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Biological, Technical, and Financial Feasibilities Study of *Spirulina* sp. Biomass Production with Modified Commercial Medium in Indonesia

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Abstract

Spirulina sp. is the most common cyanobacteria commodity used in the bioindustry for functional food, source of protein, bioactive compounds, and biopigment. Production of *Spirulina* sp. still facing several problems such as high cost of culture medium with the less effective result, especially in developing countries. The medium was modified with commercial chemicals and fertilizers locally available in Indonesia to reduce the production cost. This study aimed to assess the biological, technical, and financial feasibility of *Spirulina* sp. biomass production using a modified commercial medium. Based on the biological feasibility study, the modified commercial medium (ZK1 and ZK2) gives a similar result to the standard medium, equal for growth rate and protein content. However, the result contains lower fat, carbohydrates, and biopigment. The financial feasibility analysis suggested that the system is feasible starting from 1.2-1.5 kg biomass production in a month. The best result gained on the production capacity of 5 kg biomass using ZK2 medium, with NPV of IDR 183,208,962 (US$12,769), IRR of 73%, B/C ratio of 7.8, and payback period in 7 months. It can be concluded that modified commercial medium was biologically, technically, and financially feasible to be applied in industrial biomass production of *Spirulina* sp.

Keywords: bioindustry; commercial medium; feasibility study; mass production; *Spirulina*

1. Introduction

Spirulina sp. is blue-green algae containing highly bioactive compounds introduced as the "best food for the future" at the World Food Conference since 1974. *Spirulina* sp. could be used as a source of nutritional supplements with several advantages, e.g., high potential to be cultured even in a limited space, integrable with aquaculture production systems, and accountable in needs of protein and vitamin sources for food crisis (1). In 1993, the World Health Organization (WHO) introduced *Spirulina* sp. as an "interesting food for multiple reasons, contain rich iron and proteins, also eligible to be administered to children without any risk". Since then, *Spirulina* sp. treated as a superfood, a highly beneficial healthy food, and market demand for *Spirulina* sp. product continue to increase (2). According to Meticulous Research (3) the global *Spirulina* sp. market is estimated to grow to 68,025.2 tons per year in 2025. The fastest growth will likely occur in the Asia-Pacific region, within any sectors such as the nutrition sector, the food and beverage industry, agriculture, and the cosmetics industry.

The biomass production of *Spirulina* sp. is considered less feasible in developing countries because of high production costs due to high medium costs and production technology. Research and development of alternative medium for *Spirulina* sp. cultivation has been widely done in Indonesia, including utilizing industrial wastewater. However, the alternative medium is limited to laboratory scale, and the unstandardized nutrient of culture medium could affect biomass product quality. In this study, the standard medium was modified with commercial chemicals and fertilizers locally available in Indonesia to reduce the production cost and make it feasible for industrial biomass production without decreasing the nutrient content. The

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feasibility study was carried out by analyzing the biological, technical, and financial feasibilities of modified commercial medium for the biomass production of *Spirulina* sp.

2. Materials and Method

This research was conducted from September 2019 to March 2020 in Aquatic Ecology Laboratory and Biopond Room SITH ITB. The study was conducted in three steps: the analysis of biological feasibility; analysis of technical feasibility or operational; and financial feasibility analysis, on a pilot scale (with 500 L of medium volume) outdoors.

2.1. Research Materials

Spirulina sp. culture obtained from the Brackish Water of Fisheries and Aquaculture Center (BBPBAP) Jepara, Indonesia. The used culture medium is differentiated into three formulations, i.e., the Zarrouk Medium as a standard medium for *Spirulina* sp. (ZM), Zarrouk Medium substituted with commercial chemicals and fertilizers (ZK1), and substituted medium with reduction of some commercial chemicals and fertilizers (ZK2). Formulations of each medium are shown in **Table 1**.

