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Optimization, modelling and simulation to scale-up the production of rice bran extract and defatted rice bran

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Abstract. Rice bran is the source of rice bran oil, but much of it is used as livestock feed without being extracted for oil. Some food industries utilize the stabilized rice bran as a source of fiber, protein, and cooking oil. It contains lipase that catalyzes triglyceride hydrolyzation into glycerol and fatty acids, which leads to rancidity. A stabilization process must therefore be introduced to increase oxidation resistance in rice bran and oil hydrolysis. Defatted rice bran still contains protein, fiber, vitamins, and minerals. There has not been much research on integrated production process of crude rice bran oil and defatted rice bran. This research aimed to study the procedures to optimize, model, and simulate, generate Process Engineering Flow Diagram (PEFD). The phases in this study included laboratory-scale extraction with rice bran feed capacities of 10g, 25g, 100g, dan 500g; optimization using mathematical computations, simulations of mass-balance scale up and generation of PEFD from the pilot plant of 5kg rice bran capacity. The results of this research, including optimization, modelling, and simulation showed that to increase production scale from a number of raw materials of 57.690g to 5kg in a single batch required 5kg rice bran and 23.121kg n-hexane and produced 0.671kg oil and 4.121kg defatted rice bran, 13.212kg of reusable n-hexane and this study also provided a PEFD of the rice bran oil production process for a 5 kg rice bran capacity.

Keywords: Flow Diagram, Optimization, Modelling, Rice bran, Simulation

1. Introduction

Rice cultivation in Indonesia amounts high productivity. According to BPS and BPPT, rice harvest area in the country in 2018 covered an area of 10.90 million hectares, and produced 56.54 million metric tons of dry un-milled grain [1]. When this number is converted into milled grain, the number turns into 32,42 million tons of milled rice grain. Rice bran is a significant part of rice milling by-product, because it contributes to 10% of un-milled rice grain gross. Rice bran is a source of vitamins, minerals, essential fatty acids, and other sterol food fiber, as well as γ -oryzanol [2].

Currently, rice bran is directly used mostly for livestock feed without any treatment, such as oil extraction. Some practitioners in the beverage product already use stabilized rice bran as a source of



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fiber and proteins, incorporate rice bran oil in their products [3]. An important limiting factor of rice bran oil utilization in the food industry is its short shelf life. Lipase, present in rice bran oil, catalyzes the hydrolyses of triglycerides into glycerol and fatty acids, which leads to rancidity [4].

Therefore, utilization of rice bran oil requires stabilization of rice bran to increase oxidation resistance on the rice bran and its oil. Rice bran that has undergone oil extraction is called defatted rice bran, which still contains proteins and other nutrients, such as fiber, vitamins, and minerals. Defatted rice bran can be incorporated in food products, like biscuits [5].

Defatted rice bran is a low-value agroindustry waste and is commonly used in the feed industry. It contains 97.37mg/ 100g of γ -aminobutyric acid [6]. Research on oil extraction from rice bran in laboratory scale has been frequently conducted. In a study did a large-scale pilot of 900-kg capacity of rice bran [7].

On another research conducted a study on modelling, flow-sheeting, and economic analyses on the extraction of rice bran oil from a combination of batch supercritical fluid extraction (SFE) and counter current (CC) processes. In this study, they used SFE to separate the free fatty acid (FFA) fraction from the extracted oil. However, there was no further treatment of the defatted rice bran [8].

This study aimed to develop an integrated procedure to optimize, generate a model, and simulate, as well as produce a Process Engineering Flow Diagram (PEFD) of the crude rice bran oil and defatted rice bran processing at the scale of 5-kg rice bran.

2. Materials and Methods

There were three phases involved in this study. The first phase was laboratory-scale extractions to obtain oil and defatted rice bran at the capacities of 10g, 25g, 100g, and 500g of rice bran. The second phase was to optimize the production by conducting mathematical computations on the data obtained from the previous laboratory-scale trials. The last phase was to simulate balanced-mass scale up and produce PEFD of the pilot plant with a 5-kg capacity.

