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Product, process and net present worth analysis of a palm oil-based beta carotene industry

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ABSTRACT

Despite having abundant of natural sources of vitamin A, Indonesia currently imports all its need for vitamin A, which amounted to 683 tons in 2018. This paper evaluated possible alternatives and recommended the best scheme to establish a domestic vitamin A industry based on technical, economic and social aspects. Possible natural sources for producing vitamin A were discussed and the best choice was selected. Then, the most suitable vitamin A product and process were designed together with a financial scheme to enable its operation. Our analysis showed that the best ingredient to produce local vitamin A industry is crude palm oil (CPO), processed through extraction using hexane and isopropanol as solvents and HP-20 DIAION as adsorbent, resulting high concentrate beta carotene and light-colored CPO for further palm cooking oil production. The proposed business scheme was to integrate the proposed industry with an existing palm cooking oil industry for a guaranteed raw material supply and further process into palm cooking oil. Investment required in this design was IDR 108.3 billion (USD 7.3 million) for a capacity of 100 kg/day (35 ton/year) with expected 63.6% internal rate of return and 3 years payback period.

Keywords: Crude palm oil (CPO), Vitamin A, Beta carotene, Extraction, Net present worth.

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1. INTRODUCTION

Indonesia currently fulfils its domestic need of vitamin A through imports, which amounted to 683 tons in 2018 (CNBC-Indonesia, 2020). The need for vitamin A in the country has been increasing along with the enforcement of government's vitamin A fortification program in palm cooking oil, according to the national standard (SNI) 7709:2019. Food fortification was launched by the government to reduce cases of vitamin A malnutrition. One form of malnutrition caused by vitamin A deficiency is stunting (Desmond and Casale, 2017; Fatimah and Chondro, 2020). According to the Indonesian Basic Health Research (RISKESDAS) 2018, the prevalence of stunting among children under 5 years old in Indonesia is 27.7% (Budiastutik and Nugraheni, 2018), meaning that approximately 9.3 million children under 5 in Indonesia are affected by stunting.

Beta carotene is the most widely used natural pro-vitamin A in various industries. The demand for beta carotene is increasing globally for several uses such as fortification of food products, dyes for medicines, food supplements, animal feed, and for cosmetic products. The global beta carotene market is projected to grow by 3.93% (compound annual growth rate) over the period of 2020–2025 (Global-Market-Insights, 2021).

Indonesia is one of the largest countries producing palm cooking oil in the world, and palm cooking oil has a high content of beta carotene (Darnoko et al., 2002; Van het Hof et al., 2000; Rice and Burns, 2010). In the production process of palm cooking oil, carotenoids, the red source of vitamin A in palm oil, are gradually eliminated because customers do not like red/dark color in cooking oil. To fulfil government's requirement of vitamin A content in palm cooking oil, producers then fortify the cooking oil with imported synthetic vitamin A, which costs only USD 60 per kg and has bright-yellow color, thus favorable for use by cooking oil industries.

Meanwhile, beta carotene contained in commodities other than palm oil has not been commercialized to fulfil the domestic demand. Dunaliella Salina microalgae also has a high beta carotene content (Harvey and Ben-Amotz, 2020). Unfortunately, this microalgae is rarely produced, so that producing vitamin A from it requires integration with a cultivation of the microalgae.

The objective of this paper is to develop a thorough plan for a domestic vitamin A industry using available natural source of beta carotene in Indonesia. The scopes of this paper are to select raw material, to design product and process, and to study the feasibility of the proposed vitamin A industry from technical, economic and social viewpoints. Existing literature data was used for the selection and design. The results of this study will help policymakers and investors with making informed decisions about novel domestic vitamin A industry.

2. MATERIAL AND METHODS

2.1 Raw Material Selection

2.1.1 Vitamin A and Its Precursors

Vitamin A is a micronutrient that important in maintaining vision, immunity, reproductive growth and fetal development (Blomhoff, 2001). Pro-vitamin A is a precursor of vitamin A derived from plant foods. The term "pro-vitamin" is used to label a substance with little or no vitamin activity, but which can be converted to an active form through normal metabolic processes (Olson, 1989).

In general, pro-vitamin A has a form of carotenoid. Beta carotene is a type of carotenoid used in all industries in global market (Britton et al., 2009). Beta carotene is commonly used in pharmaceutical, nutraceutical, animal feed and dye industries for food and cosmetics (Das et al., 2007; Britton et al., 2009). The types of carotenoid converted to vitamin A in the body are beta carotene, alpha-carotene and beta-kryptoxanthin (Noviendri et al., 2011). Based on these facts, beta carotene is the appropriate vitamin A precursor to be produced in industries (Gul et al., 2015).

2.1.2 Potency of Beta Carotene Commercialization

Beta carotene in the global market is projected to grow at a compound annual growth rate (CAGR) of over 6%, with a value of more than USD 520 million between 2021 and 2027 (Global-Market-Insights, 2021). The significant use of beta carotene in animal nutrition and food and beverage industry is contributing to the growth of the global beta carotene market. The beta carotene market is divided into several uses, e.g., food coloring (with a major application in providing the yellow color to margarine), as a food additive to enhance the color of the flesh of fish and yolk of eggs, and to improve the health and fertility (Priyadarshani and Rath, 2012). Based on the type of production, beta carotene is divided into natural product extraction, chemical synthesis, microalgae extraction and fermentation methods (Market-Study-Report, 2019).