The phosphate source on the standard medium, KH_2PO_4, is modified and substituted with Super Phosphate in ZK1 and ZK2. The substitution was performed due to the less affordable cost of K2HPO4 and its unavailability of commercial grade. The cost of K2HPO4 amounted to IDR 9,000 per gram while the cost of Super Phosphate was IDR 4 per gram, then this substitution suppresses the medium cost significantly. Super Phosphate was also used by Raoof et al. (4) and Ranjith et al. (5) to reduce medium cost for industrial scale.

Table 1. *Spirulina* sp. medium formulations.

Zarrouk Medium ($g.l^{-1}$)		ZK1 medium ($g.l^{-1}$)		ZK2 medium ($g.l^{-1}$)	
$NaHCO_3$	16.8	$NaHCO_3$*	16.8	$NaHCO_3$*	16.8
$NaNO_3$	2.5	$NaNO_3$*	2.5	$NaNO_3$*	2.5
K_2SO_4	1	K_2SO_4*	1	Super Phosphate	0.33
NaCl	1	NaCl*	1	$MgSO_4$*	0.2
K_2HPO_4	0.5	Super Phosphate	0.33	Na_2EDTA*	0.08
$MgSO_4$	0.2	$MgSO_4$*	0.2	$FeCl_3$*	0.01
Na-EDTA	0.08	Na_2EDTA*	0.08	Note :	
$CaCl_2$	0.04	$CaCl_2$*	0.04	*: commercial grade	
$FeSO_4$	0.01	$FeCl_3$*	0.01		

2.2. Biological Feasibility Study

The assessment of biological feasibility is conducted based on biomass production performance and nutrient quality of *Spirulina* sp. Measurement of growth rate was carried out by taking Optical Density data at a wavelength of 520 nm (OD_{520}) using UV-Visible spectrophotometer. Obtained data were then converted into total biomass with a standard regression curve. Biomass productivity is calculated with the following equation :

$$Px = \frac{Xm - Xi}{Tc} \qquad (6)$$

where Px=Productivity ($g.l^{-1}.d^{-1}$); Xm=maximum biomass concentration ($g.l^{-1}$); Xi= initial biomass concentration ($g.l^{-1}$); Tc=maximum biomass time (days).

Proximate analysis is performed to determine proteins, fat, carbohydrates, and biomass water content. Protein content was measured with Semimicro Kjeldahl method, fat analysis with Hydrolysis (*Weibull*) method, carbohydrates with Titration (i.e., Luff-Schoorl method), and biomass moisture analysis with Gravimetric (Oven) method.

Chlorophyll and carotenoid content were analyzed by mixing the methanol solvent with 10 mL centrifuged biomass of *Spirulina* sp. culture at 6,000 rpm for 5 minutes. The supernatant was then separated from biomass to be extracted using 10 ml solved methanol for 30 minutes. Then, centrifugation was carried out to obtain pigment extract at 6,000 rpm for 15 minutes. The supernatant was observed with a spectrophotometer at a wavelength of 461 nm, 650 nm, 653 nm, and 664 nm [6]. The chlorophyll and carotenoid content were then calculated using the following equation :

$$\text{Chlorophyll (mg/L)} = 25.5 \times A650 + 4 \times A653 \qquad (7)$$

$$\text{Carotenoids (mg/L)} = (A461 + (0.046 \times A664)) \times 4 \qquad (7)$$

2.3. Technical Feasibility Study

The technical feasibility is assessed based on the biomass production scheme and operational necessities for biomass

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production. Materials, equipment, and facilities required for cultivation were accounted for technical analysis based on their specification and quantity. The production scheme was developed based on the real condition in *Spirulina* sp. production site during the study period.

