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THE ANCILLARY PRODUCTS OF RUBBER (*Hevea brasiliensis* Muell. Arg.): POTENTIAL RESOURCES TO ENHANCE SUSTAINABILITY

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Abstract Indonesia is one of the major natural rubber-producing countries. The low rubber prices severely affect rubber agribusiness as farmers and rubber companies depend on latex as the only source of income. This condition leads to an unprecedented challenge to rubber agribusiness sustainability. This systematic review aims to encourage the use of part of rubber plants as a source of revenue for rubber plantations to maintain their sustainability. Non-latex parts of the rubber plant can be utilized, including latex serum and skim waste, parts of rubber seeds, and rubberwood. The strength of the ancillary product of *Hevea brasiliensis* is that the raw materials are abundant, yet the weakness is that the rubber companies have no experience exploiting them. The opportunity for utilizing is widely open, as many methods have been researched; however, the main thread is how to compete with the existing products. Therefore, careful market research and feasibility studies are recommended.

Keywords: *agribusiness, bioenergy, latex serum, rubber prices, rubberwood, seeds*

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INTRODUCTION

Rubber (*Hevea brasiliensis* Mull. Arg.) is Indonesia's significant estate crop commodity. The Directorate General of Estate Crops of Indonesia reported that in 2020 the rubber plantation area in Indonesia was estimated to reach around 3.6 million hectares, consisting of smallholder farmers (88.12 %), state-owned plantations (5.17 %), and private plantations (6.71 %). In 2018, Indonesia exported 2.81 million tons of rubber worth around USD 3.95 million. Regarding employment, it is estimated that around 2.6 million workers were involved in rubber agribusiness, reflecting the importance of rubber commodities to the Indonesian economy.

The most valuable part of the rubber plant is the sap, so-called latex. A polyisoprene compound biosynthesized in laticifer cells through the mevalonate (MVA) and 2-c-methyl-d-erythritol-4-phosphate (MEP) pathways (Chow et al., 2012). It is harvested by tapping, slicing the bark to obtain latex that contains 30-45% of rubber particles (Jacob et al., 1993; Liengprayoon et al., 2017). Natural rubber can be processed into various products, mainly raw materials for vehicle tires, medical equipment, and household appliances. Natural rubber is usually blended with other synthetic rubber to produce desired outcomes.

The global natural rubber process has remained low in the last decade. Low rubber prices severely affect rubber agribusiness since farmers and rubber companies only depend on latex as their only source of income. Smallholding farmers generally sell rubber in form of cup lumps, while the large companies harvest rubber in the form of latex and cup lumps. Latex is processed into concentrated latex or ribbed smoke sheets. Cup lumps and other low-quality rubber such as ground lumps and scrap

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are processed into crumb rubber. Other parts of the rubber plant have potential as a source of income yet have not been optimized.

The rubber research has resulted in advances in non-latex utilization. Almost every part of the rubber plant can be processed into products with high economic value. Rubber seeds have been widely studied as raw materials for biodiesel, food and feed, and activated carbon (Nadia et al., 2021; Oladipo and Betiku, 2020; and Zulfikar et al., 2020). Rubber processing waste has been studied as a source of protein and bio-fertilizer (Iewkittayakorn et al., 2018; Tahir and Misran, 2019). Rubberwood can be processed as a substitute for forest wood (Arsad, 2009; Parra-Serrano et al., 2018). Other parts of the plant, such as leaves and roots, can be processed into biomass. To our knowledge, these ancillary products have not been exploited on an industrial scale.

This review summarizes the research in non-latex products of *H. brasiliensis*, describes the derivative products and discusses the challenges for actualization. It aims to encourage the use of part of rubber plant as a source of revenue to support rubber agribusiness competitiveness and sustainability. With such great potency, especially with the sizeable cultivated area possessed by Indonesia and the long lifespan of the plant, the ancillary products can support farmers and plantations amid low rubber prices.

RESEARCH METHODS

The systematic review work started with problem identification threatening rubber agribusiness sustainability, followed by strategy selection to withstand and listing of products and methods (Figure 1). Bibliographic databases accessed from online searching included Web of Science, Scopus, PubMed, ScienceDirect, Directory of Open Access Journals (DOAJ), Journal Storage (JSTOR), Agris-FAO, Agritrop-CIRAD, and Google Scholar.