Animal feed applications contribute more than 30% of the overall beta carotene market share (Global-Market-Insights, 2021). Beta carotene is widely used in animal feed due to its antioxidant properties, which perform nutritional and regulatory functions in poultry, livestock, and fishery (Novoveská et al., 2019). In powder form, natural beta carotene is commonly used for coloring and for pro-vitamin A in animal feed for livestock, and poultry feed and fish and shrimp aquaculture (Kläui and Bauernfeind, 1981; Surai et al., 2001; Englmaierová et al., 2013). It acts as an essential nutrient and as an essential pro-vitamin to increase fertility and immunity for livestock.

Synthetic beta carotene dominates share of global beta carotene industry in 2019 (Global-Market-Insights, 2021). This product displays a very high conversion rate to vitamin A. Synthetic beta carotene holds a major share due to its wide-scale use in powdered soft drinks, butter (Mezzomo and Ferreira, 2016), and pharmaceuticals and cosmetic preparations (Stahl and Sies, 2012). However, with increasing health awareness regarding the harmful effects of artificial or synthetic ingredients, consumers in both developed and developing countries are turning to natural beta carotene products (Bogacz-Radomska and Harasym, 2018).

Powder form accounts for more than 80% of the overall beta carotene market size in 2019 (Global-Market-Insights, 2021). Powdered products are mainly used in pharmaceutical, animal feed and food processing applications due to their easier handling, low shipping costs, and good stability. It is mainly used for food and beverages, tablets, capsules, water-soluble foods, beverages, cosmetics, animal feed, and dietary supplements.(Globe-News-Wire, 2020).

2.1.3 Potential Sources of Beta Carotene

The selection of raw materials for the proposed vitamin A industry was analyzed based on beta carotene content in each raw material and their availability in Indonesia. Considering the potency of palm oil which has a high beta carotene content, the potency of palm oil is identified from palm oil derivative products (Table 1). Furthermore, the calculation of the potential value of beta carotene in each raw material is carried out to predict the beta carotene that can be produced annually. In Table 2, the potency of beta carotene (in ton/year) from palm oil and other sources are calculated based on annual production of each raw material in Indonesia.

The calculation in Table 2 suggested that crude palm oil (CPO) has the highest potency to be the raw material for producing beta carotene. The data shows that in 2020, Indonesia produced 49.12 million tons of CPO containing 18,518 tons of beta carotene, and the production is continuously increasing. The carotenoid content in red palm oil (RPO) is estimated to be 80% of CPO carotenoid (Sundram et al., 2003), while Nagendran et al. (2000) explained that RPO contains 258 ppm of beta carotene. From this data we can see that the beta carotene content in RPO is lower than in CPO because RPO has experienced a heating process so that the beta carotene content is reduced. RPO annual production data is obtained from the calculation of RPO yielded from the CPO process, where RPO yields from CPO is 90% (Purnama et al., 2020). Therefore, it is estimated that the annual production of RPO is 90% of the annual production of CPO.

In addition to palm oil, the potency of mango is noticeable due to its high annual production. However, the content of beta carotene in carrot (in ppm) is much higher than mango. While beta carotene content in carrot is around 80% of the carotene value (Jeszka, 1997), beta carotene content of carrot generally ranges from 60 to 120 mg per 100 grams, and there are several varieties of carrot that contain up to 300 mg of carotene per 100 grams. Thus, carrot has the potency to be another alternative for the raw material for beta carotene production. However, since palm oil is massively cultivated for the production of palm cooking oil and biodiesel (Tan et al., 2009), the potency of beta carotene from palm oil is currently much higher than any other sources.

We selected palm oil as the raw material of beta carotene for the proposed industry based on two reasons. First, the potency of beta carotene from palm oil is much higher than any other sources, according to Table 2. Second, selecting palm oil as the raw material will open the opportunity to integrate the proposed industry with a currently operating palm cooking oil industry, thus help the implementation of the proposed industry.

2.2 Product Design

2.2.1 Main Product

The main product of the proposed vitamin A industry is beta carotene extracted from CPO, a product from palm oil through the extraction of palm bunches. CPO extraction from palm bunches can be physical or mechanical and does not need any chemicals. The specification of carotene as the product of the proposed industry is explained as follows.

- **Content:** According to Rivani et al. (2009), carotenoid content in palm oil ranges from 600–1000 ppm consisting of two components, i.e., xanthophylls (5%) and carotene (95%). In carotene, there are 29% of alpha-carotene, 64% of beta carotene, and 4% of gamma carotene, where alpha and beta carotene has pro-vitamin A activities between 0.9 and 1, respectively.
- **Daily requirements:** Daily requirements to meet the needs of vitamin A are shown in Table 3. Based on the need for vitamin A in Table 3, the consumption of beta carotene (which is equivalent to vitamin A) for adults is about 9,000 IU per day. Meanwhile, for children, it can be consumed at a dose of 2,000 IU per day. Beta carotene can be taken in the form of supplement or in the form of vegetables and fruits. If taken as supplement, there are two types of beta carotene supplements can be consumed, i.e., water-based supplements and oil-based supplements. It is known that water-based beta carotene supplements can be absorbed better by the body compared to oil (Zhang et al., 2021). This may be due to the smaller water molecules compared to oil, which makes it easier for them to enter the cells and tissues in the body.
- **Raw material:** As discussed in Section 2.1, the raw material for beta carotene extraction is CPO since it is known that CPO has the largest beta carotene content than other natural ingredients (carrot and tomatoes). CPO is hugely available in Indonesia because of its large production of around 49 million tons per year. Additionally, after beta carotene extraction, CPO can still be reused for producing cooking oil.