2.4. Financial Feasibility Study

The financial feasibility was analyzed based on collected data from surveys and experiments. Before being analyzed for financial feasibility, all data were projected to produce 1,2-1,5 kg, 3 kg, and 5 kg dry biomass/period during five years of production. The financial feasibility is analyzed based on the investment feasibility, which is determined by the net present value (NPV), internal rate of return (IRR), benefit-cost (B/C) ratio, and payback period. The formulas are described below :

$$NPV = \frac{Net\ Value\ 1}{(1+r)} + \frac{Net\ Value\ 2}{(1+r)^2} + \cdots - Investment\ Cost \quad (8)$$

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2} \times (i_2 - i_1) \quad (8)$$

$$BC\ ratio = \frac{\sum PV\ Net\ Value}{\sum PV\ Investment} \times 100\% \quad (8)$$

$$Payback\ Period = \frac{Investment}{net\ value/\ year} \times 1\ year \quad (8)$$

where, i1 = discount rate 1; i2 = discount rate 2; NPV1 = net present value 1; NPV2=net present value 2.

2.5. Statistical Analysis

All data were subjected to one-way variance analysis (ANOVA) using IBM SPSS Statistics.

3. Results and discussion

3.1. Biological Feasibility Analysis

3.1.1. Growth Rate and Biomass Production

Biomass production profile was measured to determine *Spirulina* sp. growth on a pilot scale that will be used to determine the production flow, harvest time, and find out the amount of biomass produced. Before entering the stationary phase, the harvest time was chosen when the culture growth reached the middle of the log phase. This consideration aims to keep the culture in the log phase after harvesting to the maximum production rate. *Spirulina* sp. biomass production profile in pilot-scale and biomass productivity is shown in **Figure 1** and **Table 2**.

A single production period using ZK1 medium was carried out for 24 days with three harvesting times without medium addition. The first harvest was on the 10th culture day with the amount of biomass 1.48 gram/liter, the second harvest was on the 17th culture day with the amount of biomass 1.44 gram/liter, and the third harvest was on the 24th day with the amount of biomass 1.33 gram/liter. Whereas on ZK2 medium, a single production period was carried out for 26 days. The first harvest was done on the 10th day with the amount of biomass produced was 1.68 gram/liter, the second harvesting on the 18th day with the amount of biomass was 1.61 gram/liter, and the third harvesting on the 26th day with the amount of biomass was 1,52 gram/liter. Biomass produced from ZK2 medium was more than biomass from ZK1 medium ($p<0.05$). For 500-liter scale production, the use of ZK1 medium can produce 379 grams of dry biomass, while the ZK2 medium produces 429 grams of biomass. Therefore it is known that biomass productivity for ZK1 medium is 0.140±0,031 gram/liter/day and ZK2 medium is 0.144±0,017 gram/liter/day (**Table 2**).

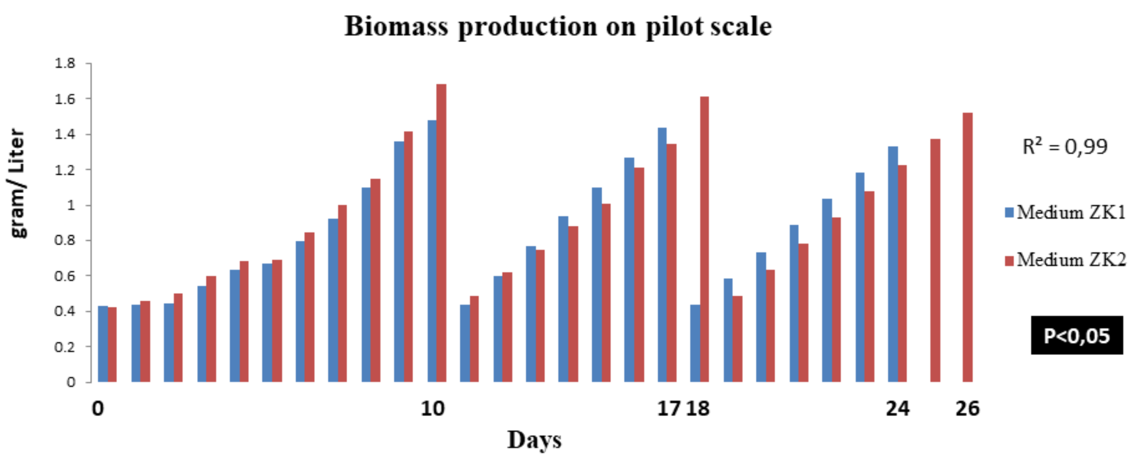

Figure 1. The biomass production profile of *Spirulina* sp. on a pilot scale.

