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Performance and Prospects of Mobile Rice Mill Unit

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***Abstract*—Rice milling is one of the important steps in post-harvest operations to get good quality white rice. As an innovation in improving customer service, a mobile rice mill unit (MRMU) has recently been operated in various rice-producing areas. The objective of this study was to evaluate the performance and prospects of MRMU based on technical and economic analysis. The research was conducted in East Lampung Regency, Lampung, Indonesia, by observing three MRMUs. Each mill was observed for three working days to obtain MRMU performance data, namely grain quality, milled yield, working time, fuel consumption, working capacity, and quality of white rice produced. Other information includes machine price, the machine age, estimated economic life, investment, interest rate, fuel consumption, operator wage, milling charge, and repair and maintenance costs. Results showed that MRMU had an actual capacity between 63.29–98.82 kg/hour with a milled yield between 60.41–64.96%. The white rice produced has a proportion of head rice 58.26–61.42%, with a whiteness index less than the SNI for rice quality standards. The unit cost of the rice milling process using MRMU was an average of 457.91 IDR/kg. At a milling charge of 666.67 IDR/kg, the operation of MRMU is economically feasible at an annual working hour higher than 1000 h. In addition, the MRMU operation was not economically acceptable at a milling charge of 500 IDR/kg. With the rapid growth in the rice milling numbers, an unbiased regulation is required to avoid unhealthy competition among the MRMU enterprises.**

***Keywords*— Rice mill; portable; economy; whiteness index; degree of milling.**

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I. Introduction

Rice is one of the significant cereal crops cultivated in no less than 120 countries worldwide, with an annual production of around 680 million tons (Mt) and feeds almost half of the population [1]–[3]. Rice production has been an important industry in many Asian countries, Europe, Africa, Australia, and the Americas [4]. Peoples prefer rice because of its high nutrition and affordable price [5], [6]. In Indonesia, rice is the main staple food for most people. Indonesia's per capita rice consumption in 2020 has reached 111.58 kg/y and is among the world's highest rice consumption levels. Indonesia is the largest rice producer in Southeast Asia and the third-largest worldwide [7]. In 2019, rice productivity in Indonesia reached 5.46 t/ha, so with a harvest area of 10.68 million ha, rice production reached 54.60 Mt of dry raw rice (DRR), equivalent to 31.31 Mt white rice [8]. Therefore, rice has an important position in Indonesia. This is also reflected in the harvested area of rice production, which is the largest cultivated food crop. Lampung Province is one of the regions on Sumatra island that produces significant amounts of rice with a contribution of 2.16 Mt DRR or 4.0% of the national production [8].

White rice grain is covered by two layers, husk as the outer layer and bran as the inner layer. Husk or hull is not edible, whereas bran reduces the shine of white rice. White rice, together with its by-products (rice husks and bran), is produced from the rice milling process using a rice mill unit (RMU). Rice milling removes foreign material, husks, bran, and broken kernels from dry rice grains to produce white rice for various purposes. Milling of raw rice into white rice involves various unit operations but can be classified essentially into two steps [9]–[11], namely: (i) dehulling or dehusking of dry, rough rice grains to remove the husk and produce brown rice, and (ii) polishing of brown rice to remove the bran and produce white rice. Rice milling of paddy grains produces brown rice, white rice, rice hull, fine broken rice, and bran [12]. Generally, rice grains comprise around 69% white rice (starchy endosperm), 20% rice hull, and 11% rice bran [3].

Rice milling is of great economic importance to the rice industry, not only because the process particularly produces white rice important for human consumption but also because up to 40% can be lost during the milling process [3]. Rice millers play essential roles in processing rough rice paddy, delivering consumable white rice to the market, and supporting the availability of rice nationally [13], [14]. Rice milling units are vital nodes of rural industrial areas and play a great role in rice commodity marketing chains [15]. Rice milling determines the availability and quality of food consumed by the community, the price level consumers must pay, the income earned by farmers, and the availability of employment in rural areas. Rice mills can act as a channel for the spread of agricultural technology among farmers. In short, rice milling is the next flow of the production subsystem, and whatever is required by rice mills will concern farmers.

Rice milling systems are classified broadly into two types based on working mechanisms: abrasive and friction. The former type produces lower broken rice because of lower and more uniform pressure inside the milling chamber [16]. The utilization of RMU in Indonesia has a long history, since the 1950s, as stated in Government Regulation No. 42 in 1954 on Limitation of Milling and Polishing Rice Enterprises. The rice processing business is divided into three, viz. Rice Milling to produce white rice from DRR grains; Huller to produce brown rice only from DRR grains; and Polishing to produce white rice from brown rice only [17]. It should be noted that until 1971, around 80% of the conversion of raw husked rice into white rice was done by hand-pounding. Since then, the Indonesian government introduced the RMU, and within only three years, 10% of the rice was milled manually; the rest was processed with the RMU [18]. Based on the milling capacity, rice mills are classified into three: large, medium, and small, with a white rice production capacity of more than 3 t/h, 1.5–3 t/h, and less than 1.5 t/h [19]. From the beginning of 1972 till now [20], small rice mills have been the most appropriate for Indonesia. The RMU was built permanently in each sub-district with a large potential for rice and was operated by a KUD (village cooperative unit), which is called the cooperative rice mill unit (CRMU). Each unit consists of two machines: a huller to separate husks from DRR grains and produce brown rice and a polisher to remove the bran and produce white rice. This CRMU is facilitated with a building as a storage room and adequate drying floors. One complaint against CRMU is the waiting time. The CRMU will start to work if the supply of DRR has met a certain amount, so people have to wait till the minimum amount is reached. If a wholesaler is booking the RMU, people also must wait their turn. With people's economic power development, some permanent RMUs (PRMU) similar to CRMU are operated as individual businesses.

To anticipate the disadvantages of the CRMU, mobile RMUs (MRMU), also called portable or commuting RMU, are recently in operation in various regions as small and medium enterprises (SMEs). As in many other countries, SMEs play an important role in economic development in Indonesia [21]. In general, MRMUs still use simple technology. As a result, the rice produced has low quality and yield. In addition, the total milling capacity is much greater than the national grain production, resulting in fierce competition among the mills. Many rice mills do not work optimally and even work only about one-third of their maximum capacity. With this condition, rice milling companies face high production costs, making it very difficult to cover the investment that has been incurred. To grow and reach more consumers, SMEs must be innovative and creative [22]. Mobile mills are a form of innovation and creativity from SMEs with a person selling or ball pick-up marketing strategy.

MRMUs typically consist of a two-stage process with a huller, and a polisher mounted separately on a self-propelled carry truck deck. These MRMUs also develop in Vietnam, Cambodia, and the Philippines. The existence of MRMU is a logical consequence of the demands on a business with servant style to consumers. As the name suggests, MRMU goes around, comes to, and serves the customer who will mill their rice grains. The MRMU service system is opposite to the PRMU. At the PRMU, raw rice is brought to RMU to be milled.

