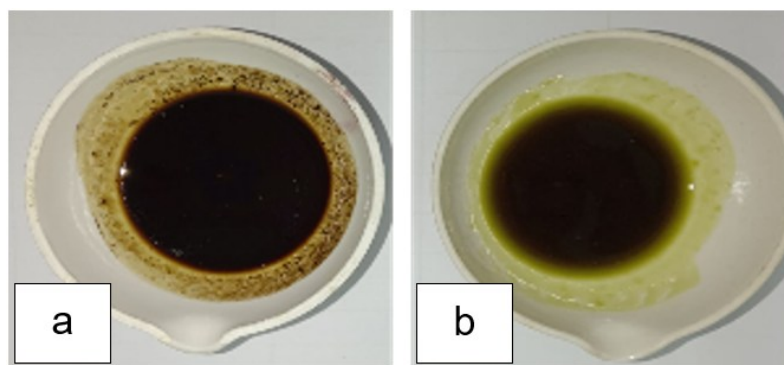


Figure 1. Sembada Hitam rice bran oil extracted by methanol (a) Sembada Hitam rice bran oil extracted by n-hexane (b).

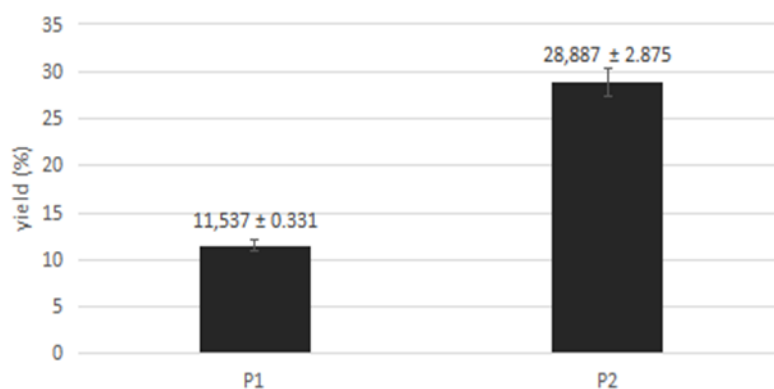


Figure 2. CRBO from Sembada Hitam rice extracted using different solvent extraction; P1: is crude RBO with N-hexane solvent, P2: is crude RBO with methanol solvent. Bars labelled with different letters indicate statistically significant differences in the retained percentage ($p \leq 0.05$).

Physico-chemical properties

The colour characteristic observed in the CRBO sample produced in this research is shown at Figure 1. One of the most important characteristics from visualisation of RBO is colour. In this research, it was found that both n-hexane extract and methanol extract RBO samples gave different colours. The colour of the n-hexane extract of bran oil is dark green while the methanol extract of bran oil tends to be dark purple. This is caused by the dominance of the extracted pigments by different solvents in the two samples. Chlorophyll pigments are thought to be mostly extracted in crude oil with n-hexane solvent. Richmond (2008) revealed that chlorophyll is a green pigment in plants that is non-polar and can dissolve in nonpolar solvents, making it possible that the n-hexane extract of bran oil has a greenish colour. While the methanol extract of rice bran oil has a purplish colour, this is presumably due to the dominating content of the extracted anthocyanin pigments. Anthocyanins are compounds belonging to the class of flavonoids and are polar in nature (Tarone et al. 2020). For density, water content, saponification value, acid value, and peroxide value the results are show in table 1.

Table 1. Physico-chemicals of CRBO from Sembada Hitam.