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Table 2. Biomass production and productivity.

ZK1 medium			ZK2 medium		
Day	Biomass ($g.l^{-1}$)	Productivity ($g.l^{-1}d^{-1}$)	Day	Biomassa ($g.l^{-1}$)	Productivity ($g.l^{-1}d^{-1}$)
0	0.428	0.140±0.031	0	0.425	0.144±0.017
10	1.48		10	1.68	
17	1.44		18	1.61	
24	1.33		26	1.52	

3.1.1. Biochemical Analysis

Biochemical compounds were analyzed for protein, lipid, carbohydrates, water content, and biopigment chlorophyll and carotenoid. The results of biomass biochemical compounds from the ZK1 and ZK2 medium compared to the biomass produced from the standard medium (ZM), are shown in **Figure 2**. The biomass protein content of ZK1 medium was 52.29%, ZK2 medium was 52.25%, not significantly different.from the ZM medium, which was 52.95%. For fat content, biomass from ZK1 medium was 3.01%, ZK2 medium was 2.99%, lower than ZM medium, which was 7.16%. Also, for carbohydrates content, ZK1 medium was 6.76%, ZK2 medium was 5.97%, lower than ZM medium, which was 13.2%. Proximate content of *Spirulina* sp. from modified commercial medium (ZK1 and ZK2) generally have equivalent to the standard medium (ZM) for protein content but lower for lipid, carbohydrates, and biopigment (**Figure 2**).

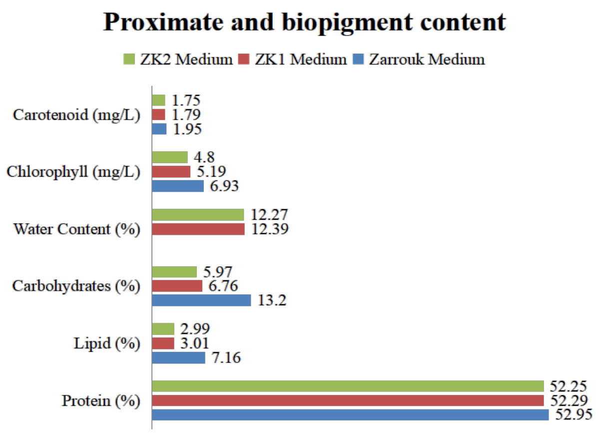

Figure 2. Biochemical analysis of *Spirulina* sp. biomass from each medium.

3.2. Technical Feasibility Analysis

3.2.1. Production Requirement

At each stage of the production flow, identification of production equipment and materials is carried out along with ongoing research. The needs for tools and materials are generally grouped into pre-production materials, production materials, and post-production materials. The need for raw materials for production is analyzed in terms of specifications and quantity that will be used for financial analysis. The primary raw materials are *Spirulina* sp. inoculum, growth medium, and freshwater. The production equipment is cultivation tanks, aeration equipment, electricity, water pumps, harvesting equipment, and drying equipment (**Table 3 – 6**).

Based on the facilities and production analysis results, the farm layout can be determined to produce *Spirulina* sp. biomass using a modified commercial medium. The sizes and specifications of the farm layout are referred to the facilities' needs of each medium and production volume (**Figure 3 and 4**).

Table 3. Production factors and specifications.

Production Factors	Specifications
Spirulina sp. inoculum	*Spirulina* sp. inoculum as a starter to have a biomass of about 1.5 $g.l^{-1}$, obtained from *Spirulina* sp. culture that has been in the maximum growth phase or stationary phase (after 10 days of cultivation).
Medium	The growth medium is made with a modified formulation. Chemicals are grounded physically before being used.
Freshwater	The freshwater has been sterilized using chlorine and Na-thiosulfate. Chlorine is added as much 1.2 $mL.L^{-1}$ and aerated for 24 hours, then add 0.06 $g.l^{-1}$ of Na-thiosulfate and aerated for 24 hours. After that, the water was sterile and ready to be used for cultivation.