Table 1. Content of beta carotene from palm oil derivative products (Nagendran et al., 2000)

Palm oil derivative products	Carotenoid content (ppm)	Beta carotene percentage (%)	Content of beta carotene (ppm)
CPO	673	56	377
Red palm oil	545	47.4	258

Table 2. Beta carotene potency from various natural sources (Southon and Faulks, 2003)

Source of pro-vitamin A		Beta carotene content (ppm)	Production in 2020 (ton/year)	Beta carotene potency (ton/year)
Palm oil	CPO	377	49,120,000	18,518
	RPO	258	44,208,000	11,406
Vegetable	Carrot	80*	650,000	52
	Spinach	45*	157,000	7.1
Fruit	Mango	31*	2,898,588	89.8
	Pawpaw	6.4*	1,016,388	6.5

*Common dietary sources of carotenoids in regular meals (µg/100 fresh weight)

- **Food Safety:** In the human body, beta carotene will be converted into two molecules, where only one molecule will be converted into vitamin A can be converted into vitamin A in human retinal pigment epithelial (RPE) cells in a regulated manner (Chichili et al., 2005). Until now, it is known that excess beta carotene content in the body can be changed and well controlled in the body so that there is no risk of vitamin A excess. This is quite different from synthetic vitamin A, because excessive synthetic vitamin A will become toxins in the body (Fallon and Boyer, 1990). The absorption of beta carotene in the human body is very quick, around 3–7 h after food enters the digestive tract (Wang, 1994). In other studies conducted on animals, it is shown that carotenoids are not mutagenic and teratogenic (Mathews-Roth, 1986). Doses of up to 180 mg of beta carotene per day have been used for many years to treat patients with erythropoietic protoporphyria, without evidence of vitamin A toxicity and without the development of abnormally elevated blood vitamin A concentrations.

Table 3. Daily requirements for vitamin A (Institute-of-Medicine et al., 2002)

Age	Daily requirements (mcg)			
	Male	Female	Pregnancy	Lactation
0-6 months	400	400	-	-
7-12 months	500	500	-	-
1-3 years	300	300	-	-
4-8 years	400	400	-	-
9-13 years old	600	600	-	-
14-18 years	900	700	750	1,200
19-50 years	900	700	770	1,300
51+ years	900	700	-	-

2.2.2 Side Product

The side product resulted from the extraction of beta carotene is CPO with reduced beta carotene content of approximately 200 ppm that can still be used for cooking oil production. Kasmin et al. (2016) showed that CPO quality slightly decreased from CPO before extraction in terms of free fatty acids (FFA), deterioration of bleaching index (DOBI), carotene content, oxidative stability and fatty acid composition of the oil. A slight increase in the value of fatty acid in the extracted CPO occurs due to heating in the extraction process and also separation using a solvent. Then, an increase in the value of moisture and purity can occur because it is less efficient in removing the isopropanol solvent residue.

CPO with low content of beta carotene can further be processed to produce cooking oil, i.e., through refinery, bleaching and deodorization stages.

2.3 Process Design

2.3.1 Methods of Beta Carotene Isolation from Palm Oil

Possible methods to isolate beta carotene from CPO at industry-scale are shown in Table 4. There are three methods considered for the proposed industry, i.e., adsorption, esterification and fluid extraction.

Since CPO in Indonesia is largely used to produce palm cooking oil, it would be an advantage to choose a method that is easier to integrate with existing cooking oil industries. With this in mind, we proposed to apply adsorption for beta carotene isolation since this method results reduced-red color CPO as a side-product that can be further processed to produce cooking oil. Meanwhile, esterification is commonly used to produce biodiesel (Chongkhong et al., 2009), and supercritical fluid extraction (SFE) is associated with high investment costs related to high pressure operations (Rosa and Meireles, 2005).

2.3.2 Production Process

The isolation of beta carotene from CPO will use synthetic polymer adsorbent as much as 0.777 mg of carotenoids per 1 gram of CPO, or about 90% of the total carotenoids (Wiyaratn and Watanapa, 2014). The extracted beta carotene will be in liquid form in the carotenoids. Raw materials used in the production process are CPO, HP-20 DIAION adsorbent, and hexane and isopropanol solvents. The use of HP-20 DIAION as adsorbent was based on You et al. (2001). The tools used in this production process are designed according to the needs of the CPO, i.e., storage tank, solvent tank I, solvent tank II, chromatography column, adsorption tank, CPO and solvent mixing tank, chromatography column, pump, stirrer, UV-vis spectrophotometry.