2.1. Rice bran oil extraction

This process was performed on a laboratory-scale with varying initial capacities of 10g, 25g, 100g, and 500g rice bran. The material used is rice bran from rice mills that are randomly selected around the border area between Jakarta and West Java, Indonesia and n-hexane (98% purity, Merck). The equipment consisted of glassware (Pyrex), vacuum pump (Yhzkb), condenser (400 mm, liebig), ultrasonic extractor (Wisd[™] WUC-D06H), centrifuge (Gemmy industrial corp, PLC-03) and pneumatic press machine (ATS). The working procedure is presented in Figure 1.

2.2. Optimization of Data with Golden Section Method

The optimization process performed was a maximization using the golden section method. This procedure is used to solve non-linear programming problems with one variable in the form of maximization or minimization $f(x)$ with the error value of $a \leq \alpha \leq d$. [9]. Golden Section is a numerical optimization technique that find the maximum or minimum function of a single variable at an interval [10]. This method essentially narrows the area (α) that may produce optimal values of an objective function iteratively. Using this method, the optimal value from a laboratory phase can be more easily achieved [11].

The first step to determine the optimal point was conducted by deciding the simulation interval based on the laboratory trial data, which contains the maximum peak. This step was applied to both trials, which were the determinations of optimal conditions for obtaining oil and defatted rice bran.

The presentation of the resulting data is in the graphic form based on the non-linear formula from the golden section method. This process was assisted by Quick Basic[™] software.

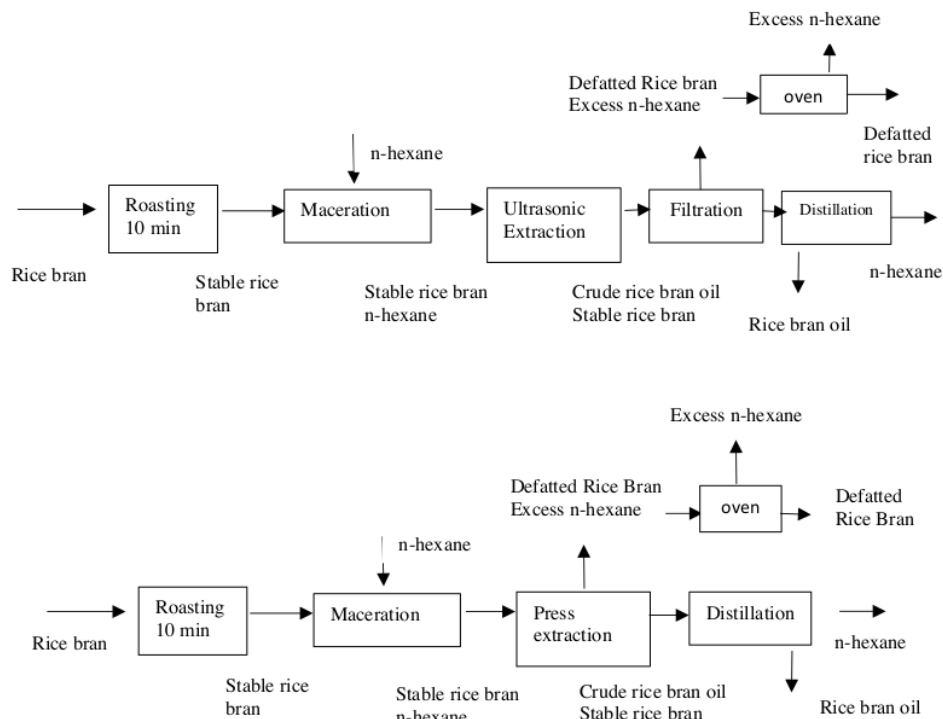


Figure 1. Block diagram of oil extraction and defatted rice bran processes

2.3. Scale up simulation

Using the data based on the optimal production of rice bran oil, scale up production at 5-kg capacity was devised. The computational process was performed with MS ExcelTM. The phases of the study are presented on Figure 2.

2.4. Process Engineering Flow Diagram

The next step was employing the results of Mass Balance calculations to generate a Process Engineering Flow Diagram. Process Flow Diagram (PFD) is a flow of major equipment and controls for a production process. The major equipment is usually in the form of columns, reactors, heat exchangers, pumps, agitators, filters, etc.