Parameters	CRBO		CODEX Standard*
	P1	P2	
Density	0.920 ± 0.0000	1.027 ± 0.0003	0.881 - 0.927 g mL ⁻¹
Water Content	0.017-0.0003	0.49 ± 0.2081	0.2 %
Acid Value (AV)	79.203 ± 0.1114	86.427 ± 0.3245	6 mg KOH g ⁻¹
Saponification Value (SV)	167.450 ± 0.2800	199.723 ± 11.0778	168-265 mg KOH g ⁻¹
Peroxide Value (PV)	5.953 ± 0.0634	118.233 ± 0.6333	15 mEq kg ⁻¹ oil

P1: N-hexane solvent; P2: methanol solvent; *: Codex Standard for Named Vegetable Oils (CXS 210-1999) Amend-
ed 2019 (FAO 2019)

The physical attributes oil, as revealed by density measurement, which are influenced by the structures of its triglyceride molecules-specifically, the degree of unsaturation and the length of their hydrocarbon chains. An increase in the oil's saturations level leads to a reduction in its density (Rahmani 2008). The water content can determine the quality of an oil. The high amount of water acts as catalyst for the hydrolysis reaction of oil/fat into free fatty acids, glycerol, and hydroperoxides which can cause rancidity in the oil (Maulidna et al. 2019). The Acid Value (AV) formed as a result of hydrolysis of triglycerides into glycerol and FFA by lipase activity, leads to an enhancement in the acid value following the milling process. The conversion of triglycerides into FFA and glycerol due to the hydrolysis oil/fat reaction causes an increase in the AV the oil/fat. So, AV can show how much Free Fatty Acid (FFA) is in the oil. Determination of the AV in the oil is important for detecting the level of free fatty acids in the sample to determine the quality of the sample oil (Desta et al. 2020). A higher saponification (SA) suggests the presence of short-chain fatty acids on the glycerol backbone in a sample, while a lower saponification indicates the presence of triacylglycerols with a longer fatty acyl chain. Therefore, AV determination can be used to identify the length of the fatty acid chain of a particular fat/oil (Ivanova et al. 2022). The density and water content of the crude oils were 0.920–1.027 g mL⁻¹ and 0.0167–0.49 %, respectively. The substitution of solvent given different physico-characters of CRBO. In this study, it was observed that oil with n-hexane solvent had a lower density number compared to rice bran oil with methanol. The difference in the density of n-hexane and methanol solvent oils is probably due to impurities such as phosphatides, waxes, esters, and high amounts of unsaponified compounds that are also extracted by methanol solvent (Susanti et al. 2012). Besides being able to extract polar components, methanol can also extract nonpolar components. Santoso et al. (2020) and Susanti et al. (2012) carried out research with similar methodologist using n-hexane and methanol solvent. The result obtained a density of rice bran oil of 0.885–0.98 g mL⁻¹. The lower amount of polyunsaturated fatty acids from the rice bran oil extract in the sample probably caused the oil density to be higher than the results of previous studies. Density of the oil will decrease as the degree of unsaturation of the oil increases (Rahmani 2008). As for SNI 0610-1989-A, the allowable density of rice bran oil ranges from 0.910–0.920 g mL⁻¹. Based on the CODEX standards and SNI, samples of oil extract with n-hexane met the requirements, but not oil extract with methanol. The average water content of the extract with n-hexane and methanol were 0.017–0.49 %, respectively. A similar previous study was conducted by Hartono et al. (2017) obtained rice bran oil water content ranging from 0.87 ± 0.06 % to 0.91 ± 0.02 %. The water content affects the quality of the oil, where the higher the water content of an oil the higher the free fatty acid content in it. WHO/FAO defines a maximum water content for edible vegetable oils (edible oil) i.e. 0.2 % (Negash et al. 2019). The presence of high amount of water content will accelerate the hydrolysis reaction of the oil into free fatty acids and hydroperoxides which can cause a rancid odour in the oil (Maulidna et al. 2019). The av-