Contrary to the MRMU, the machine is brought to the customers ready with DDR grains. With a competitive rent, MRMU is increasingly developing in the Regency of East Lampung. The presence of MRMU competes with PRMU, so MRMU is prohibited from operating in the District of East Lampung [23]. However, the community has received many benefits and continues to use MRMU services so that the MRMU business continues to run and is even growing, as seen from the increasing number of MRMUs operating in East Lampung. The technical performance of the MRMU will be influenced by factors such as the type of machine (single pass or multi-pass), the brand and age of the mill unit, the quality of grains (variety, age of harvest, moisture content), and operator skill. Few economic studies were performed locally on the rice milling unit performance in Indonesia, covering only technical or economic aspects [24], [25]. There is a need to find the economic sustainability of the MRMU for better policies. This research aims to evaluate the MRMU operation's viability in the East Lampung Regency. The study is expected to provide useful knowledge concerning technical and economic aspects for the future of MRMU. MRMU performance is used to analyze the future prospect and sustainability of MRMU entrepreneurship.

II. Materials and Methods

A. Location Description

The research was conducted in East Lampung, one area in Lampung Province with a large harvested area (131,113 ha) and production of 700,294 tons of dry raw rice [26]. The MRMU performance was observed in three districts purposively selected for their potential (Table I): Batanghari, Sekampung, and Bumi Agung (Figure 1).

B. Unit Specification

All MRMUs observed in this research were the two-stage or two-pass type, where dehulling and polishing are performed separately [27]. Table II provides specifications of the observed unit. One of MRMUs and its important components is depicted in Figure 2. A local workshop designed most MRMUs operating in East Lampung Regency with used materials. MRMU is operated by two people, one as the main operator and the other as the helper. The main operator is usually the owner of the MRMU himself. The milling fee the customer must pay uses the "bawon" system using white rice to pay at a ratio of 1:15, where for every 15 kg of white rice produced, MRMU will get 1 kg of rice. Of this, wages will be divided by 25% for operators. This bawon system is commonly used in the operation of rice milling units, but the operators' ratio and share can differ. For example, the ratio of 1:10 with 1/3 share for operators is commonly applied in the Pringsewu Regency areas [25]. All mill units were two-stage milling types with two separate machines for dehusking (huller) and polishing. The out-of-operation carry truck frames were used as the body for the transportation unit, while the milling machines were collected from used rice milling machines. The MRMU is driven by using a diesel engine (20–28 HP) with a simple and locally designed power transmission system as illustrated in Figure 3. The engine axle was coupled with a 5-row pulley connected using V-belt to different moving parts. The first 2-rows were connected to the truck shaft (main) drive for transportation, the second 2-rows to the milling machines, and the last row to a dynamo charge. Connection to the truck axle and milling machines are carried out by alternately pulling up the fastening lever. The lever is pulled upwards to connect the transmission, and it is pulled down to disconnect the transmission. If the diesel power is connected to the truck axle, the connection to the mill machine is turned off (the lever drops), and vice versa.

TABLE I
HARVESTED AREA AND GRAIN RICE PRODUCTION IN THE STUDY AREAS

No	District	Harvested Area (ha)			Rice Production (ton DHR)		
		Wetland	Dryland	Total	Wetland	Dryland	Total
1	Batanghari	7,463	12	7,475	43,673	38	43,711
2	Sekampung	6,905	529	7,434	36,362	1,599	37,961
3	Bumi Agung	1,452	75	1,527	7,732	235	7,967

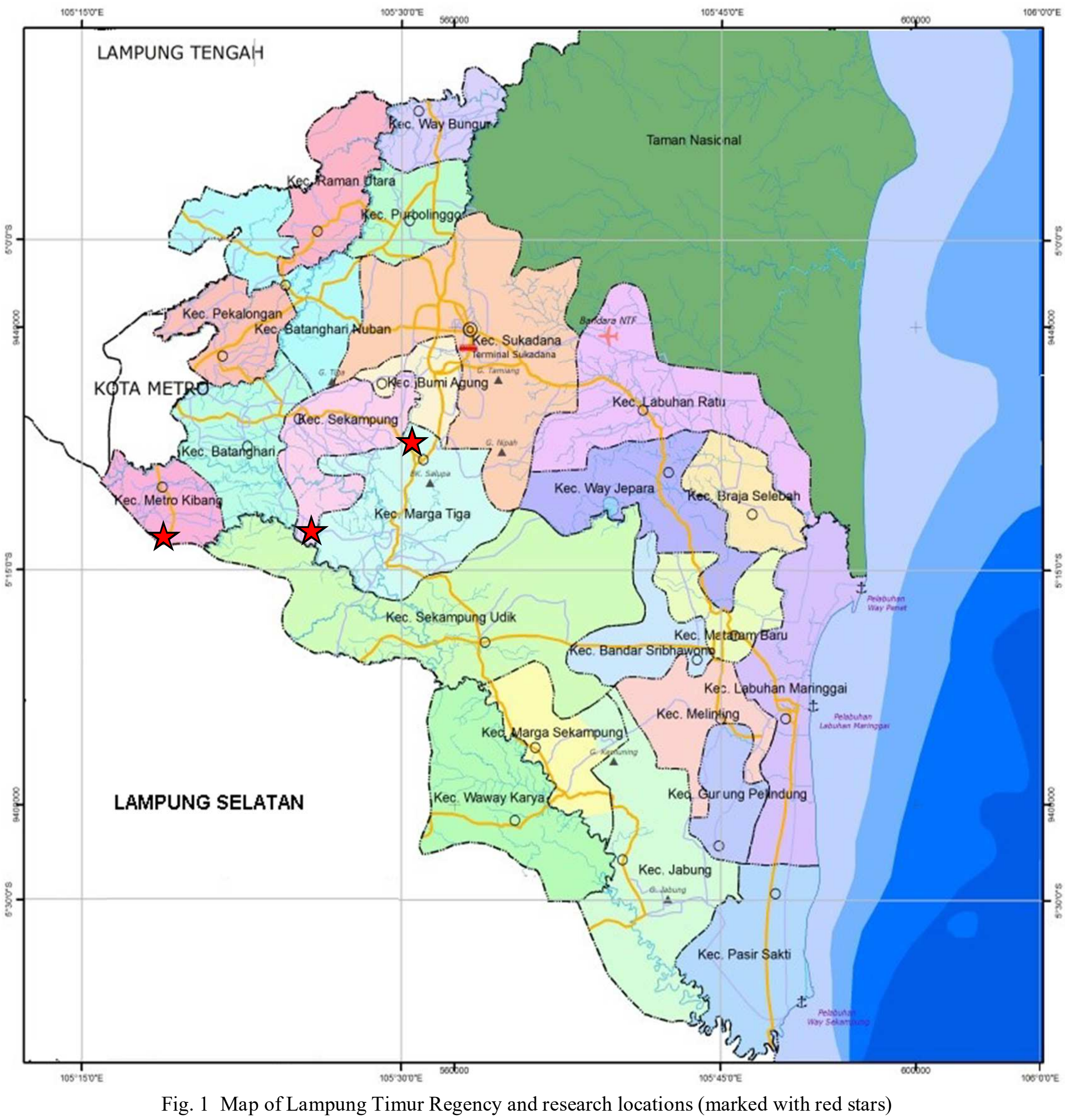

Fig. 1 Map of Lampung Timur Regency and research locations (marked with red stars)