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Table 4. Production materials quantity among different production capacity.

Production materials	Production with ZK1 medium			Production with ZK2 medium		
	1.5 kg	**3 kg**	**5 kg**	**1.2 kg**	**3 kg**	**5 kg**
Spirulina sp. starter	200 L	400 L	660 L	150 L	350 L	600 L
Medium	2000L	4000 L	6600 L	1500 L	3500 L	6000 L
Freshwater	1800 L	3600 L	5940 L	1350 L	3150 L	5400 L
Chemicals and Disinfectants	3 sets	5 sets	8 sets	2 sets	4 sets	7 sets

Table 5. Production facilities specifications.

Production Facilities	Specifications
Cultivation tank	As the main equipment for cultivation, the tank is round with 175 cm length, 100 cm width, and height of 50 cm.
Aeration Equipment	Serves to provide aeration or air supply in *Spirulina* sp. culture. It consists of an aerator, aeration hoses and air regulator, and aeration stones.
Electricity	Electricity is an energy source for lights, aerators, and water pumps.
Water pump	Function to drain water from and to the system at the beginning of cultivation and when harvesting.
Harvest Equipment	Serves to harvest biomass. It consists of filter cloth, mesh basket, and spatula to collect biomass.
Drying Equipment	Serves to dry the biomass of *Spirulina* sp. so the biomass can be stored for a long time. Drying equipment consists of an oven, drying mat, blender, and airtight container.

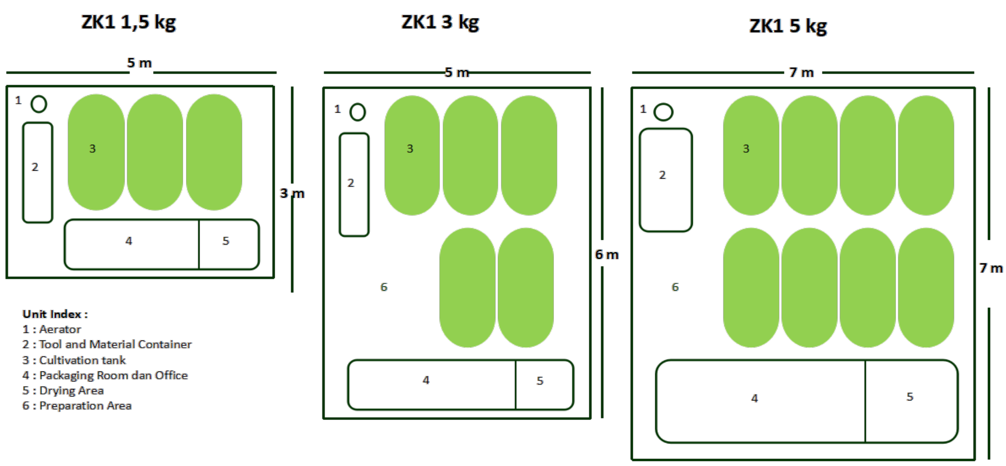

Figure 3. Farm layout of *Spirulina* sp. biomass production with ZK1 medium in different production capacities.