Problems identification

A literature survey was carried out on global rubber production, consumption, and prices to identify problems encountered by rubber agribusiness. The effect of rubber prices on smallholding farmers and rubber companies was obtained through scientific publications.

Strategy Selection

Literature survey identified some strategies to withstand low rubber prices, including cost efficiency, increasing land productivity, and income diversification. To date, the latter strategy has not been widely studied. Therefore, it was selected as the strategy to be followed up.

Literature Survey on the Ancillary Products and Methods

A literature survey was carried out on using non-latex rubber parts with various methods. The literature survey allowed the identification of seven different strategies on latex serum utilization (Table 1). For skim waste processing, eight different methods were identified. Total 36 scientific papers on rubber seed processing were placed, consisting of 22 papers on seed kernel, 11 papers on seed shell, three papers on seed pericarp (Table 2). Six papers were included in the list for rubberwood utilization, while four papers were identified for the sawdust. These papers show how the ancillary products of rubber plants have been widely studied. Other studies besides those on the list may be available.

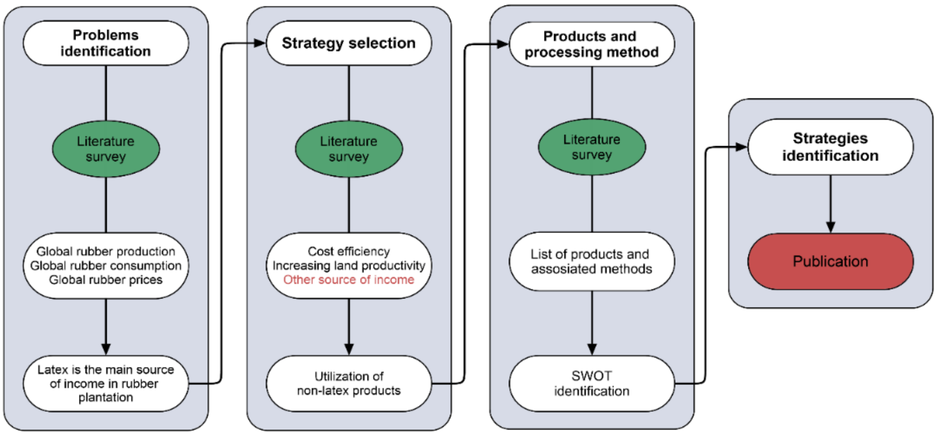

Figure 1. Strategies applied for literature review study

Strengths, weaknesses, opportunity, and threats identification

A guide from Sarsby (2012) was used for identification of strengths, weaknesses, opportunities, and threats (SWOT). The SWOT identification allowed for establishing a business strategy to exploit rubber ancillary products.

RESULTS AND DISCUSSION

Main Challenges of Rubber Agribusiness Sustainability

The rubber plant originates from upper stream of the Great Amazon River, covering parts of Brazil, Columbia, Guyana, Ecuador, and Venezuela. This perennial tree species can grow up to 40 m in height under optimum conditions (Wychherley, 1992). The most economically valuable part of *H. brasiliensis* is the latex, a milky colloidal compound that consists of 30 – 45 % of natural rubber particles. The percentage of rubber particles in a specific volume of latex is expressed as Dry Rubber Content (DRC). For the plant, latex is suggested to be part of the defense system from herbivores and pathogens (Konno, 2011; Ramos et al., 2019). Latex can be produced by 22 families of monocots and dicots covering +12,500 species (Lewinsohn, 1991). However, *Hevea brasiliensis* is the most economical latex producer due to its larger volume of latex produced than other species. Latex is harvested through the tapping activity for collecting fresh latex or coagulated cup lumps. Hundreds of rubber-derived products are used in daily life, including industrial equipment, construction, transportation, health, and household appliances.