TABLE II
SPECIFICATION OF SELECTED MRMU

Specification	Batanghari (MRMU A)	Sekampung (MRMU B)	Bumi Agung (MRMU C)
Rice milling type	Two steps	Two steps	Two steps
Year of manufacture	2012	2007	2009
Drive engine type	Diesel engine	Diesel engine	Diesel engine
Year of engine manufacture	2012	2007	2015
Engine capacity (HP)	28	24	20
Overall dimension (cm): w/l/h	186/441/252	162/434/235	178/416/244
Truck frame type	L 300	T Hiace	Carry
Wheelbase (cm)	158 cm	153 cm	153 cm
Axle space (front to rear, cm)	243	230	236
Power transmission	Belt-pulley	Belt-pulley	Belt-pulley

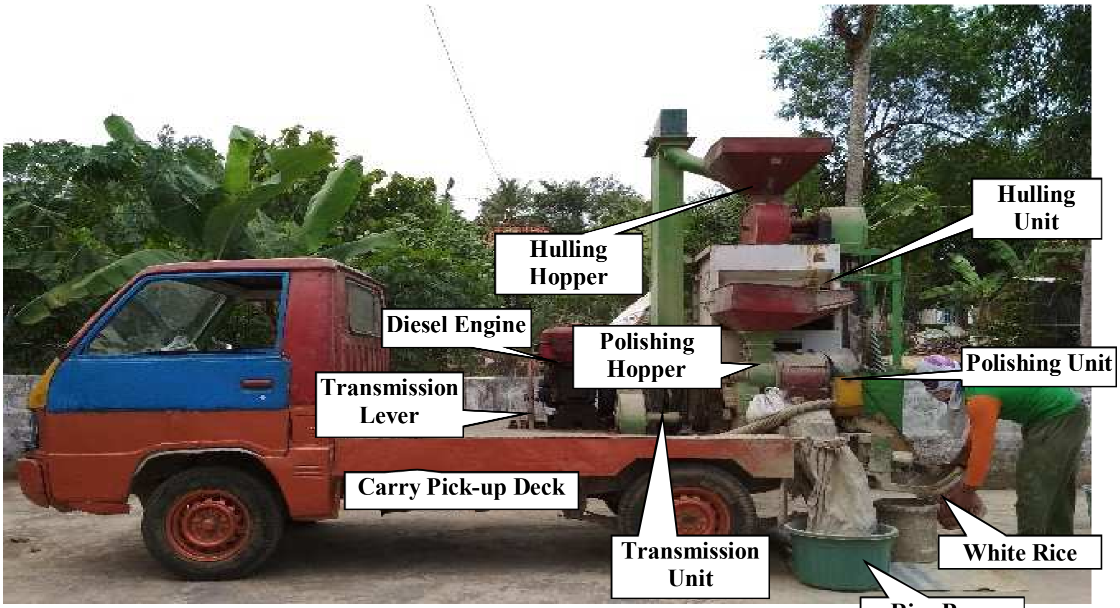

Fig. 2 Important parts of MRMU (brown rice and rice husk outlets on the other

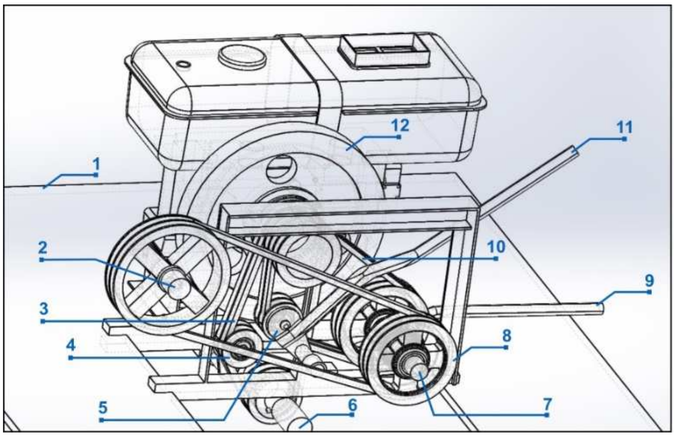

Fig. 3 Scheme of the transmission system in MRMU (1. Truck deck, 2. Polishing machine shaft, 3. Truck axle belt, 4. Fastening transportation belt, 5. Fastening milling machine belt, 6. Truck axle, 7. Rice milling shaft, 8. Rice milling pulley, 9. Fastening lever for rice milling, 10. Rice milling belt, 11. Fastening lever for transportation, 12. Flywheel).

C. Unit Specification

Data acquisition was conducted for three working days for each MRMU to observe the following parameters:

- Milling time is the sum of the milling times of different customers during a day.
- Total working time, calculated from time of the MRMU left home until the time back home (including milling time, transportation, and other activities during a day).
- Variety and quality of dry rice paddy (moisture content, empty grains, and foreign materials).
- Milling yield and milling capacity.
- Milled rice quality (moisture content, head rice, broken rice, bran, degree of milling and whiteness index).
- Details financial data (investment, interest rate, tax, and expected economic life).
- Operator wage, milling rent, and annual working day.
- Fuel consumption, lubrication, part, and maintenance.