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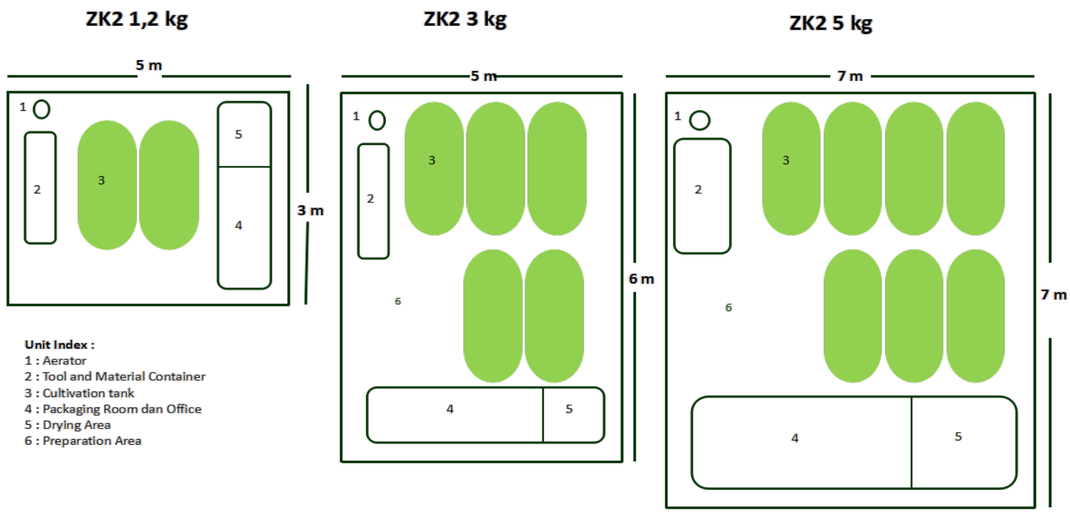

Figure 4. Farm layout of *Spirulina* sp. biomass production with ZK2 medium in different production capacities.

Table 6. Production facilities quantity among different production capacity.

Pronduction facilities	**Quantity (Scale)**		
	1.2-1.5kg	**3 kg**	**5 kg**
Land and Building	15 m^2	30 m^2	49 m^2
Pre-Production set			
Tool and material containers	2 units	2 units	2 units
Digital scale (5kg)	1 unit	1 unit	1 unit
Beaker glass (500 mL)	1 unit	1 unit	1 unit
Drop pipette	1 pc	1 pc	1 pc
Spatula/spoon	1 pc	1 pc	1 pc
Duster	1 pc	2 pc	2 pc
Cultivation set			
Cultivation tank	3 units	5 units	8 units
Aerator	1 unit	1 unit	1 unit
Aeration hose	1 roll	1 roll	1 roll
Aeration stone	6 pc	10 pc	16 pc
Electrical terminal	1 pc	1 pc	1 pc
LED lights	3 units	5 units	8 units
Harvesting set			
Water pump	1 unit	1 unit	1 unit
PVC hose ¾ inch	6 m	6 m	6 m
Screening (100x160 cm)	1 pc	1 pc	1 pc
Harvesting containers	1 unit	1 unit	1 unit
Drying set			
Oven	1 unit	1 unit	1 unit
Alumunium pan	3 pc	3 pc	3 pc
Polyvinyl plastic (200x100cm)	1 pc	1 pc	1 pc
Blender	1 unit	1 unit	1 unit
Mortar (d. 6 cm)	1 pc	1 pc	1 pc
Spatula	1 pc	1 pc	1 pc
Biomass containers	2 units	2 units	2 units

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3.3. Financial Feasibility Analysis

The financial feasibility of *Spirulina* sp. biomass production with the modified commercial medium was analyzed based on the calculation of overall costs, such as cost of raw materials, equipment, and production facilities, the supporting costs needed during the production process, as well as the profits obtained. Furthermore, investment analysis is calculated to determine the feasibility of *Spirulina* sp. biomass production with ZK1 and ZK2 medium, each with three production scales: 1.2-1.5 kg/month, 3 kg/month, and 5 kg/month dry biomass.

The financial feasibility of *Spirulina* sp. biomass production with the modified commercial medium was analyzed with the assumptions: Single production period last about ± 30 days; products are sold per 100 grams at a price of IDR.150,000/pcs; the production costs are *Spirulina* sp. inoculum or starter cost, medium cost, electricity, freshwater, sterilization materials, and other supplies in the form of consumable goods; the investment costs are the cost of production facilities which consist of pre-production set, production set, harvesting set, and drying set, in the form of non-consumable goods; supporting cost consist of the cost of labor, packaging, and marketing; investment discount rate of 12%.