Table 4. Methods to isolate beta carotene from CPO

Method	Extraction process	Side results
Adsorption, solvolysis, distillation (Harahap et al., 2018)	Using a synthetic adsorbent that can absorb beta carotene. The adsorbent can be used 3-5 times. Followed by separation using certain solvents (e.g. isopropanol and hexane).	CPO (reduced/lost red color), adsorbent, solvent
Esterification, solvolysis, distillation (Razi et al., 2022)	Using the esterification method to produce fatty acid methyl ester (FAME). Followed by separation using a solvent (hexane).	FAME (biodiesel industry), solvent
SFE (Davarnejad et al., 2008)	Extraction using supercritical fluids as the extracting solvent, using certain tools at low temperatures and high pressures.	CPO (reduced/lost red color), adsorbent, solvent

The production process of beta carotene (1 MIU/gr) was based on (Karo-Karo and Pardosi, 2017) as shown in Fig. 1. First, CPO will be dissolved in isopropanol solvent until it is well dissolved. Furthermore, the adsorbent will be activated with isopropanol solvent before being loaded into the chromatographic column. After the adsorbent is inserted into the chromatographic column, CPO dissolved in isopropanol is also added to the column. Then, elution is performed using isopropanol solvent again and CPO will result a small amount of beta carotene. CPO from the chromatographic column will be evaporated until the residual solvent amount is small and can be reused for the production of cooking oil.

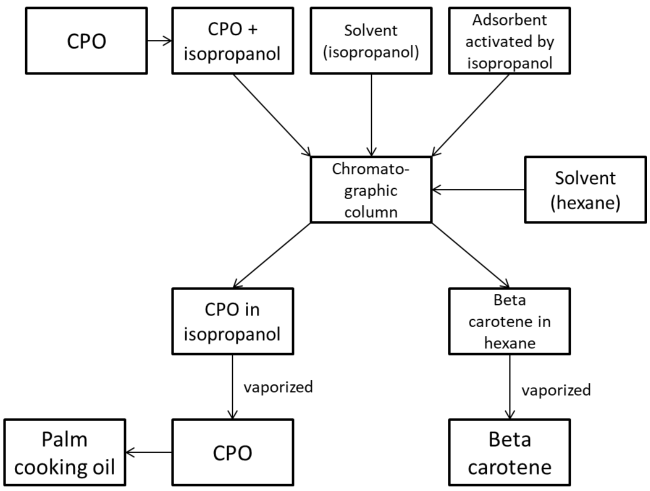

Fig. 1. Separation tool design

Extraction of beta carotene can be carried out using hexane solvent at a temperature of 30–50°C. Hexane is used because it can adsorb beta carotene compounds solved in the adsorbent. Hexane will continue to flow into the adsorbent until the color of the adsorbent is not red anymore, which means that all of the beta carotene has been successfully adsorbed from the adsorbent. Beta carotene in hexane then will also be evaporated until the solvent residue left is not more than 50 ppm.

In the process of beta carotene extraction from CPO, an adsorbent is used, i.e., equivalent DIAION HP-20 adsorbent which can be used up to three extraction runs. After that, the adsorbent should be replaced with a new one because the adsorbent may be saturated and cannot adsorb beta carotene anymore. We also proposed to use hexane and isopropanol as solvents, which can be used repeatedly because after the evaporation process, the solvent can be recaptured and reused through distillation (Aboagye et al., 2021). This is possible because the solvent is still clean and can function properly.

The main equipment used in beta carotene extraction is a chromatography tool, which is used to separate CPO and beta carotene according to the desired capacity. The design of the beta carotene separation device was based on Karo-Karo and Pardosi (2017), which provided an equipment design for a capacity of 100 kg CPO/day. The design of our proposed equipment linearly scaled this design to reach our planned capacity as provided in Section 2.4.

The extracted beta carotene can be delivered in the form of emulsion or liquid in a closed container, which has a shelf life of at least 3 months (Gomes et al., 2013). If a longer shelf life of beta carotene is desired, it can be stored in capsule or tablet form (Hosseini and Jafari, 2020). Additionally, beta carotene can also be formed into crystals so it can be stored much longer, and this can reduce the antioxidant activity of beta carotene (Gomes et al., 2013). Microencapsulation can also be performed to maintain beta carotene by encapsulating beta carotene in certain particles such as proteins and saccharides. Since the proposed industry will deliver its products to the next production stage, we proposed to deliver the product in containers.

2.3.3 Safety of Using Solvents in Beta Carotene Extraction

In the extraction of beta carotene using adsorption method, a solvent is used as a CPO solvent and beta carotene extraction. Beta carotene is a compound with long carbon that insoluble in polar water, acids, and alkalis. Therefore, beta carotene can be dissolved in chloroform, ether, hexane and oil. According to CODEX standards, beta carotene has been agreed to be used as food additives as a colorant or as a supplement (Beutner et al., 2001). Using a solvent to extract beta carotene, there are several solvents that are allowed such as hexane, acetone, methanol, and ethanol solvents (de Souza Mesquita et al., 2021).

2.4 Net Present Worth (NPW) Analysis

2.4.1 Production Capacity and Sales Projection

The proposed vitamin A industry was planned to have an installed a capacity of 100 kg of beta carotene per day or 30 tons per year. Product sales was projected to increase as shown in Table 5. The installed capacity is projected to be fully utilized in the 10th year.

Table 5. Beta carotene sales projection

Year	1	2	3	4	5	6	7	8	9	10
Beta carotene (ton)	3	5	8	11	14	17	21	24	27	30

2.4.2 Financial Summary

Our planned capacity was to produce 100 kg of beta carotene per day, which is equivalent to 128.7 tons of CPO as the raw material. This capacity was 1,287 times larger from that proposed in Karo-Karo and Pardosi (2017), which planned to process 100 kg of CPO per day. Assuming a linear scale up for main machinery, the total investment costs amounted to IDR 108.3 billion (see Table A1 in Appendix).