erage oil acid value of extracts with n-hexane and methanol is 79.203–86.427 mg KOH g⁻¹ respectively. The results are different from previous studies. Based on previous research by Handayani et al. (2020), it has result that the robtained acid value of rice bran oil extract with n-hexane solvent ranged from 67 mg KOH g⁻¹ oil. While the acid value of the rice bran oil extract with methanol was 46.571 mg KOH g⁻¹ of oil (Susanti et al. 2012). The difference in the acid value obtained is probably caused by the difference in the shelf life of the oil samples. Moreover, the storage method is not good and it accelerates the oxidation process of aldehydes and ester hydrolysis so that the acid value increases (Hidayati & Khaerunisa 2018). Based on the analysis of the acid value from the two samples, it was stated that the sample oil exceeded the standard for rice bran oil set by SNI 0610-1989-A, 0.6 mg KOH g⁻¹ of oil and CODEX standards where the maximum acid value of vegetable oil is 0.5 mg KOH g⁻¹ of oil. The acid value in the oil can be reduced through purification steps aimed at removing free fatty acids (Mingyai et al. 2017). The mean saponification value obtained with n-hexane and methanol respectively were 167.450 ± 0.2800 mg KOH g⁻¹ and 199.723 ± 11.0778 mg KOH g⁻¹. From these data, it can be concluded that the methanol extract which is a polar solvent has a greater saponification value than the extract with a nonpolar solvent, n-hexane. A lower value of saponification indicates a long-chain fatty acid on the backbone of glycerol in a sample, and conversely, a higher saponification value indicates a triacylglycerol with a shorter fatty acyl chain (Ivanova et al. 2022). Anwar et al. (2005) previously stated that bran oil has a saponification value of 177 to 190 mg KOH g⁻¹. These results are slightly different from this study. This is possible because of the differences in glycerides (monoacylglycerol, diacylglycerol and triacylglycerol) formed during transesterification in different samples (Hutami & Ayu 2015). The results of the saponification value in this study approached the saponification value of other natural vegetable and animal oils such as rapeseed oil, sunflower oil, soybean oil, beef and chicken fats, where these oils are dominated by long-chain fatty acids such as C18 fatty acid (oleic and linoleic acid) as the main constituents, and modest amount of palmitic acid (C: 16) following small amount of linolenic acid with a saponification value of 168–196 mg KOH g⁻¹ oil (Kampa et al. 2022; Ivanova et al. 2022). In line with the screening results, the fatty acid profile of rice bran oil from previous research showed that the composition of rice bran oil was dominated by oleic, linoleic and palmitic acids (Mingyai et al. 2017). The standard saponification rate for vegetable oils for household use and consumption is in the range of 175–250 mg KOH g⁻¹ of oil (Gunstone et al. 1994 in Olaganju et al. 2022). Based on the results of this study, samples of oil extract with n-hexane and methanol are quite close to these standards. The mean peroxide value obtained using n-hexane and methanol solvents were 5.953 ± 0.0634 mEq kg⁻¹ oil and 118.233 ± 0.6333 mEq kg⁻¹ oil respectively. From these data, it can be concluded that the methanol extract which is a polar solvent has a higher peroxide value than the extract with a nonpolar solvent, n-hexane. Lipid oxidation activity can be evaluated through peroxide value determination. Lipid oxidation negatively affects to the oil/lipid quality. Peroxide value is inversely proportional to sample quality. Thus, peroxide value serves as a critical parameter, where lower values reflect better oil quality (Arlene et al. 2010). Based on the results of this study, it is known that the peroxide value in oil with n-hexane is lower, which can be said that the quality of the oil is better than methanol oil extract. Based on the CODEX standard, only oil samples with n-hexane have been considered to the standards as generally recognised vegetable oils. These results are quite different from the research conducted by Mingyai et al. (2017) obtained the peroxide value of several rice varieties of 2.12 to 2.23 mEq kg⁻¹ of oil and Wang et al. (2022) obtained a peroxide value of crude bran oil of 8.63 ± 0.29 mEq kg⁻¹ oil. This

difference is probably due to the different varieties of rice used and the climate where rice grows (Wang et al. 2022). Then the oil extract with methanol has a very high peroxide value which is possible due to the spontaneous oxidation of unsaturated fatty acids in the oil samples by air and the decomposition of oil/fat by microorganisms due to the high amount of water content both in methanol and sample (Susanti et al. 2012). In addition, this may be influenced by the quality of the raw material (bran) prior to use caused by lipase activity, which deteriorates the bran quality due to prolonged and improper storage conditions even before extraction process.