Malaysia Rubber Council (MRC) reported that in 2020 global rubber production reached 27.4 million tonnes, while the consumption was 26.9 million tonnes (Figure 2A) (Malaysian Rubber Council, 2021). The Association of Natural Rubber Producing Countries (ANRPC) noted that global rubber prices have decreased since reaching their highest price of the current decade in February 2011 (USD 619.64/kg for Bangkok RSS) (Figure 2B) (Association of Natural Rubber Producing Countries, 2021). In the same period in 2020, the price of rubber for the same type of product was only USD 225.02/kg). Low rubber prices lessen the welfare of rubber farmers (A'ini and Jannah, 2016; Syarifa et al., 2016). For rubber plantation companies, low prices threaten the sustainability of rubber agribusiness amid production and labor costs. Su et al. (2019) identified five factors determining the global rubber prices i.e. supply and demand, smallholders' market inefficiencies, oil prices, exchange rate, and climate.

The low rubber prices effect is severely affected rubber agribusiness due to latex, to date, being the main or maybe the only product of rubber plantation. When the rubber prices decline, the revenue soon follows drastically drop. It is uncertain when the world economy could rebound from the global pandemic of COVID-19 effects, leaving rubber prices unclear at least for the next few years. On the other hand, production costs, including labor, fertilizer, pesticide, electricity, etc., keep increasing. This condition calls a perspective that rubber plantations could not rely only on latex as the source of revenue. Product diversification is a compulsion amid low prices and increasing costs. This paper highlights several by-products of rubber plants that have high economic values

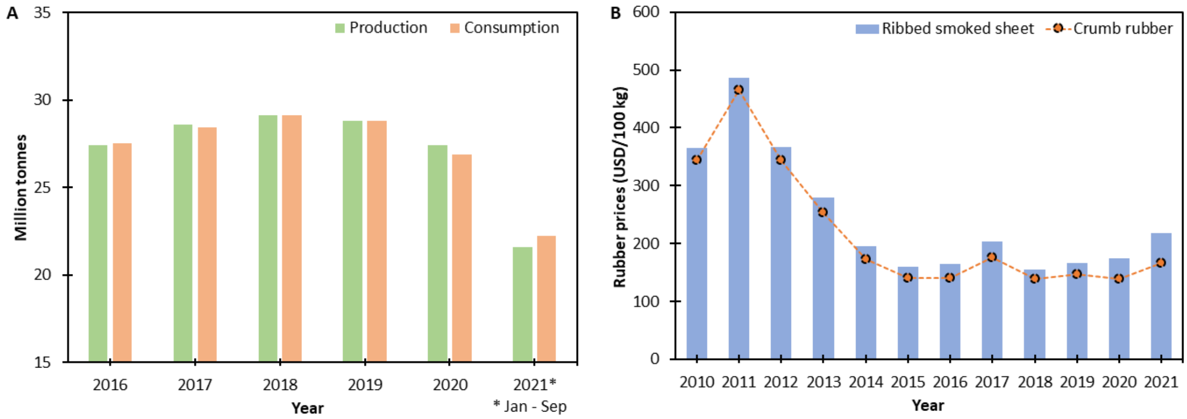

Figure 2. Global rubber production and consumption from 2016 to 2021 according to Malaysian Rubber Council (A) and global rubber prices from 2010 to 2020 according to The Association of Natural Rubber Producing Countries (B)

The Ancillary Products of Latex Serum and Skim Waste

The fresh latex contains about 60 % of water, 35 % of cis-1,4-polyisoprene (natural rubber), and 5 % of non-isoprene molecules. The non-isoprene compounds mainly consist of carbohydrates, proteins, lipids, and minerals (Bottier, 2020). Fresh latex can be separated into four fractions i.e. large rubber particles, small rubber particles, C-serum, and bottom fraction consisting of lutoids and Frey-Wyssling particles (also called B-serum) through a simple centrifugation method (Liengprayoon et al., 2017; 2021). The rubber industry is mainly interested in rubber particles, so latex serum has not received adequate attention. Several studies showed that latex serum could be processed into high-value products (Table 1). Kongjan et al. (2014) and Jariyaboon et al. (2015) reported that latex serum could produce bio-hydrogen and bio-methane, valuable bio-energy resource. Other researchers extracted protein from latex serum and showed a potential value, especially for pharmaceutical purposes

In the process of concentrated latex manufacturing; from 1 ton of the ammoniated field latex, it can yield 0.4 tons of concentrated latex and 2.4 m^3-mixed wastewater in the form of wash water and skim latex serum (Jariyaboon et al., 2015). The effluent degrades surface water quality besides generating malodor (Kumlanghan et al., 2008). The skim waste can be processed into various products. It can be transformed to produce hydrolases by dialysis method (Nazhirah and Faridah, 2013) or can be used as fungi and bacteria growing media by simple pH adjustment (Taysum, 1956; Mahat and MacRae, 1992). As skim waste contains ammonia; the chemical used to avoid unnecessary latex coagulation, it can be a useful fertilizer through a series of treatments.