3.3.1. Financial Cost Calculation

Production costs needed for production using ZK1 medium at 1.5 kg/month production capacity is IDR. 793,300, Required cost for 3 kg/month production capacity is IDR 1,463,860, and for 5 kg/month production capacity is IDR 2,342,440. Whereas, required cost for production with ZK2 medium at 1.2 kg/month production capacity is IDR 564,830, 3 kg/month production capacity requires a cost of IDR 1,176,740, and 5 kg/month production capacity requires a cost of IDR 1,922,650.

Operational cost per production period calculated from production cost, depreciation, and supporting cost in one production period. Investment costs for production with ZK1 medium at 1.5 kg/month production capacity is IDR 12,196,400, IDR 21,434,400 for 3 kg production capacity, and IDR 36,791,400 for 5 kg production capacity. As for production with ZK2 medium at 1.2 kg, production capacity requires a cost of IDR 11,077,400, at a production capacity of 3 kg/month requires a cost of IDR 21,434,400, and at a production capacity of 5 kg of IDR 35,672,400 (**Table 7**).

3.3.2. Financial Ratio Calculation

A project is considered feasible if the NPV is positive, the IRR value is greater than the interest rate, and the value of the B/C ratio is greater than 1 (8). It is known that the ZK1 medium is feasible to be used in the production of *Spirulina* sp. with a minimum production scale of 2000 L with a production capacity of 1.5 kg of dry biomass, with a positive NPV value of IDR 35,996,141, the IRR is greater than the 12% interest rate which is 16%, the B/C ratio is greater than 1 which is 5.06, and the payback period in 11 months. The ZK2 medium is feasible to be used for the production of *Spirulina* sp. with a minimum production capacity of 1500 L with a production capacity of 1.2 kg of dry biomass, with an NPV of IDR 28,245,878, IRR of 42%, B/C ratio of 4.5, and payback period in 13 months. The best result is obtained from the production of *Spirulina* sp. with ZK2 medium with a production scale of 6000 L with a production capacity of 5 kg of dry biomass in a month (**Table 8**).

3.3.3. Cost Efficiency of Modified Commercial Medium

Modified commercial medium from the Zarrouk medium used in this study has several advantages. Those are easy to obtain because of their availability in local market suppliers, low cost, and ability to compete with the standard medium productivity. However, the disadvantage of the commercial medium is its solubility is not as good as the Zarrouk medium because the available supply form is some material in granular form, and not all are available in powder. This can be overcome by grinding the medium physically before use. Cost efficiency obtained with this modified commercial medium could reduce costs up to 96% compared to the Zarrouk medium (**Figure 5**). Comparison of medium cost and productivity compared to previous studies is shown in **Table 9**.

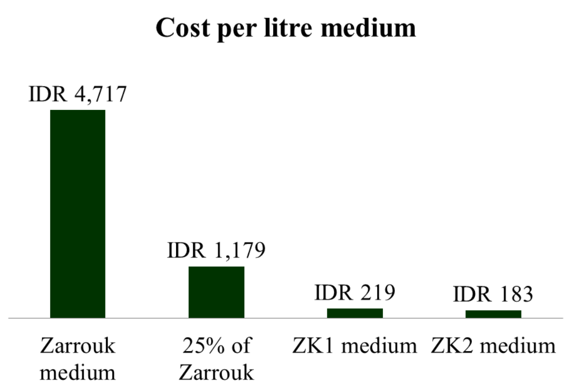

Figure 5. Modified commercial medium (ZK1 and ZK2) cost compare with Zarrouk medium.

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Table 7. Financial cost calculation among different medium and production capacities.