Variable production costs of beta carotene consisted of the cost of raw material, operators and electricity. For producing 1 kg of beta carotene, we required 1,287 kg of CPO, 429 kg of adsorbent, together with solvents and packaging for the resulting products. The production cost of beta carotene equaled to IDR 48,421 per gram (see Table A2 in Appendix). Based on the variable costs calculated above, the proposed selling price of beta carotene is IDR 65,000 per gram, which is sold in 100-gram packages for pharmaceutical and food industries. Meanwhile, fixed costs for the proposed industry consisted of indirect worker salaries, maintenance, depreciation and general fees. Projected fixed costs per year amounted to IDR 22.2 billion (see Table A3 in Appendix).

The financial summary for the proposed industry is presented in Table 6. Projected revenues for the ten-year period are shown in column 3, obtained by multiplying the selling price and sales projection in column 2 (sales projection in column 2 came from Table 2). The revenues were then reduced by variable cost to obtain gross profit, then by fixed cost to obtain earning before tax and interest (EBIT), then by interest and tax to obtain earning after tax (EAT), consecutively in column 4 to 10. Finally, cash flow at year 0 in column 11 shows investment costs, also cumulative cash flow in column 12.

Net present worth (NPW) of the proposed industry is given by Equation (1):

$$NPW = CAPEX + \sum_{t=1}^{n} \frac{CF_t}{(1+i)^t} \quad (1)$$

where CAPEX is the total investment cost, CF_t is cash flow at year t, i is the interest rate, and n is the analysis period. At an interest rate of 12 percent, the cash flow in Table 6 resulted an NPW of IDR 721.2 billion. Internal rate of return (IRR) of the project, the interest rate that results NPW = 0, is 63.6%. Meanwhile, the payback period, the time point where the cumulative cash flow (column 12 in Table 6) equals to zero, is 2.8 years.

3. RESULTS AND DISCUSSION

From the vitamin A industry proposed in Section 2, we have several notable points to discuss. First, we showed that the vitamin A industry proposed in this study is feasible technically, based on the availability of raw materials and process technology at industry scale, as presented in Section 2. Second, the beta carotene from the proposed industry was priced at IDR 65,000 per gram in bulk, while the price of imported beta carotene products in the market starts from IDR 466,000 per gram. This means, the product has a good opportunity to compete with imported beta carotene products in the market. The competitive price and the positive Net Present Worth resulting from the sales projection showed that the proposed industry is feasible economically. The fact that the product cannot yet compete with imported synthetic vitamin A (which costs only USD 60 or IDR 900,000 per kg) does not eliminate the economical feasibility since natural and synthetic vitamin A are two different products, and natural vitamin A (beta carotene) is better than the synthetic one in its absorption and its safety to human body.

Third, the best implementation scheme for the proposed industry is to integrate it with an existing palm cooking oil industry. This scheme will provide a certainty in the supply of CPO as the raw material, as well as an assurance that the side product of proposed industry will be used to produce palm cooking oil. As the proposed industry will not disturb the existing palm cooking oil supply chain nor will it harm the environment, we concluded that the industry is feasible socially. Fourth, since this study did not provide a detail engineering design (DED) for the proposed industry, a small scale plant should be piloted before establishing the proposed industry in a full scale. A pilot plant will detail and sharpen the production process and equipment thus helping the DED development.

Table 6. Projected cash flow per year (IDR millions)

Year [1]	Sales (kg) [2]	Revenue [3]	Variable cost [4]	Gross profit [5]	Fixed cost [6]	EBIT [7]	Interest [8]	Tax [9]	EAT [10]	Cash flow [11]	Cum. cash flow [12]
0										(108,325)	(108,325)
1	3,000	195,000	145,262	49,738	22,066	27,672	16,249	1,714	9,710	9,710	(98,615)
2	5,000	325,000	242,103	82,897	22,066	60,831	14,792	6,906	39,133	39,133	(59,482)
3	8,000	520,000	387,365	132,635	22,066	110,569	8,922	15,247	86,400	86,400	26,917
4	11,000	715,000	532,627	182,373	22,066	160,307	0	24,046	136,261	136,261	163,179
5	14,000	910,000	677,889	232,111	22,066	210,045	0	31,507	178,539	178,539	341,717
6	17,000	1,105,000	823,151	281,849	22,066	259,784	0	38,968	220,816	220,816	562,533
7	21,000	1,365,000	1,016,833	348,167	22,066	326,101	0	48,915	277,186	277,186	839,719
8	24,000	1,560,000	1,162,095	397,905	22,066	375,839	0	56,376	319,463	319,463	1,159,183
9	27,000	1,755,000	1,307,357	447,643	22,066	425,577	0	63,837	361,741	361,741	1,520,923
10	30,000	1,950,000	1,452,619	497,381	22,066	475,316	0	71,297	404,018	404,018	1,924,941

This study has made its contribution on several things. First, it provided a commercialization scheme on the beta carotene adsorption technology proposed in Bangun et al. (2015). While the adsorption method in Bangun et al. (2015) is promising, it required further study to implement the method in industry-scale, which this paper contributed. Second, this study provided a scaled up the small-scale prototype in Karo-Karo and Pardosi (2017) from 100 kg of raw material (CPO) to 100 kg of product (beta carotene). Therefore, this study provided investors and decision makers an alternative of implementing a lab-scale technology into an industry level.