The information contained in the PFD is the equipment number and a brief description, material and energy balance, equipment size, material, flow direction [12].

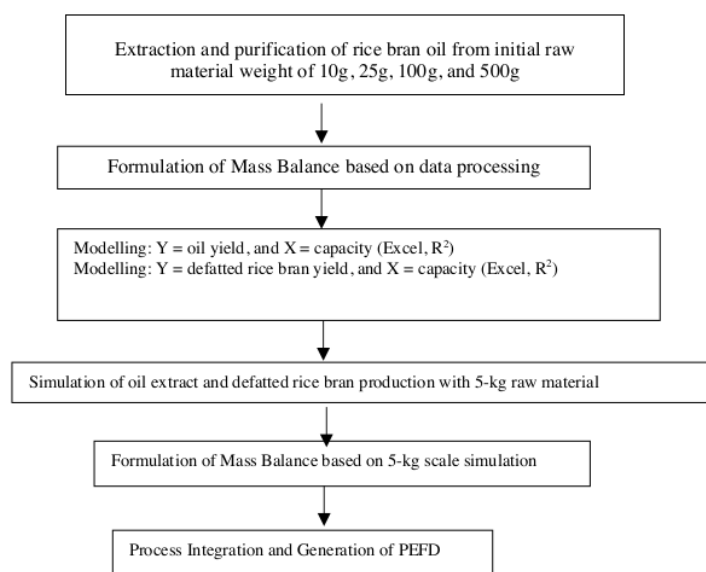


Figure 2. Trial stages in optimization, modelling, and scale-up production simulation of rice bran oil and defatted rice bran.

3. Results and Discussions

Results and discussion are presented on each phase of the study. The analyses included the percent yields of rice bran oil and defatted rice bran from different initial masses of raw material, optimal capacities in productions of rice bran oil and defatted rice bran, and the mass balance of production with 5-kg initial mass of rice bran.

3.1. Results of laboratory-phase of rice bran oil extraction

The results of rice bran oil extraction and defatted rice bran at laboratory-scale at various capacities of initial rice bran weight of 10g, 25g, 100g, and 500g are shown in Table 1.

Table 1. Results of rice bran extraction from different initial capacities of raw material

No	Capacity	Treatment step	Dry Rice Bran (g)	N-hexane (ml)	Oil (g)	Defatted Rice Bran (g)
1	10 g, n-hexane 70 ml by ultrasonic	Roasting	8.9			
		Maceration	8.9	70		
		Ultrasonic				
		Filtration	8.9	70		
		Distillation			30	0.64
2	25g N-hexane 175 ml by ultrasonic	Oven	8.9	40	0.64	3.85
		Roasting	22.62			
		Maceration	22.62	175		
		Ultrasonic				
		Filtration	22.62	175	2.49	
		Distillation			100	2.49
		Oven	22.62	75		20.13

Cont'd. Table 1

3	100 g N-hexane 700 ml by ultrasonic	Roasting	95.4			
		Maceration	95.4	700		
		Ultrasonic				
		Filtration	95.4	700		
		Distillation		400	8.6	
4	500 g N-hexane 3.5 L by manual press	Oven	95.4	300	8.6	89.57
		Roasting	450			
		Maceration	450	3500		
		Press				
		Filtration	450	3500	30.96	
		Distillation		2000	30.96	
		Oven	450	1500		400

3.2. Results of data optimization with golden section method

The optimization process was initiated by deciding the intervals among data from the laboratory trials. The first modelling was on the optimization of rice bran oil extraction and used the result data to plot a capacity vs oil yield curve. This graph shows the optimal peak occurring between 10g and 100g (Figure 3). This optimization resulted in the optimal point of 57.69 g capacity with a yield of 14.49%.