Fatty acid profile

Table 2 displays the fatty acid composition of the oil sample. There were ten fatty acids found including methyl tetracosanoate (myristic acid), 9-Hexadecenoic acid (palmitoleic acid), Hexadecanoic acid, methyl ester (palmitic acid), 9,12-Octadecadienoic acid, methyl ester (Linoleic acid), 10 - Octadecenoic methyl ester (Oleic acid), Stearic acid methyl ester, Methyl myristate (myristate acid), Methyl elaidate (elaidic acid), Arachidic acid methyl ester, and Methyl behenate (Behenic acid).

Metabolite compounds as the main component of black rice bran oil with an area percentage of more than 1 % are found in fatty acids such as Hexadecanoic acid methyl ester (palmitic acid), 10 - Octadecenoic methyl ester (oleic acid), 9,12-Octadecadienoic acid methyl ester (linoleic acid), and stearic acid. The results of this study are similar to previous research from Mingyai et al. (2017) where the main fatty acids found in black rice bran oil of the Hom-nin variety were palmitic acid (17.87 %), oleic (42.24 %), linoleic (31.43 %), and stearic acid (2.65 %) with a dominance of unsaturated fatty acid over saturated fatty acids. Higher content of unsaturated fatty acids particularly oleic and linoleic acids is considered beneficial for dietary uses due to their recognised role in supporting human health. Oleic acid is reported has ability to reduce LDL cholesterol and lipid levels while promoting an increase in HDL levels in the blood, thus lowering risk of developing cardiovascular disease (Kwon & Choi 2015). Linoleic acid or also called omega-6 is included as an essential oil which is thought to be able to lower serum cholesterol but does not have a significant effect in cardiovascular treatment (Lee et al. 2006).

Table 2. Fatty acid composition of CRBO from Black Rice (*Oryza sativa* L. 'Sembada Hitam').

No	Fatty acid composition	Molecular Formula	Peak Area (%)	Group
1.	Methyl tetracosanoate (Myristic acid)	C ₂₅ H ₅₀ O ₂	0.35	Fatty Acid Methyl ester
2.	Hexadecenoic acid (Palmitoleic acid)	C ₁₇ H ₃₂ O ₂	0.22	Fatty Acid Methyl ester
3.	Hexadecanoic acid, methyl ester (Palmitic acid)	C ₁₆ H ₃₂ O ₂	14.58	Saturated Fatty Acid Methyl ester
4.	9,12-Octadecadienoic acid, methyl ester (Linoleic acid)	C ₁₈ H ₃₂ O ₂	37.52	Unsaturated Fatty Acid Methyl ester
5.	10 - Octadecenoic methyl ester (Oleic acid)	C ₁₈ H ₃₄ O ₂	43.44	Unsaturated Fatty Acid Methyl ester
6.	Stearic acid methyl ester	C ₁₈ H ₃₆ O ₂	2.08	Saturated Fatty Acid Methyl ester
7.	Methyl myristate (myristate acid)	C ₁₅ H ₃₀ O ₂	0.53	Saturated Fatty Acid Methyl ester
8.	Methyl elaidate (elaidic acid)	C ₁₉ H ₃₆ O ₂	0.67	Unsaturated Fatty Acid Methyl ester
9.	Arachidic acid methyl ester	C ₂₁ H ₄₂ O ₂	0.22	Saturated Fatty Acid Methyl ester
10.	Methyl behenate (Behenic acid)	C ₂₃ H ₄₆ O ₂	0.39	Saturated Fatty Acid Methyl ester