D. Analysis and Measurement

Quality of raw rice was evaluated from percentage of its moisture content (*MC*), empty grain, and foreign materials. Moisture content is the mass percentage of water over mass of sample and was measured gravimetrically using oven (Memmert, UM 500) at temperature 105°C for 24 h. The *MC* is calculated from initial mass (M_0) and final mass (M_f) as:

$$MC = 100 \times (M0 - Mf)/M0 \quad (1)$$

The technical performance of the milling process was evaluated from capacity, total rice yield, product composition (white rice, husk, and bran), fuel consumption, and fuel productivity. Milling capacity is classified into two types, namely theoretical or ideal capacity (Ct), which considers milling time (MT) only, and actual capacity (Ca), which considers whole working time (WT), including transportation, milling preparation, and other unproductive times. While field efficiency (Ef), a measure for functional effectivity, is a ratio of actual to theoretical efficiency. A RMU has high field efficiency if $Ef \geq 80\%$, and vice versa. The capacity and efficiency are calculated as the following:

$$Ct = (RR/MT) \quad (2)$$

$$Ca = (RR/WT) \quad (3)$$

$$Ef = (Ca/Ct) \times 100\% \quad (4)$$

Total rice yield (TRY), also called milled rice recovery, is defined as the mass percentage of white rice (WR) from raw rice (RR) and is calculated as [9]:

$$TRY = 100 \times WR/RR \quad (5)$$

Milled rice quality included head rice yield, moisture content, degree of milling, and whiteness index. Head rice consists of milled rice kernels having at least three-quarters of the whole length of the kernel [28]. Head rice yield (HRY) is the mass percentage of head rice (HR) from brown (BR) rice and is calculated as [29]:

$$HRY = 100 \times HR/BR \quad (6)$$

The whiteness index (WI) was calculated based on the measurement of head rice whiteness by spectrophotometry. The degree of milling (DM) of rice can be defined by measuring the extent of bran layers removal from brown rice kernels during polishing operations. The increase in DM results in the increased whiteness of rice [30]. Brown rice, also known as hull-cracked rice, is an intermediate product obtained from dehulling or dehusking dry raw rice using a huller or husker machine. Brown rice is healthier than whole rice, including bran and germ [31], due to its high content of minerals, vitamin B, dietary fibers, and essential fatty acids [32]. During MRMU operation, brown rice is not measured because the operator has to work rapidly. Therefore, in this research DM is calculated by modifying an equation [33]–[35] based on white rice (WR) and bran (RB) yield as the following:

$$DM = 100 \times RB/ (WR + RB) \quad (7)$$

Fuel consumption was measured when the MRMU came home by adding fuel into the tank till it was full, as the MRMU went out from the garage. Fuel productivity (in kg/L) was calculated based on the amount of raw rice being milled divided by the fuel consumption. In the meantime, the economic performance of MRMU was evaluated from its unit cost (UC, IDR/kg), break-even point (BEP), benefit-cost ratio (BCR), net present value (NPV), internal rate of return (IRR), and payback period (PBP) calculated as in the following:

$$UC = (FC + VC)/AC \quad (8)$$

$$BEP = FC/(R - VC) \quad (9)$$

$$BCR = NPVB/NPVC \quad (10)$$

where the fixed cost (FC) and variable cost (VC) in combination form a total cost (TC). R is rice milling rent (IDR/kg), and subscript B and C are for benefit and cost, respectively. Fixed cost consists of depreciation (D), interest (I), and tax (if any). VC is composed of fuel consumption, oil and grease, spare parts, operator wage, and repair and maintenance. With salvage value S (10% of investment, P) and economic life N, and interest rate r, the depreciation (D) and interest (I) are calculated as the following:

$$D = (P - S)/N \quad (11)$$

$$I = r (P + S)/2 \quad (12)$$

Parameters such as NPV, IRR, and PBP were calculated through financial functions available in the Excel application. In addition, sensitivity analysis was performed by changing the milling charge and working hours.

III. Results and Discussion

A. Raw Rice Quality

Farmers in East Lampung Regency cultivate several rice varieties. Table III shows that the Ciherang cultivar dominates the farmers' choice of seeds, followed by the Mapan cultivar and others. The Ciherang is suitable for planting in the rainy and dry seasons with an altitude below 500 m above sea level. This variety, which has a plant height of 107-115 cm, is resistant to brown planthopper (*Nilaparvata lugens*) and leaf blight caused by the bacteria *Xanthomonas oryzae pv oryzae* (Xoo). With a harvest age of 116-125 days, the Ciherang variety has the potential to produce 5.0–8.5 t/ha [36] and become the most popular variety cultivated in Indonesia [37]. Meanwhile, the Mapan variety is suitable for low to medium land rice fields (altitude 50–300 m asl.) with good irrigation. This variety was released in 2006 and has a potential yield of 9.52 t/ha DRR. However, it is slightly sensitive to brown planthopper and leaf blight even though it is somewhat resistant to *tungro* [38]. The uniformity of rice varieties and planting date is required to avoid pests and plant diseases. In this case, farmers are guided by agricultural extension workers in collaboration with farmer groups and farmer group associations.

Table III also shows raw rice characteristics sampled from the customers. Generally, rice grains are of average quality. However, raw rice grains also contain foreign matter such as gravel stone, straw, sand, bag string, and soil particles that must be removed before milling. The grains from the farmers have a moisture content of around 14%, which is resulted from traditional drying under the sun's rays. Moisture content is crucial because it determines the quality of the milling process in terms of extraction rate (milling yield), the percentage of broken grains, and the cooking properties of the milled rice [39]. Drying is a vital process to increase yield in rice production, and improper drying can negatively impact grain quality for subsequent processing [40]. Poor drying operation may reduce the quality of white rice and the head rice yield [41]. Like in other tropical countries, paddy is generally harvested at 20% to 28% wet moisture content [42]. The optimum moisture content for a good milling process is 13–14% [37]. Grains with too high moisture content will result in fragile milled rice [43], while too dry grains will result in high broken rice. An undesirable relationship between milled rice yields and broken grains is reported as 18-20% moisture content during harvest time [44]. Therefore, after harvesting, rice grains have to be dried to a certain level of water content before milling into consumable white rice [41], especially in humid tropical conditions like Indonesia, where humidity and temperature rapidly deteriorate the quality of grains [45].

TABLE III
QUALITY OF DRY RAW RICE

Parameter	Unit	Batanghari	Sekampung	Bumi Agung	Total
Number of samples	-	13	16	15	44
Variety and numbers of sample	-	Ciherang (5) Mapan (4) Others (4)	Ciherang (9) Mapan (2) Others (5)	Ciherang (10) Mapan (2) Others (3)	Ciherang (24) Mapan (8) Others (13)
Moisture content	% (wb)	13.90 ± 1.92	14.25 ± 1.41	13.73 ± 1.23	13.97 ± 1.50
Empty grain	%wt.	1.61 ± 0.79	1.80 ± 0.73	1.82 ± 0.82	1.75 ± 0.77
Foreign material	%wt.	0.20 ± 0.29	0.42 ± 0.33	0.38 ± 0.31	0.34 ± 0.32

Our observation showed that water content variation was quite evenly distributed in the three sub-districts, with the lowest value of 10.16% and the highest of 16.54% wet basis (wb). The data imply that farmers are not really aware of the moisture content of the grains. This may relate to the fact that the white rice will be consumed. It will be different if rice is used as a trade commodity. In this case, different floors or mats used during sun-drying can be a reason for this discrepancy. Rice grains dried on a concrete floor result in higher white rice yield than those dried on a mat which may be caused by a slower drying rate [37]. Drying uniformity is another important factor affecting milling quality, and rotary dryers with continuous stirring result in higher head rice by 7.6% than fixed bed dryers [46].