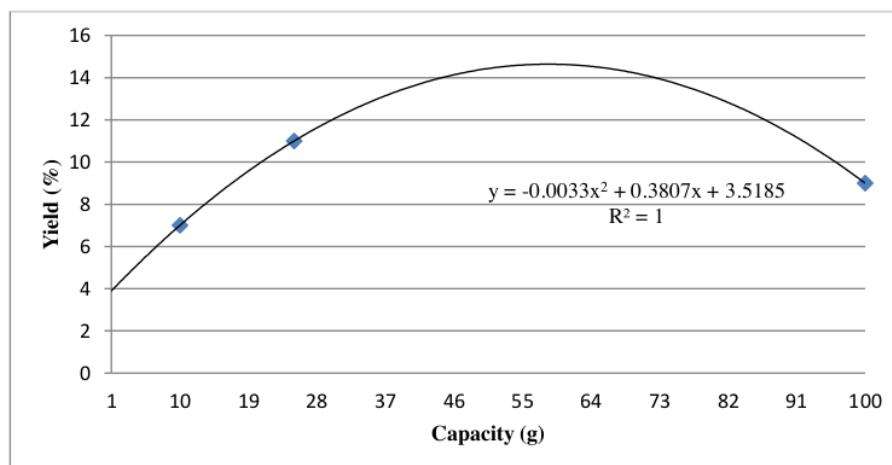


Figure 3. Correlation curve between capacity (g) and oil yield (%)

Based on Figure 3, the determination of capacity that would produce the optimal yield was conducted with golden section method using Quick Basic™ software. The second model was on the defatted rice bran by generating a curve on capacity vs defatted rice bran yield. This exercise produced the optimal point in between 25g and 500g as shown in Figure 4.

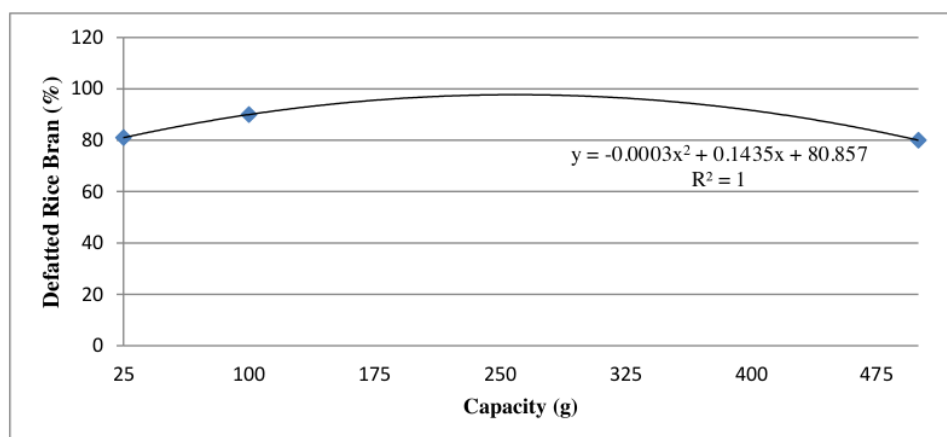


Figure 4. Correlation curve between capacity (g) and defatted rice bran yield (%)

Based on Figure 4, the determination of capacity that would produce the optimal yield was conducted with golden section method using Quick Basic™ software. This optimization analysis produced an optimal point at 239.19-gr capacity with a defatted rice bran yield of 98.01%. The optimization results were compared and 57.69-gr capacity was favoured because it generated the highest yield of oil extract of 14.49% and acceptable defatted rice bran yield of 88.18%, as shown in Table 2.

Table 2. Yield comparison between production capacities of 57g and 239g

No	Capacity (gr)	Oil Yield (%)	Defatted Rice Bran Yield (%)
1	57.69	14.49	88.13
2	239.19	8.30	98.01

3.3. Scale-up simulation results

The scale-up simulation of 5-kg capacity of raw rice bran (5 - 10% water content) generated a Mass balance that referred to the optimal production capacity of 57.69 gram. The calculation results are presented in Table 3.