It is necessary to remind some important notes related to the results of this study. First, the product and the process designed in this study can be implemented in any country. However, the Net Present Worth (NPW) analyzed in this study is dependent to the location of the industry. Thus, the NPW needs to be recalculated if the plan will be implemented outside Indonesia. Second, as a long term initiative, it is necessary to carry out further studies on the potential for vitamin A production from natural ingredients other than palm oil. The recommended natural material for further study is Dunaliella Salina as discussed briefly in Section 2. This microalgae has a very high beta carotene content per gram of its body, thus promising a high efficiency in producing beta carotene. Last, another relevant long term issue regarding to this study is the importance of educating Indonesian people about the goodness of red cooking oil, which contains a high content of beta carotene. If people accept red palm oil as their cooking oil, existing palm cooking oil industries can modify their production process to keep beta carotene in the cooking oil, thus there is no need to fortify the cooking oil with vitamin A.

4. CONCLUDING REMARKS

To reduce Indonesia's dependence on imported vitamin-A, a local pro-vitamin A industry can be established by using CPO as the raw material, based on its huge availability in Indonesian plantations, its high content of beta carotene and the availability of an efficient technology to extract beta carotene from it. The product of the proposed industry is beta carotene concentrate which can be used as raw material for pharmaceutical and food industries. Our study showed that the proposed industry is feasible in technical, economical and social aspects. Further studies need to be conducted on the potential for pro-vitamin A production from natural ingredients other than palm oil, such as carrot and microalgae.

REFERENCES

Aboagye, E.A., Chea, J.D., Yenkie, K.M. 2021. Systems level roadmap for solvent recovery and reuse in industries. Iscience, 24, 103–114.

Bangun, N., Sembiring, S.B., Putri, N.K., Karo, J.K. 2015. Performance of m-silicate and m-polystyrene sulfonate in extraction of carotenoids from crude palm oil. Procedia Chemistry, 16, 349–356.

Beutner, S., Bloedorn, B., Frixel, S., Hernández Blanco, I., Hoffmann, T., Martin, H.D., Mayer, B., Noack, P., Ruck, C., Schmidt, M. 2001. Quantitative assessment of antioxidant properties of natural colorants and phytochemicals: Carotenoids, flavonoids, phenols and indigoids. The role of β-carotene in antioxidant functions. Journal of the Science of Food and Agriculture, 81, 559–568.

Blomhoff, R. 2001. Vitamin A and carotenoid toxicity. Food and Nutrition Bulletin, 22, 320–334.

Bogacz-Radomska, L., Harasym, J. 2018. β-Carotene—properties and production methods. Food Quality and Safety, 2, 69–74.

Britton, G., Liaaen-Jensen, S., Pfander, H. 2009. Carotenoids: Volume 5: Nutrition and health.

Budiastutik, I., Nugraheni, S.A. 2018. Determinants of stunting in Indonesia: A review article. International Journal of Healtcare Research, 1, 43–49.

Chichili, G.R., Nohr, D., Schäffer, M., von Lintig, J., Biesalski, H.K. 2005. β-Carotene conversion into vitamin A in human retinal pigment epithelial cells. Investigative Ophthalmology & Visual Science, 46, 3562–3569.

Chongkhong, S., Tongurai, C., Chetpattananondh, P. 2009. Continuous esterification for biodiesel production from palm fatty acid distillate using economical process. Renewable Energy, 34, 1059–1063.

CNBC-Indonesia. 2020. Indonesia has the opportunity to become the world's king of vitamin A and E producers (ri berpeluang jadi raja produsen vitamin A dan E dunia). CNBC Indonesia. Retrieved 2022-12-09 from www.cnbcindonesia.com/news/20201209180712-4-207954/ri-berpeluang-jadi-raja-produsen-vitamin-a-dan-e-dunia.

Darnoko, D., Siahaan, D., Nuryanto, E., Elisabeth, J., Erningpraja, L., Tobing, P., Naibaho, P., Haryati, T. 2002. Palm oil processing technology and its derivative products (Teknologi pengolahan kelapa sawit dan produk turunannya). Pusat Penelitian Kelapa Sawit, Medan.[Indonesian].

Das, A., Yoon, S.-H., Lee, S.-H., Kim, J.-Y., Oh, D.-K., Kim, S.-W. 2007. An update on microbial carotenoid production: Application of recent metabolic engineering tools. Applied Microbiology and Biotechnology, 77, 505–512.

Davarnejad, R., Kassim, K., Zainal, A., Sata, S.A. 2008. Supercritical fluid extraction of β-carotene from crude palm oil using CO_2. Journal of Food Engineering, 89, 472–478.

de Souza Mesquita, L.M., Martins, M., Pisani, L.P., Ventura, S.P., de Rosso, V.V. 2021. Insights on the use of alternative solvents and technologies to recover bio-based food pigments. Comprehensive Reviews in Food Science and Food Safety, 20, 787–818.

Desmond, C., Casale, D. 2017. Catch-up growth in stunted children: Definitions and predictors. PloS One, 12, e0189135.

Englmaierová, M., Skrivan, M., Bubancová, I. 2013. A comparison of lutein, spray-dried chlorella, and synthetic carotenoids effects on yolk colour, oxidative stability, and reproductive performance of laying hens. Czech Journal of Animal Science, 58, 412–419.