Controlling a linoleic acid diet is also thought to have a significant effect on reducing body fat mass and symptoms of rheumatoid arthritis (Vergeer et al. 2010). Many vegetable oils contain saturated fatty acids. A common saturated fatty acid found in vegetable oil and often consumed by humans are palmitic acid and stearic acid. Consumption of saturated fatty acids has a dominant effect on increasing total and LDL cholesterol levels (Müller 2003). However, the effect of stearic acid in increasing blood fat and cholesterol levels and other cardiometabolic risks was not significant, in contrast to palmitic acid which significantly affected blood fat and cholesterol levels (Baer et al. 2003; van Rooijen & Mensink 2020). The effect of increasing blood cholesterol levels triggered by consumption of long-chain saturated fatty acids was reported to be different from the effect of increasing cholesterol levels by adjusting the diet of medium-chain saturated fatty acids. These differences are thought to include digestive and metabolic processes as well as differences in the bioactive substances produced. Indeed, it can be said that each type of fatty acid group will provide different biological and physiological effects on the body (de Roos et al. 2001; Lichtenstein et al. 2006).

CONCLUSION

The CRBO extracted from *Oryza sativa* L. 'Sembada Hitam' black rice bran using different solvents exhibited distinct physico-chemical properties. The yield ranged from approximately 11.537 to 28.887 %; with a water content between 0.017 to 0.49 %. The density varied from 0.920 and 1.027 g mL⁻¹, saponification value from 167.450 to 199.72 mg KOH g⁻¹, peroxide value 5.953 to 118.233 mEq kg⁻¹; and acid value from 79.203-86.427 mg KOH g⁻¹. The fatty acid profile of CRBO was dominated by unsaturated fatty acids, with oleic acid (43.44 %) and linoleic acid (37.52 %) as the primary components, followed by palmitic acid (14.58 %) and stearic acid (2.08 %). These results underscore the nutritional and functional potential of CRBO from *Sembada Hitam* black rice.

AUTHORS CONTRIBUTION

F.A.P., A.M.K, and Z.I.A collecting the sample. F.A.P analysing the data and wrote the manuscript. L.H and Y.A.P designed and supervised the research.

ACKNOWLEDGMENTS

This research was financially supported by RTA 2023 (*Rekognisi Tugas Akhir*) research program by Universitas Gadjah Mada, No.2338/UN1/DITLIT/Dit-Lit/PT.01.00/2023.

CONFLICT OF INTEREST

The authors have no conflict of interest in participating in this research. The funder had no role in the study design, data collection, and analysis, decision to publish, or preparation of the manuscript.

REFERENCES

- Abedi, E. & Sahari, M.A., 2014. Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties. *Food Science and Nutrition*, 2(5), pp.443-463. doi: 10.1002/fsn3.121
- Anwar, F., Anwer, T. & Mahmood, Z., 2005. Methodical characterization of rice (*Oryza sativa*) bran oil from Pakistan. *Grasas y Aceites*, 56, pp.125-134.
- Apridamayanti, P. et al., 2017. Anthocyanin, nutrient contents, and antioxidant activity of black rice bran of *Oryza sativa* L. 'Cempo Ireng' from Sleman, Yogyakarta, Indonesia. *Indonesian Journal of Biotechnology*, 22 (1), pp.49-54. doi: 10.22146/ijbiotech.26401