The utilization of latex serum and skim waste is potential to be developed. The raw material of this industry is abundant in rubber plantations and can be supplied all year long. The other benefit is it may alleviate the environmental effect generated by rubber industry wastewater. The main challenge is that the results are still mainly at a research level; no real industry has been well established. Therefore, up-scaled research and prototype construction are required before industrial-level implementation can be reached.

Table 1. Potential use of *Hevea* latex serum and skim waste

Part of plant	Product	Method	Utility	Literatures
Latex serum	Bio-hydrogen and bio-methane	Sequential batch	Bio-energy	Jariyaboon et al. (2015)
	Bio-hydrogen and bio-methane	Up-flow anaerobic sludge blanket (UASB)	Bio-energy	Kongjan et al. (2014)
	L-quebrachitol	$Ba(OH)_2$, cationic and anionic exchanges	Pharmaceutical	Danwanichakul et al. (2019)
	α-globulin	Centrifugation, freeze-drying	Pharmaceutical	Archer and Cockbain (1955)
	Serum-C	Centrifugation, lyophilized	Anti-fungal	Daruliza et al. (2011)
	Serum-C	Centrifugation, freezing	Antioxidants	Kerche-Silva et al. (2016)
	Serum-B	Centrifugation, dialysis	Anti-cancer	Lee et al. (2012)
Skim waste	Fungi growing media	pH adjustment by NaOH	Single-protein production	Mahat and MacRae (1992)
	Bacteria growing media	pH adjustment	Research	Taysum (1956)
	Hydrolases	Centrifugation, dialysis	Industry	Nazhirah and Faridah (2013)
	Centrifuged residue	Drying under sunlight	Fertilizer	Uttraporn et al. (2012)
	Protein	Salting out, multiple centrifugations	Metal extraction	Tahir and Misran (2019)
	Compost	Mixing with NH_4OH	Fertilizer	Iewkittayakorn et al. (2017)
	Compost	EM4 composting agent	Fertilizer	Simanjuntak et al. (2018)
	Compost	Blending with organic matter	Fertilizer	Iewkittayakorn et al. (2018)

Derivative Products of Rubber Seed

The mature rubber fruit is a large three-lobed capsule, 3–5 cm in diameter, having a woody endocarp and a thin, leathery mesocarp, and contains three seeds. The fruit reaches its maximum size in about 80–90 days. The endocarp becomes woody in about 110 days and the endosperm matures in 130 days (Priyadarshan, 2011). *Hevea* seed behaves as recalcitrant with no dormancy, undergoes drying when physiologically ripe, and loses its viability quickly (Shuib et al., 2018). The main utilization of rubber seed is for rubber propagation as rootstocks in the grafting method. Although millions of seeds are required for planting material production annually, they are still more of them left on the field. When seeds become saplings, they behave as weeds and take the cost of controlling them. Rubber seed by-products are listed in Table 2.

Rubber seed utilization is one field that has been widely studied. A comprehensive review was published by Bhattacharjee et al. (2021). Various researches showed the potencies of rubber seed as vegetable oil (Abduh et al., 2016), feed (Lee and Wendy, 2017), food (Oluodo et al., 2018; Udo et al., 2018), and many other derivative products. At least three parts of the seed can be exploited. One is the seed kernel, which can produce bio-oil, protein, and biomass. The other parts are seed shells and pericarp which are usually processed to become activated carbon. Readers are encouraged to inspect the literature provided for further information. The main challenge to using rubber seeds on an industrial scale is that rubber plants produce seeds seasonally. The seed season only occurs once or twice a year in a concise period (1-2 months). As the geographical position determines the flowering season, seed season is also different from one place to another. It gives the advantage that the raw materials can be supplied throughout the year. For this, a wide range of supply chains needs to be established.