Fallon, M.B., Boyer, J.L. 1990. Hepatic toxicity of vitamin A and synthetic retinoids. Journal of Gastroenterology and Hepatology, 5, 334–342.

Fatimah, D., Chondro, F. 2020. Relationship between giving vitamin A capsules and caregiver knowledge with stunting in children aged 24–59 months (Hubungan pemberian kapsul vitamin A dan pengetahuan caregiver dengan stunting pada anak usia 24–59 bulan). Jurnal Biomedika dan Kesehatan, 3, 176–182.

Global-Market-Insights. 2021. Beta carotene market size 2021–2027. Retrieved 2023-01-05 from www.gminsights.com/industry-analysis/beta-carotene-market.

Globe-News-Wire. 2020. beta carotene market value to hit $640 million by 2026, Says Global Market Insights, Inc. Retrieved 2022-11-10 from https://www.globenewswire.com/en/news-release/2020/11/10/2123479/0/en/Beta-Carotene-Market-value-to-hit-640-Million-by-2026-Says-Global-Market-Insights-Inc.html.

Gomes, G.V.D.L., Borrin, T.R., Cardoso, L.P., Souto, E., Pinho, S.C.D. 2013. Characterization and shelf life of β-carotene loaded solid lipid microparticles produced with stearic acid and sunflower oil. Brazilian Archives of Biology and Technology, 56, 663–671.

Gul, K., Tak, A., Singh, A., Singh, P., Yousuf, B., Wani, A.A. 2015. Chemistry, encapsulation, and health benefits of β-carotene-A review. Cogent Food & Agriculture, 1, 1018696.

Harahap, S., Nazar, A., Yunita, M., Pasaribu, R., Panjaitan, F., Yanuar, F., Misran, E. 2018. Isothermal approach to predict the removal efficiency of β-carotene adsorption from CPO using activated carbon produced from tea waste. IOP Conference Series: Materials Science and Engineering.

Harvey, P.J., Ben-Amotz, A. 2020. Towards a sustainable Dunaliella salina microalgal biorefinery for 9-cis β-carotene production. Algal Research, 50, 102002.

Hosseini, H., Jafari, S.M. 2020. Introducing nano/microencapsulated bioactive ingredients for extending the shelf-life of food products. Advances in Colloid and Interface Science, 282, 102210.

Institute of Medicine, Panel on Micronutrients, Food and Nutrition Board, Subcommittee on Upper Reference Levels of Nutrients, Subcommittee of Interpretation and Use of Dietary Reference Intakes, Standing Committee on the Scientific Evaluation of Dietary Reference Intakes. 2002. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Dietary Reference Intakes.

Jeszka, W. 1997. Food colorants. Chemical and functional properties of food components. Technomic Publishing Company Lancaster., 293.

Karo-Karo, J.A., Pardosi, H. 2017. Design and performance test of adsorption carotenoids separation equipment from palm oil (Rancang bangun dan uji kinerja peralatan pemisah karotenoida dari minyak sawit (CPO) hasil adsorpsi). Jurnal Teknik dan Teknologi, 12, 17–24.

Kasmin, H., Lazim, A.M., Awang, R. 2016. Effect of heat treatments on the yield, quality and storage stability of oil extracted from palm fruits. Malaysian Journal of Analytical Sciences, 20, 1373–1381.

Kläui, H., Bauernfeind, J. 1981. Carotenoids as food colors. Carotenoids as colorants and vitamin A precursors. Food Science and Technology.

Market-Study-Report. 2019. Global Beta Carotene Market 2019 by Manufacturers, Regions, Type and Application, Forecast to 2024. Retrieved 2022-12-12 from https://www.marketstudyreport.com/reports/global-beta-carotene-market-2019-by-manufacturers-regions-type-and-application-forecast-to-2024?gclid=Cj0KCQiAsqOMBhDFARIsAFBTN3fwknJ6QiONXFDuehImeEJVfkGSy2nbYJjJOqjlZCoCp29PYiu_K7QaAh68EALw_wcB.

Mathews-Roth, M.M. 1986. Beta-carotene therapy for erythropoietic protoporphyria and other photosensitivity diseases. Biochimie, 68, 875–884.

Mezzomo, N., Ferreira, S.R. 2016. Carotenoids functionality, sources, and processing by supercritical technology: A review. Journal of Chemistry, 2016.

Nagendran, B., Unnithan, U., Choo, Y., Sundram, K. 2000. Characteristics of red palm oil, a carotene-and vitamin E–rich refined oil for food uses. Food and Nutrition Bulletin, 21, 189–194.

Noviendri, D., Hasrini, R.F., Octavianti, F. 2011. Carotenoids: Sources, medicinal properties and their application in food and nutraceutical industry. Journal of Medicinal Plants Research, 5, 7119–7131.

Novoveská, L., Ross, M.E., Stanley, M.S., Pradelles, R., Wasiolek, V., Sassi, J.-F. 2019. Microalgal carotenoids: A review of production, current markets, regulations, and future direction. Marine Drugs, 17, 640.

Olson, J.A. 1989. Provitamin A function of carotenoids: the conversion of β-carotene into vitamin A. The Journal of Nutrition, 119, 105–108.

Priyadarshani, I., Rath, B. 2012. Commercial and industrial applications of micro algae–A review. Journal of Algal Biomass Utilization, 3, 89–100.