- Ardiansyah, H. et al., 2006. Rice bran fractions improve blood pressure, lipid profile, and glucose metabolism in stroke-prone spontaneously hypertensive rats. *Journal Agriculture Food Chemichal*, 54(5), pp.1914-1920. doi: 10.1021/jf0525611
- Arlene, A., Steviana, K. & Suharto, I., 2010. Pengaruh Temperatur dan F/S terhadap Ekstraksi Minyak dari Biji Kemiri Sisa Penekanan Mekanik. *Seminar Nasional Rekayasa Kimia dan Proses*, pp.C-12-1-C-12-6
- Baer, D.J. et al., 2003. Stearic acid absorption and its metabolizable energy value are minimally lower than those of other fatty acids in healthy men fed mixed diets. *The Journal of nutrition*, 133(12), pp.4129-4134. doi: 10.1093/jn/133.12.4129
- Banjerdpongchai, R., Wudtiwai, B. & Sringarm, K., 2013. Cytotoxic and apoptotic inducing effects of purple rice extracts and chemotherapeutic drugs on human cancer cell lines. *Asian Pacific Journal of Cancer Prevention : APJCP*, 14(11), pp.6541-6548. doi: 10.7314/apjcp.2013.14.11.6541
- BSN, n.d., 'SNI 01-3555-1998', in *Pesta Online Badan Standardisasi Nasional*, viewed 20 March 2022, from <https://pesta.bsn.go.id/produk/detail/3939-sni01-3555-1998>
- Caterina, R.D., Liao, J.K. & Libby, P., 2000. Fatty acid modulation of endothelial activation 1-3. *American Journal of Clinical Nutrition*, 71, pp.213S-223S. doi: 10.1093/ajcn/71.1.213S.
- de Roos, N.M., Bots, M.L. & Katan, M.B., 2001. Replacement of dietary saturated fatty acids by trans fatty acids lowers serum HDL cholesterol and impairs endothelial function in healthy men and women. *Arteriosclerosis, thrombosis, and vascular biology*, 21(7), pp.1233-1237. doi: 10.1161/hq0701.092161
- Deng, G.F. et al., 2013. Phenolic Compounds and Bioactivities of Pigmented Rice. *Critical Reviews in Food Science and Nutrition*, 53, pp.296-306. doi: 10.1080/10408398.2010.529624
- Desta, M., Molla, A. & Yusuf, Z., 2020. Characterization of physico-chemical properties and antioxidant activity of oil from seed, leaf and stem of purslane (*Portulaca oleracea* L.). *Biotechnology Report*, 27, e00512. doi: 10.1016/j.btre.2020.e00512
- Etiasih, T., Ahmadi, K. & Santoso, V., 2021. Senyawa bioaktif dan potensi bekatul beras (*Oryza sativa*) sebagai bahan pangan fungsional). *Jurnal Teknologi Pangan*, 12(1), pp.30-43
- Food and Agriculture Organization (FAO), 2015. FAO Rice Market Monitor October 2015. *FAO Rice Market Monitor*, 18(3), pp.1-38.
- Food and Agriculture Organization (FAO), 2019, 'Codex Standard for Edible Fats and Oils not Covered by Individual Standards (CODEX STAN 19-1981, Rev. 2 - 1999)', in *SECTION 2. Codex General Standard for Fats and Oil*, viewed 12 March 2022, from <https://www.fao.org/4/y2774e/y2774e04.htm#TopOfPage>
- Handayani, S., Fajirah, S. & Enjarlis, E., 2020. Rice Bran Oil Extraction as Trioxolane Raw Material. *Simetrikal: Journal of Engineering and Technology*, 2(1), pp.13-19. doi: 10.32734/jet.v2i1.3063
- Hartono, H.S., Soetjipto, H. & Kristijanto, A.I., 2017. Extraction and Chemical Compounds Identification of Red Rice Bran Oil Using Gas Chromatography Mass Spectrometry (GC-MS) Method. *EKSAKTA: Journal of Sciences and Data Analysis*, 17(2), pp.98-110. doi: 10.20885/eksakta.vol17.iss2.art2
- Hidayati, N. & Khaerunisa, D., 2018. Pengaruh Jenis Pelarut pada Pengambilan Minyak Daun Kelor Dengan Metode Ultrasonic Asited Extraction. *Symposium Nasional RAPI XVII FT UMS*.