	ZK1 medium			ZK2 medium		
Production capacity	**1.5 kg**	**3 kg**	**5 kg**	**1.2 kg**	**3 kg**	**5 kg**
Production Cost (IDR)						
Medium	440,000	877,000	1,447,000	275,520	642,880	1,102,080
Spirulina sp. starter inoculum	200,000	400,000	660,000	150,000	350,000	600,000
Electricity	120,000	129,400	143,640	115,110	129,360	138,800
Chemicals	18,300	30,500	48,800	12,200	30,500	42,700
Freshwater	12,000	24,000	40,000	9,000	21,000	21,000
Other	3,000	3,000	3,000	3,000	3,000	3,000
Total (IDR)	**793,300**	**1,464,000**	**2,342,440**	**564,800**	**1,176,700**	**1,922,600**
Operational Cost (IDR)						
Labor (3 x 3 hours)	150,000	150,000	300,000	150,000	150,000	300,000
Packaging	50,000	50,000	50,000	50,000	50,000	50,000
Marketing	50,000	50,000	50,000	50,000	50,000	50,000
Depreciation	92,610	138,532	196,782	76,115	138,532	177,365
Total (IDR)	342,600	388,500	596,700	326,100	388,500	577,300
Total Cost/cycle	**1,136,000**	**1,852,500**	**2,940,000**	**891,000**	**1,565,000**	**2,500,000**
Capital Cost (IDR)						
Pre-production set	579,400	579,400	579,400	579,400	579,400	579,400
Cultivation set	4,312,000	6,550,000	9,907,000	3,193,000	6,550,000	8,788,000
Harvesting set	158,000	158,000	158,000	158,000	158,000	158,000
Drying set	1,147,000	1,147,000	1,147,000	1,147,000	1,147,000	1,147,000
Land and Building	6,000,000	13,000,000	25,000,000	6,000,000	13,000,000	25000000
Total (IDR)*	**12,196,400**	**21,434,400**	**36,791,400**	**11,077,400**	**2,143,4400**	**35,672,400**

*tax not included

Table 8. Financial ratio calculation among different medium and production capacities.

	ZK1 medium			ZK2 medium		
Dry Biomass	1.5 kg	3 kg	5 kg	1.2 kg	3 kg	5 kg
Revenue/cycle (IDR)	**2,250,000**	**4,500,000**	**7,500,000**	**1,800,000**	**4,500,000**	**7,500,000**
COGM (IDR)	75,727	61,750	58,784	74,245	52,175	43,500
Profit/cycle	11,14,090	2,647,477	4,560,778	909,055	2,934,737	5,059,985
NPV	35,996,141	93,088,345	160,495,608	28,245,878	105,514,441	183,208,962
IRR	16%	48,00%	71,00%	42,00%	72,00%	73,00%
B/C ratio	5.06	6.85	6.87	4.5	7.5	7.8
Payback Period	11 months	9 months	8 months	13 months	8 months	7 months

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Table 9. Medium cost and productivity among the different mediums of *Spirulina* sp. biomass production.

Medium	Medium cost/ton	Productivity ($g.l^{-1}.d^{-1}$)	Reference
RM6	16 US$	0,03	(4)
Zarrouk (Egypt)	80 US$	$5,2x10^{-5}$	(9)
Reduced Cost Medium	13 US$	$2,8x10^{-5}$	
Zarrouk (India)	7635,128 Rs	-	(5)
Modified Zarrouk	7108,128 Rs	-	
NRC	5022,46 Rs	-	
Modified NRC	5215,06 Rs	-	
NPK (P2C2)	86,62 US$	0,077	(10)
CMU02	13,14 US$	0,037	(11)
SKM	180,80 US$	0,121	(6)
MKM	5,47 US$	0,141	
Zarrouk (Indonesia)	329,86 US$	-	This study
ZK1	15,31 US$	0,140	
ZK2	12,79 US$	0,144	

4. Conclusion

Based on the biological feasibility study, the modified commercial medium (ZK1 and ZK2) gives a similar result to the standard medium (Zarrouk), equal for growth rate and protein content. However, the result contains lower fat, carbohydrates, and biopigment. The technical feasibility analysis suggested that the production period with ZK1 medium was 24 days with 3 times of harvesting (day 10, 17, and 24), and the ZK2 medium was 26 days with 3 times of harvesting (day 10, 18, and 26). The financial feasibility analysis suggested that the system is feasible starting from 1.2-1.5 kg biomass production in a month. Based on this study, it can be concluded that the modified commercial medium is feasible for Spirulina sp. biomass production at a small-scale home industry in Indonesia.

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