Table 3. The mass balance results from 5-kg capacity simulation with various equipment

<i>Maceration Tank</i>			
Material	F1	F2	F3
Rice bran (g)		4631.245	4631.245
N-hexane (g)	23121		23121
Oil (g)			
Defatted rice bran (g)			
Amount	23121	4631.245	27752.25
Total		27752.25	27752.25

Cont'd. Table 3

Filter Press			
Material	F3	F4	F5
Rice bran (g)	4631.245	4121	
N-hexane (g)	23121	9909	13212
Oil (g)			671
Defatted rice bran (g)			
Amount	35674	17376	18298
Total	35674	35674	

Oven			
Material	F4	F6	F7
Rice bran (g)	4121		
N-hexane (g)	9909	9909	
Oil (g)			
Defatted rice bran (g)			4121
Amount	14031	9909	4121
Total	14031	14031	

Distillation Column			
Material	F5	F8	F9
Rice bran (g)			
N-hexane (g)	13212	13212	
Oil (g)	671		671
Defatted rice bran (g)			
Amount	13883	13212	671
Total	13883	13883	

The next step was employing the results of mass balance calculations to generate a process engineering flow diagram which is shown in Figure 5.

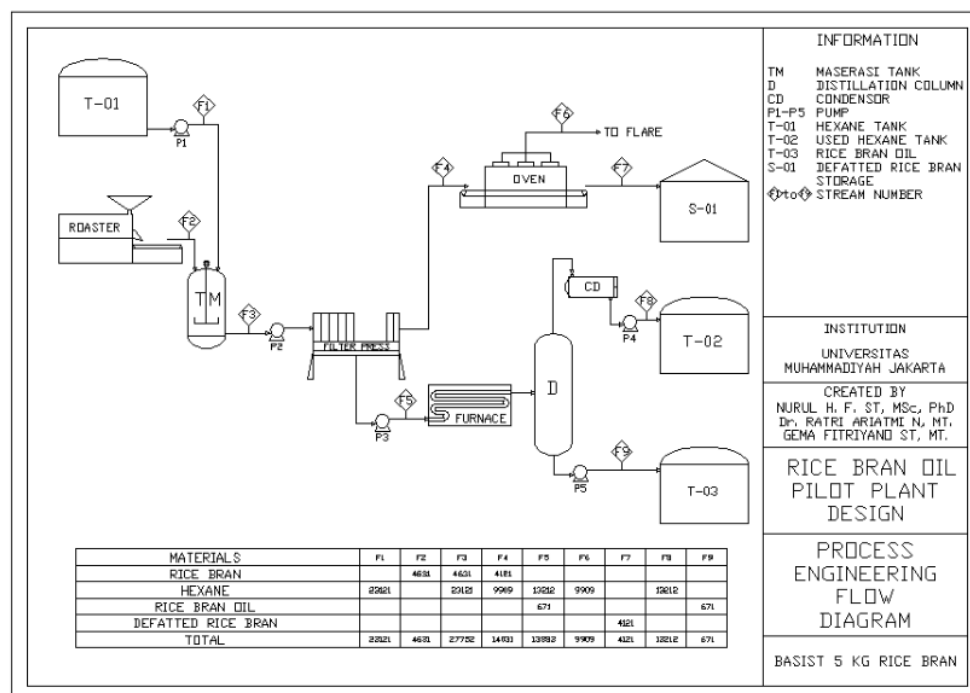


Figure 5. Process Engineering Flow Diagram (PEFD) for a Rice Bran Oil Plant Design

4. Conclusions

This study produced several conclusions. The first is that ultrasonic extraction method yields more than manual press. The second is that the result of optimization process using golden section method is 14.49% weight yield of rice bran oil from an initial weight of 57.69 grams. The third is drawn from the production of rice bran oil and defatted rice bran that has been scaled up from 57.69 grams to 5 kg. Based on the production simulation, when the initial capacity is scaled up to 5 kg of raw rice bran, the process requires 23.121 kg of n-Hexane and produces 0.671 kg of rice bran oil and 4.121 kg of defatted rice bran, as well as 13.212 kg of reusable n-Hexane. and also provided a PEFD of the rice bran oil production process for a 5 kg rice bran capacity. For further research, it can be directed to simulate an increase in pilot plant scale production capacity and it is necessary to study the compatibility factor of equipment to raw materials and products characteristics.

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