- Hou, Z. et al., 2013. Identification of anthocyanin isolated from black rice (*Oryza sativa* L.) and their degradation kinetics. *Food Research International*, 50(2), pp.691-697.
- Hutami, R. & Ayu, D.F., 2015. Pembuatan dan karakterisasi metil ester dari minyak goreng kelapa sawit komersial. *Jurnal Agroindustri Halal*, 1(2), pp.124-131. doi: 10.30997/jah.v1i2.371
- Hyun J.W. & Chung, H.S., 2004. Cyanidin and malvidin from *Oryza sativa* cv. Heugjinjubyeo mediate cytotoxicity against human monocytic leukemia cells by arrest of G2/M phase and induction of apoptosis. *Journal Agriculture Food Chemistry*, 52(8), pp.2213-2217. doi: 10.1021/jf030370h
- Ichikawa, H. et al., 2004. Antioxidant activity of anthocyanin extract from purple black rice. *Journal Medical Food*, 4(4), pp.211- 218. doi: 10.1089/10966200152744481
- Ivanova, M. et al., 2022. Saponification Value of Fats and Oils as Determined from 1H-NMR Data: The Case of Dairy Fats. *Foods*, 11(10), 1446. doi: 10.3390/foods11101466
- Kampa, J., Frazier, R. & Rodriguez-Garcia, J., 2022. Physical and chemical characterisation of conventional and nano/emulsions: Influence of vegetable oils from different origins. *Foods*, 11(5), 681. doi: 10.3390/foods11050681
- Khatoon, S. & Gopalakrishna, A.G., 2004. Fat-soluble nutraceuticals and fatty acid composition of selected Indian rice varieties. *Journal American Oil Chemistry's Society*, 81(10), pp.939-943. doi: 10.1007/s11746-004-1005-5
- Kristamtini & Purwaningsih, H., 2009. *The use of Yogyakarta local black rice as functional foods source*. Sukamandi: Balai Besar Penelitian Tanaman Padi.
- Kristamtini et al., 2012. Morphological of genetic relationships among black rice landraces from Yogyakarta and surrounding areas. *ARPJ Journal of Agriculture and Biological Sciences*, 7, pp.982-989.
- Kwon, H.N. & Choi, C.B., 2015. Comparison of lipid content and monounsaturated fatty acid composition of beef by country of origin and marbling score. *Journal of the Korean Society of Food Science and Nutrition*, 44, pp.1806-1812. Doi: 10.3746/jkfn.2015.44.12.1806
- Lee, S. et al., 2006. Current clinical applications of ω -6 and ω -3 fatty acids. *Nutrition in clinical practice*, 21(4), pp.323-341. Doi: 10.1177/0115426506021004323
- Lichtenstein, A.H. et al., 2006. Diet and lifestyle recommendations revision 2006: a scientific statement from the American Heart Association Nutrition Committee. *Circulation*, 114(1), pp.82-96. doi: 10.1161/CIRCULATIONAHA.106.176158
- Maulidna et al., 2019. Perhitungan neraca massa pada proses pemurnian Crude Palm Kernel Oil (CPKO) menjadi Refined Bleached Degummed Palm Kernel Oil (RBDPKO) pada Unit Refinery di PT. Pacific Medan Industri. *Ready Star*, 2(1), pp.58-63.
- Mingyai, S. et al., 2017. Physicochemical and Antioxidant Properties of Rice Bran Oils Produced Colored Rice Using Different Extraction Methods. *Journal of Oleo Science*, 66(6), pp.565-572. doi: 10.5650/jos.ess17014
- Ministry of Agriculture, 2020. Outlook Komoditas Pertanian Sub Sektor Tanaman Pangan. Pusat Data dan Sistem Informasi Pertanian Kementerian Pertanian.
- Müller, H. et al., 2003. The serum LDL/HDL cholesterol ratio is influenced more favorably by exchanging saturated with unsaturated fat than by reducing saturated fat in the diet of women. *The Journal of nutrition*, 133(1), pp.78-83. doi: 10.1093/jn/133.1.78
- Negash, Y.A. et al., 2019. Assessment of quality of edible vegetable oils accessed in Gondar City, Northwest Ethiopia. *BMC Research Notes*, 12, 793. doi: 10.1186/s13104-019-4831-x