B. Technical Performances

Tables IV and V, respectively, show the milling capacity and technical performance of the MMRUs. The three MMRUs show almost similar performance in terms of minimum order (31–40 kg) and the number of daily customers (3–7 customers). The maximum order is respectively 159, 208, and 233 kg for MRMU A, B, and C. The average amount of raw rice achieves 305.6 kg for MRMU A, 392.0 kg (B), and 424.8 kg (C) in a day operation. The amount is related to the total work hours allocated by the operator, namely 4.06 h (A), 4.91 h (B), and 5.05 (C). The longer the working time, the more rice is obtained and milled. The MRMU A reveals the highest milling capacity (401.2 kg/h, average) as compared to B (310.7 kg/h) and C (324.6 kg/h). This is related to the machine's condition, where MRMU A is the newest among the three machines. However, the three MRMUs show a much lower actual capacity than the ideal capacity, which is only 98.82 kg/h for MRMU A, 63.29 kg/h for B, and 64.28 kg/h for C. This reveals that out of the total working time, only a small part is allocated for milling (20–25%), and the rest is for going around looking for customers and preparing milling operations.

TABLE IV
MILLING CAPACITY

Day	MRMU A			MRMU B			MRMU C		
	Weight order (kg)	Milling time (min)	Ideal capacity (kg/h)	Weight order (kg)	Milling time (min)	Ideal capacity (kg/h)	Weight order (kg)	Milling time (min)	Ideal capacity (kg/h)
I	39	5.96	392.4	208	44.01	283.2	86	19.65	262.2
	46.5	6.62	421.2	42	7.4	340.2	53	9.92	320.4
	123	19.56	376.8	40	9.55	250.8	47	8.62	327
	34.4	6.73	386.4	71	13.48	315.6	-	-	-
	107	16.2	396.0	159	28.78	331.2	-	-	-
	77.5	10.96	424.2	44	9.23	285.6	-	-	-
	-	-	-	45.5	8.86	307.8	-	-	-
II	40	6.08	394.2	112	18.76	358.2	38	8.08	282
	159	23.62	429.0	41.5	8.76	283.8	50.5	7.75	390.6
	60.5	8.9	407.4	55	10.03	328.8	48	11.43	251.4
	-	-	-	51	8.95	341.4	178	39.8	268.2
	-	-	-	49	10.42	282	87	14.93	349.2
	-	-	-	-	-	-	83	15.13	328.8
	-	-	-	-	-	-	51.5	9.28	332.4
III	48	7.03	409.2	86	14.93	345.6	233	40.11	348
	97	14.43	403.2	44	8.9	296.4	91	15.05	362.4
	54	7.85	412.2	76	15.55	292.8	116	18.38	378.6
	31	5.11	363.6	52	9.48	328.8	54.5	9.78	334.2
	-	-	-	-	-	-	58	10.43	333.6
Min.-Max order (kg)	31-159			40-208			38-233		
No. of customer	3–6			4–7			3–7		
Daily average	305.6			392.0			424.8		
Avg. ideal cap. (kg/h)			401.2			310.7			324.6
Daily working time (h)		4.06			4.91			5.05	
Avg. actual cap. (kg/h)			98.82			63.29			64.28
Avg. fuel cons. (L/h)	1.55			1.36			1.30		

Table IV also shows that the fuel consumption of the three MRMUs varies from 1.30 to 1.55 L/h. The variation corresponds to the power capacity of the engine: the bigger, the higher. MRMU A with 28 HP consumed diesel fuel of 1.55 L/h, higher than those of MRMU B (24 HP) with 1.36 L/h and MRMU C (20 HP) with 1.30 L/h. The fuel productivity of MRMU A was 880.5 kg/L, much higher than B (669.2 kg/L) and C (653.1 kg/L). As stated otherwise, the specific fuel consumption of MRMU is between 1,136 and 1,531 L/ton. This figure is comparable to that reported by other researchers, namely 1.47 L/ton for mobile rice mills [24]. It should be underlined that fuel is the largest component of energy consumption in mobile rice mills.

TABLE V
MILLING PERFORMANCES (IN %)

No	MRMU A				MRMU B				MRMU C			
	WR	RB	Hull	Loss	WR	RB	Hull	Loss	WR	RB	Hull	Loss
1	56.41	22.05	20.51	1.02	64.42	17.78	16.10	1.68	72.09	15.34	11.04	1.51
2	68.81	19.35	10.75	1.07	59.52	21.42	17.85	1.19	64.15	20.75	13.58	1.50
3	56.91	21.54	20.32	1.21	51.25	21.75	26.25	0.75	56.38	22.34	19.14	2.12
4	65.66	19.58	13.82	0.92	63.38	18.16	16.61	1.83	51.31	22.36	24.73	1.57
5	63.55	18.69	16.44	1.30	58.49	20.75	18.86	1.88	56.43	19.80	22.77	0.99
6	72.25	16.77	10.32	0.64	61.36	20.45	17.04	1.13	71.87	16.66	10.41	1.04
7	62.50	21.25	15.00	1.25	61.53	19.34	17.58	1.53	61.79	21.91	15.16	1.12
8	65.40	17.98	15.09	1.50	58.48	21.42	18.48	1.60	67.81	16.09	14.36	1.72
9	68.59	17.68	13.22	0.49	67.46	17.34	14.45	0.72	59.03	22.28	17.10	1.56
10	73.95	13.54	11.45	1.04	56.36	21.81	20.72	1.09	61.16	19.80	18.25	0.77
11	69.07	17.01	12.37	1.54	57.84	23.52	17.64	0.98	62.23	19.31	16.30	2.14
12	66.66	18.51	13.88	0.92	71.42	17.34	10.20	1.02	65.93	17.47	14.83	1.75
13	54.83	20.96	22.58	1.61	63.95	19.06	15.11	1.86	62.06	19.82	16.12	1.98
14					57.95	22.72	18.18	1.13	58.71	22.01	18.34	0.91
15					56.57	21.71	19.73	1.97	53.44	22.41	23.27	0.86
16					56.73	23.07	19.23	0.96				
Average	64.96	18.83	15.05	1.11	60.41	20.47	17.75	1.33	61.62	19.89	17.02	1.43
Minimum	54.83	13.54	10.75	0.49	51.25	17.34	16.10	0.72	51.31	15.34	11.04	0.77
Maximum	73.95	22.05	22.58	1.61	71.42	23.07	26.25	1.97	72.09	22.41	23.27	2.14