Purnama, K.O., Setyaningsih, D., Hambali, E., Taniwiryono, D. 2020. Processing, characteristics, and potential application of red palm oil-A review. International Journal of Oil Palm, 3, 40–55.

Razi, F., Azwar, A., Sofyana, S., Erfiza, N., Luxyana, M. 2022. Preparation and characterization of nanofiltration (NF) polyethersulfone and its preliminary studies on beta-carotene concentration from crude palm oil. IOP Conference Series: Earth and Environmental Science.

Rice, A.L., Burns, J.B. 2010. Moving from efficacy to effectiveness: Red palm oil's role in preventing vitamin A deficiency. Journal of the American College of Nutrition, 29, 302S–313S.

Rivani, M., Panjaitan, F., Hasibuan, H., Siahaan, D., Herawan, T. 2009. Optimasi penjumputan karotenoid dari metil ester sawit dengan proses solvolytic micellization. Jurnal Penelitian Kelapa Sawit, 17, 30–36.

Rosa, P.T., Meireles, M.A.A. 2005. Rapid estimation of the manufacturing cost of extracts obtained by supercritical fluid extraction. Journal of Food Engineering, 67, 235–240.

Southon, S., Faulks, R. 2003. Carotenoids in food: Bioavailability and functional benefits. In Phytochemical Functional Foods, 107–127.

Stahl, W., Sies, H. 2012. β-Carotene and other carotenoids in protection from sunlight. The American Journal of Clinical Nutrition, 96, 1179S–1184S.

Sundram, K., Sambanthamurthi, R., Tan, Y.-A. 2003. Palm fruit chemistry and nutrition. Asia Pacific Journal of Clinical Nutrition, 12.

Surai, P., Speake, B., Sparks, N. 2001. Carotenoids in avian nutrition and embryonic development. 1. Absorption, availability and levels in plasma and egg yolk. The Journal of Poultry Science, 38, 1–27.

Tan, K., Lee, K., Mohamed, A., Bhatia, S. 2009. Palm oil: Addressing issues and towards sustainable development. Renewable and Sustainable Energy Reviews, 13, 420–427.

Van het Hof, K.H., West, C.E., Weststrate, J.A., Hautvast, J.G. 2000. Dietary factors that affect the bioavailability of carotenoids. The Journal of Nutrition, 130, 503–506.

Wang, X.-D. 1994. Absorption and metabolism of beta-carotene. Journal of the American College of Nutrition, 13, 314–325.

Wiyaratn, W., Watanapa, A. 2014. The study of extraction beta-carotene from crude palm oil for analysis economic. Advanced Materials Research.

You, L., Baharin, B., Man, Y.C., Takagi, S. 2001. Effect of degumming process on chromatographic separation of carotenes from crude and degummed palm oil. Journal of Food Lipids, 8, 27–35.

Zhang, R., Chen, G., Yang, B., Wu, Y., Du, M., Kan, J. 2021. Insights into the stability of carotenoids and capsaicinoids in water-based or oil-based chili systems at different processing treatments. Food Chemistry, 342, 128308.

APPENDIX

Table A1. Investment cost (IDR)

No	Description	Volume	Unit	Unit cost	Total cost
	Machinery and factory facilities				
1	Raw material tank	1,287	units	4,026,275	5,181,815,925
2	Chromatographic column	1,287	units	38,652,240	49,745,432,880
3	Pump	1,287	units	9,663,060	12,436,358,220
4	Mixing machine	1,287	units	12,884,080	16,581,810,960
5	Finished product storage	1,287	units	6,442,040	8,290,905,480
6	50 kW electricity installation	1	units	48,450,000	48,450,000
7	Supporting equipment	1	set	1,000,000,000	1,000,000,000
8	Van car	1	units	300,000,000	300,000,000
9	Office furniture and equipment	1	units	500,000,000	500,000,000
				Sum	94,084,773,465
	Land and buildings				
1	Land acquisition 1 ha	10000	m^2	150	1,500,000,000
2	Factory building	5148	m^2	2,300,000	11,840,400,000
3	Office building	200	m^2	4,500,000	900,000,000
				Sum	14,240,400,000
	Total investment				108,325,173,465

Table A2. Variable cost per kg of beta carotene (IDR)

No	Description	Volume	Unit	Unit price	Total price
1	Raw material				
	- CPO	1,287	kg	1.3	1,673,100
	- Diaion HP20 eq. adsorbent	429.0	kg	90	38,610,000
	- Isopropanol	77.2	liter	45	3,474,900
	- Hexane	64.4	liter	35	2,252,250
	- Packaging	10	pack	15	150
2	Operator	8	man day	153,846	1,230,769
3	Electricity	710	kWh	1.45	1,029,600
	Production cost per kg				48,420,619
	Production cost per gram				48,421

Table A3. Fixed cost per year (IDR)

No	Description	Volume	Unit	Unit price	Total price
1	Indirect worker salary				
	General manager	13	man month	20,000,000	260,000,000
	Production manager	13	man month	15,000,000	195,000,000
	Admin manager & general	13	man month	12,000,000	156,000,000
	Staff	78	man month	8,000,000	624,000,000
2	Maintenance	1	set	7,477,762,143	7,477,762,143
3	Depreciation	1	set	10,682,517,347	10,682,517,347
4	General & admin fees	1	set	2,670,629,337	2,670,629,337
	Fixed cost per year				22,273,908,826