- Olaganju, A.I., Adelakun, O.S. & Olawoyin, M.S., 2022. The effect of rice bran extract on the quality indices, physicochemical properties and oxidative stability of soybean oil blended with various oils. *Measurement: Foods*, 6, 100032. doi: 10.1016/j.meaf00.2022.100032.
- Park, Y.S., Kim, S.J. & Chang, H.I., 2008. Isolation of anthocyanin from black rice (Heugjinjubyeo) and screening of its antioxidant activities. *Korean Journal of Microbiology and Biotechnology*, 36(1), pp.55–60.
- Rahmani, R., 2008. *Penentuan Sifat Fisiko-Kimia Dan Komposisi Asam Lemak Penyusun Trigliserida Serta Optimasi Kondisi Reaksi Sintesis Biodiesel (Meti Ester) Minyak Biji Sirsak (Annona muricata)*. Universitas Indonesia.
- Richmond, A., 2008. *Handbook of Microalgal Culture: Biotechnology and Applied Phycology*. Blackwell Science Ltd.
- Rohman, A. & Windarsih, A., 2017. Characterization, biological activities, and authentication of red fruit (*Pandanus conoideus* Lam) oil. *Food Research*, 2, pp.134–138. doi: 10.26656/fr.2017.2(2).152.
- Saikia, S.C. & Deka, 2011. Cereals: From staple food to nutraceuticals. *International Food Research Journal*, 18(1), pp.21–30.
- Santoso, A. et al. 2020. Synthesis of methyl ester from rice bran oil through the esterification reaction. *Key Engineering Materials*, 851, pp.164–171. doi: 10.4028/www.scientific.net/KEM.851.164.
- Susanti, A.D. et al., 2012. Polaritas pelarut sebagai pertimbangan dalam pemilihan pelarut untuk ekstraksi minyak bekatul dari bekatul vaietasketa (*Oryza sativa* glatinosa). *Symposium Nasional RAPI XI FT UMS*.
- Tarone, A., Cazarin, B.B. & Marostica Jr, M.R., 2020. Anthocyanins: New Techniques and challenges in microencapsulation. *Food Research International*, 133, 109092. doi: 10.1016/j.foodres.2020.109092
- Tsuda, T. et al., 2003. Dietary cyanidin 3 α - β -d-glucoside-rich purple corn color prevents obesity and ameliorates hyperglycemia in mice. *The Journal of Nutrition*, 133, pp.2125–2130. doi: 10.1093/jn/133.7.2125
- van Rooijen, M.A. & Mensink, R.P., 2020. Palmitic acid versus stearic acid: Effects of interesterification and intakes on cardiometabolic risk markers—A systematic review. *Nutrients*, 12(3), 615. doi: 10.3390/nu12030615
- Vergeer, M. et al., 2010. The HDL hypothesis: does high-density lipoprotein protect from atherosclerosis?. *Journal of lipid research*, 51(8), pp.2058–2073. doi: 10.1194/jlr.R001610
- Wang, Z. et al., 2022. Optimization of Oil Extraction from Rice Bran with Mixed Solvent Using Response Surface Methodology. *Foods*, 11(23), pp.3849. doi: 10.3390/foods11233849
- Wilson, T.A., Ausman, L.M. & Lawton, C.W., 2000. Comparative cholesterol lowering properties of vegetable oils: beyond fatty acids. *Journal of the American College of Nutrition*, 19(5), pp.601–607. doi: 10.1080/07315724.2000.10718957