Note: WR = white rice, RB = Rice brand

As presented previously, dry raw rice production in East Lampung Regency is 700,294 tons. Assuming that MRMUs mill 50% of the raw rice and the annual working time of the rice mill is 2000 h, it will be required 2,215 to 3,458 units MRMU. Recently, the number of MRMUs operated in all districts within East Lampung has arrived at 1711 units. Although the calculated number of MRMU is higher than the existing units, the operation of MRMU in East Lampung is risky. The competition among mills is fierce. This can be seen from demonstrations carried out by PMRU owners asking the local government to prohibit the operation of the MRMUs. Similar actions also occurred in other areas in Indonesia such as Pekalongan, Sukoharjo and Karang Anyar (Central Java), Gunung Kidul and Bantul (Yogyakarta), Banyuwangi (East Java), and Bandar Mataram (Central Lampung). If the actual field efficiency increases by only 10% (to 30-35%), then the demand for MRMU will range from 1575-2319 units so that the presence of MRMU will become saturated and the competition will be more and more ferocious. Therefore, it is reasonable when the Government of East Lampung issued a decree to prohibit the operation of the MMRU [23]. The negative effect is reflected in RMUs working unoptimally and only a quarter of the capacity. As a result, rice mill operating cost is high, making it very difficult to cover the investment costs incurred. This condition also leads to less capacity of the MRMU than that in an optimal situation.

From Table V, we can see that the three MRMUs show relatively the same milling performance. The three MRMUs produce an average total yield of rice (*TYR*) between 60.41 to 64.96%, with the lowest values of 51.25-54.83% and the highest values of 71.42-73.95%. This finding is in line with the data provided in [27], with an average total yield of rice of 69%. All MRMUs produce hull or husk, the outer skin covering the rice between 15.0 and 17.7% and bran fraction between 18.8 and 20.5%. Loss fraction of 1.11-1.43% most likely happened from husk outlet blowing air out with strong force so that some husks went out and spread to the surrounding. Rice husk resulted in our study compared to that reported in Juliano and Tuaño [47], where the husk corresponds to 16– 28% of the raw rice.

Consumable white rice is gained after polishing which also produces rice bran. However, the bran fraction in our study is considerably high because the bran layer is very thin and contributes only 6–7% (weight base) of brown rice [37]. Rice bran is rich in protein but contains high fibers, making it a low-value product used especially for animal ration [48]. The amount of bran removed is related to the quality of the white rice. For most consumers, sensory traits such as color and appearance define grain quality [49]. The high level of bran, and thus the degree of milling, implies that the people of East Lampung prefer well-milled rice. This is a disadvantage because nutrients are concentrated mainly in the germ and bran layers of the rice grain [10]. Some important components like Vitamin B, amino acids, and minerals considerably decrease as *DM* increases [33]. Bran is not only directly related to the rice's color and appearance but also the rice's taste when it is cooked. More bran means the rice is more intensively polished and results in the rice being whiter and fluffier.

C. Rice Yield and Quality

Table VI shows the quality of mills and rice produced. From Equation (5), we can calculate the *DM* to be 22.5% for MRMU A, 23.3% MRMU B, and 24.4 MRMU C. Refereeing from the whiteness index (38.13-39.76%), white rice produced from MRMUs has the same quality as commercial rice (38.56%) in traditional markets. The whiteness index correlates directly to DM, which is defined as the extent to which the germ and bran layers of brown rice kernels are removed during the milling process. Rice whiteness is one of the key sensory parameters for evaluating milled rice quality [1]. Polishing or whitening is a vital operation of the rice milling process. Prolonging whitening duration has been reported to cause a reduction in *HRY* and an increase in *DM* [33]. Choi *et al*. [50] also observed that the whiteness value is greater significantly as *DM* increases in black rice. Sandhu et al. [30] reported a decrease of *HRY* from 69.05% at *DM* 2% to 56.28% when the *DM* is increased to 8% for a short-grain variety. Milling intensity improves lightness, which correlates to whiteness, of milled rice from 61.90 for brown rice to 66.44, 69.36, and 70.92 for light, medium, and heavy milling, respectively [51].

The white rice that resulted in our work has almost the same moisture content, between 13.98 and 14.48%, slightly higher than rice sold in traditional markets (13.23%). *TRY,* and *HRY* are other major indicators of rice milling quality [29]. The fraction of head rice reached 57.34-61.42%, lower than commercial rice in traditional markets (69.28%). Likewise, the fraction of broken rice (36.55-40.48%) was higher than commercial rice (29.41%). In addition to rice varieties, one factor that influences the composition of head and broken rice is the moisture content of the raw rice. Rice grains with a moisture content of 14% have significantly lower broken rice than those of grains with a moisture content of 8-12% [29]. *HRY* is a powerful factor affecting the price of rice [52]. The MRMU in this study produced an average *HRY* in the narrow range of 57.34 to 61.42, significantly lower than that of rice commercially sold in the traditional markets. This is also lower than the study reported in [29] using an abrasive rice miller. In addition, the lowest *HRY* of the MRMU is 35.24 to 41.05%, far below the average value of 60% for medium rice grade 3 [53]. The low quality of white rice produced from MRMU was also indicated by the high level of broken rice, which averaged between 36.55 and 40.48%. This value is significantly higher than the minimum limit for broken rice required by the national standard for medium rice grade 3, which is 35% [53]. This may have resulted from improper drying techniques, which cause high broken rice. For instance, farmers spread rice grains with a very thin layer (about 3 cm thick) to expedite the drying process. Rice drying using sun rays with a thin layer results in low-head rice [54].

The results also showed that white rice produced from MRMU mills had a whiteness index between 38.13 and 39.76%, the same as rice in traditional markets, 38.56%. The whiteness index is an important sensory parameter for milled rice. Rice with a higher whiteness index is mostly more attractive to customers [55]. The whiteness index is closely related to *DM*. A positive relationship between the whiteness index and *DM* has been reported. Polishing produces whiter rice with lower nutrients and bioactive compounds [56]. The degree of whiteness of rice produced by MRMU is in accordance with the people's general preferences. Recently, consumers have favored whiter rice with higher *DM*, though with a lower *HRY* and less nutrient [35]. For example, a recent survey in 24 cities in South and Southeast Asia (including Indonesia) shows that consumers prefer milled rice with high whiteness. In addition, consumers in Southeast Asia show fewer preferences towards characteristics of the firm and dry texture of cooked rice [55]. A survey in three major cities in Indonesia showed that rice consumed by the people has an average whiteness index of 35.55% (Ujung Pandang), 37.38% (Medan), and 39.24% (Jakarta) [57].

TABLE VI
MILLING PERFORMANCE (IN %)

Parameter		MRMU A	MRMU B	MRMU C
Degree of milling (DM, %)		22.5	23.3	24.4
Rice composition (%)				
White rice, average (%)		64.96	60.41	61.62
White rice, min–max (%)		54.83-73.95	51.25-71.42	51.31-72.09
Rice bran, average (%)		18.83	20.47	19.89
Rice bran, min–max (%)		13.54-22.05	17.34-23.52	15.34-22.41
Rice husk, average (%)		15.05	17.75	17.02
Rice husk, min–max (%)		11.45-22.58	10.20-26.25	10.41-24.73
Losses, average (%)		1.11	1.33	1.43
Losses, min–max (%)		0.92-1.61	0.72-1.97	0.77-2.14
White rice quality	Market	Machine A	Machine B	Machine C
Moisture content, average (%)	13.23	13.98	14.48	14.19
Moisture content, min–max (%)		11.58-16.74	10.76-16.44	12.78-16.39
Head rice, average (%)	69.28	61.42	57.34	58.26
Head rice, min–max (%)		41.05-75.14	37.45-71.54	35.24-74.33
Broken rice, average (%)	29.41	36.55	40.48	39.54
Broken rice, min–max (%)		24.20-55.84	27.30-59.41	24.41-61.63
Fine broken (*Menir*), average (%)	1.29	2.07	2.17	2.25
Fine broken (*Menir*), min–max (%)		0.66-3.34	1.16-3.57	1.07-3.87
Whiteness index (%)	38.56	39.53	39.76	38.13

TABLE VII
FINANCIAL EVALUATION OF MRMU OPERATION

Cost Component	MRMU A	MRMU B	MRMU C	AVERAGE
Investment (machine + garage), *P* (IDR)	29,000,000	17,000,000	20,000,000	22,000,000
Interest rate, *i* (%/y)	9	9	9	9
Economic life, *N* (year)	5	5	5	5
Total salvage value (10% *P*)	2,900,000	1,700,000	2,000,000	2,200,000
Working hour (h/y)	1,600	1,600	1,600	1,600
Actual capacity, *Ca* (kg/h)	98.43	63.58	64.06	75.36
Rice milling charge (IDR/kg)	666.67	666.67	666.67	666.67
FIXED COST (IDR/h)	*4,315.94*	*2,594.69*	*3,025.00*	*3,311.88*
Interest, *I* (IDR/h)	897.19	525.94	618.75	680.63
Depreciation, *D* (IDR/h)	3,262.50	1,912.50	2,250.00	2,475.00
Tax or equivalent annuity (IDR/h)	156.25	156.25	156.25	156.25
OPERATING COST (IDR/h)	*30,658.74*	*30,478.10*	*28,889.93*	*30,008.92*
Fuel (IDR/h)	12,368.51	10,894.35	10,423.11	11,228.65
Lubrication (IDR/h)	365.38	875.00	304.55	514.98
Parts and maintenance (IDR/h)	1,155.63	1,458.73	1,521.25	1,378.54
Operator (IDR/h)	16,000.00	16,000.00	16,000.00	16,000.00
Repair and maintenance (IDR/h)	769.23	1,250.00	641.02	886.75
TOTAL COST (IDR/h)	*34,974.68*	*33,072.78*	*31,914.93*	*33,320.80*
Unit Cost, *UC* (IDR/k)	355.33	520.19	498.21	457.91
Break Even Point, *BEP* (kg/y)	22,180	28,342	28,730	26,417
Benefit-Cost Ratio (*BCR*)	1.50	1.11	1.13	1.27
Net Present Value, *NPV* (million IDR)	166.00	43.47	50,11	86.53
Internal Rate of Return, *IRR* (%)	167.97	83.88	82.47	120.92
Payback Period, *PBP* (y)	0.635	1.257	1.277	0.882

D. Economic Performances

As discussed earlier, actual capacity, fuel consumption, and economic data, as given in Table VI, are used to calculate economic parameters. The assumptions used in this calculation include an economic life of 5 years with a residual investment value of 10%, 9% annual interest following KUR BRI 2018, 1600 hours of annual working time following the Minister of Public Works and Public Housing Regulation Number 28/2016 for small machines, and 16,000 IDR/h wages for operator and cooperator. As presented in Table VII, the results show that the total operating cost of MRMU ranges from 31,914.93 to 34,974.68, with an average of 33,320.80 IDR/h or 457.91 IDR/kg. The total operating cost consisted of the fixed cost of 3,311.88 IDR/h (10%) and the variable cost of 30,008.92 IDR/h (90%). Labor cost is the largest component of the variable cost achieving 16,000.00 IDR/h or 53.3%, Followed by diesel fuel of 11,228.65 IDR/h or 37.4%. This is in accord with other studies reporting that labor and fuels are the major components of variable cost [25]. The results also show that at the current milling charge of 666.67 IDR/kg, the MRMU operation reaches a break-even point (BEP) in the range of 22,180 to 28,730 kg/y (average 26,417 kg/y) with a very short payback period between 0.635 and 1.277 years (average 0.882 y). This implies that the MRMU business is very attractive to be considered as an economic venture. The economic viability of this business is also supported by the benefit-cost ratio (BCR) values of 1.11 to 1.50 (average of 1.27), positive NPV between 43.47 million and 166.00 million IDR (average 86.53 million IDR), and a very impressive IRR of 82.47 to 167.97%/y (average 120.92%). The government's incessant efforts to increase rice production further strengthen the prospects for MRMU in the future.

E. Sensitivity Analysis

The sensitivity analysis is carried out by reducing the annual working hours to 800 h and lowering the milling charge to 500 IDR/kg (Figure 4). A decrease in annual working time up to 800 h has increased the unit cost of the rice milling process from 457.91 IDR/kg to 468.93, 483.63, and 504.21 IDR/kg for 1400, 1200, and 1000 h, respectively. A decrease in working time up to 1000 h resulted in an increase in the unit cost by 10.1%. Assuming a fixed milling charge of 666.67 IDR/kg, the reduction in working hours also increases BEP by 13.5%, from 16,210 kg/y at 1600 h/y working hour to 18,399 kg/y at 1000 h/y working hour. The average BCR decreased significantly from 1.27 to 1.08, whereas the IRR fell from 179.24 to 68.89%. The increase in the payback period from 0.61 to 1.31 years is still much lower than the five years of economic life. Overall, the change in annual working hours from 1600 to 1000 h results in parameters that meet the economically feasible criteria, provided that the milling charge is still 666.67 IDR/kg. However, based on the BCR value, it is implied that the return will be marginally acceptable at 1000 h annual working time. Further decrease in the annual working hour up to 800 h will significantly affect the feasibility of the MRMU operation. Figure 4 reveals even though the NPV (4.20 million IDR), IRR (31.0%), and payback period (2.54 y) are still within the acceptable limits, the BCR value at 800 h working hours is 0.98, less than one. Therefore, the MRMU can be operated with working hours of at least 1000 h a year. This is important because the real working time of the MRMU, as discussed earlier, is between 4.06 and 5.05 h a day. To get 1000 h annual working hours, the MRMU must be operated for 200 to 250 days. This will be a big challenge for areas with a maximum of two times paddy cultivation, like most rice fields in East Lampung.

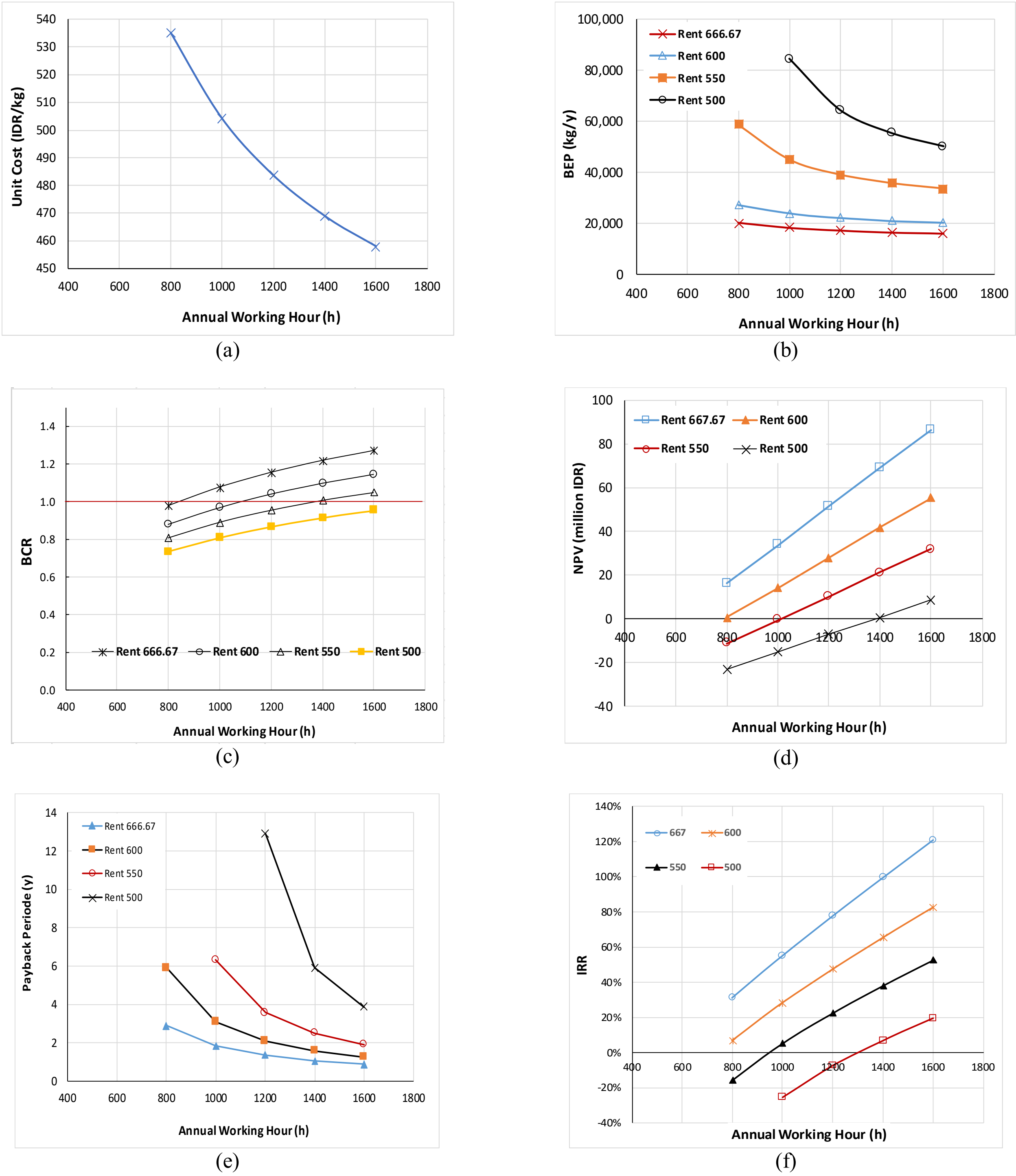

Fig. 4 Sensitivity analysis: (a) Effect of a working hour on the unit cost of MRMU; (b) Effect of working hour and milling charge on BEP; (c) BCR; (d) NPV; (e) payback period; and (f) IRR.

Figure 4 also shows the effect of decreasing annual working hours and lowering MRMU milling charges on the changes in economic parameters, namely BEP, BCR, payback period, and IRR, respectively. The reduction of the milling charge to 600 IDR/kg does not change the economic feasibility of the MRMU operation during the annual working hour from 1100 to 1600 h. If the annual working hours drop to less than 1100, then the MRMU operation with a milling charge of 600 IDR/kg will result in a BCR value of less than one, so it is not economically feasible. A decrease in milling charges up to 550 IDR/kg is still acceptable as long as the annual working hour is not less than 1400 hours with economic parameters of IRR 38%, NPV 21.06 million IDR, BCR 1.005, and a payback period of 2.5 y. However, operating an MRMU with 1400 h/y results in a marginal BCR value close to unity. At the milling charge of 550 IDR/kg, the reduction in the working hour to 1200 h/y is unacceptable because it produces a BCR of 0.95 (less than 1), even though other parameters are good, such as NPV positive (10.30 million IDR), IRR 22.42%, and payback period 3.57 y (less than five years). Figure 4 also shows that a reduction in the milling charge price of up to 500 IDR/kg is unacceptable with working hours up to 1600 h.

IV. Conclusion

Research on MRMU performance has been conducted with three samples of MRMU units in East Lampung, Indonesia. Technically the MRMU has an ideal capacity between 305.6 and 424.8 kg/hr, but the actual working capacity is only between 63.29 and 98.82 kg/h. The MRMU working time ranged from 4.06 to 5.05 h/d with a milling charge of 666.67 IDR/kg white rice. Rice milling using MRMU produced a white rice yield of 60.41 to 64.96%, with a whiteness index equal to rice sold in traditional markets. From the composition of broken rice and head rice, the milling results of MRMU have not met the national standard criteria where head rice is lower than the standard and broken rice is higher than the standard. The case study of three mobile rice mills unit in Lampung Timur suggests that the rice milling operation is profitable in the long run. The MRMU operation meets the economic feasibility criteria at a minimum working hour of 1000 h/y on a 666.67 IDR/kg milling charge. At working hours of 1600 h/y, the reduction in milling charges up to 550 IDR/kg is still profitable but very marginal. At a milling charge of 500 IDR/kg, the operation of the MRMU is not economically feasible. The operation of MRMU in East Lampung needs to be controlled to make the business still good because the number of MRMUs operating has approached the maximum point.

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