Table 2. Some derivative products from rubber seed

Part of plant	Product	Method	Utility	Literatures
Seed kernel	Bio-oil	Carbon dioxide	Cosmetic	Nian-Yian et al. (2014)
	Bio-oil	*n*-hexane	Cosmetic	Chaikul et al. (2017)
	Bio-oil	Acid esterification, base transesterification	Biodiesel	Ahmad et al. (2014) Sugebo et al. (2021)
	Bio-oil	MSCMO catalyst	Biodiesel	Nguyen & Nguyen (2017)
	Bio-oil	MeOH catalyst	Biodiesel	Oladipo & Betiku (2020)
	Bio-oil	Response surface method	Biodiesel	Panichikkal et al. (2018)
	Fatty acid	Hydrolysis	Bio-lubricant	Kamalakar et al. (2013)
	Flour	Drying at 60 ºC	Food	Nadia et al. (2021)
	Protein	Protein hydrolysis	Food	Widyarani et al. (2016)
	Protein	Biologic and microbes	Food	Abduh et al. (2017)
	Meal	Heating with wood fire	Feed - poultry	Koné et al. (2020)
	Meal	Boiling	Feed - poultry	Komilus et al. (2021)
	Meal	Soaking, cooking, toasting	Feed - poultry	Aguihe et al. (2017)
	Meal	Boiling, toasting	Feed	Udo et al. (2018)
	Meal	Hydraulic pressure	Feed - Fish	Annisa et al. (2020)
	Meal	Defatted with hexane	Feed - Fish	Fawole et al. (2016)
	Meal	Oven-dried, grinding	Feed - Fish	Lee & Wendy (2017)
	Meal	Grinding, ethanol addition	Feed - Fish	Hasan et al. (2016)
	Kaolin	NaOH reaction	Pharmaceutical	Mgbemena et al. (2013)
	Resin	Chemicals reactions	3-D printing	Hu et al. (2021)
	Bio-plastic	Copolymerization	Bioplastic	Obunwo et al. (2020)
Seed shell	Activated carbon	Grinding to be powder	Bio-absorbent	Nadarajah et al. (2018)
	Activated carbon	Ammonium chloride	Bio-absorbent	Priya & Helen (2020)
	Activated carbon	Grinding, *n*-hexane	Bio-absorbent	Zulfikar et al. (2020)
	Activated carbon	KOH activation	Bio-absorbent	Pagketanang et al. (2015) Borhan et al. (2016) Sari et al. (2020)
	Activated carbon	NaOH activation	Bio-absorbent	Wardani et al. (2021)
	Activated carbon	CO_2 activation	Activated carbon	Yan et al. (2019)
	Activated carbon	KOH activation	Capacitor electrode	Pagketanang et al. (2015) Farma et al. (2021)
	Chemicals	Semi-batch pyrolysis	Organic compounds	Reshad et al. (2018)
Seed pericarp	Activated carbon	Microwave	Bio-absorbent	Anis et al. (2014)
	Activated carbon	Heating at 400ºC	Bio-absorbent	Agarry and Owabor (2012)
	Activated carbon	HCl activation	Biochar	Hutapea et al. (2015)

Rubberwood as a Potential Revenue

Rubberwood has long been known to substitute forest wood for several purposes (Nancy et al., 2013; Towaha and Daras, 2013). The net income from rubberwood could reach IDR 29 millions, mainly used for replanting programs in large companies and smallholding farmers (Hendratno et al., 2015). Generally, rubberwood is sold to the wood processing industry; no rubber companies have processed rubberwood from their own land. If it is processed on its own, high added values can be obtained as rubberwood can be processed into various products. The well-known utilization of rubberwood is for furniture and light-structure materials. Several studies reported that rubberwood could be processed to produce bio-oil, bio-energy, and fertilizer (Table 3); even sawdust, the waste from the wood industry can be processed to become activated carbon and pellets.

Rubber plants are generally cultivated for 25-30 years. It means that approximately 4% of the total area of rubber plants has to be replanted every year. If a company has 5,000 hectares of a rubber area, it can produce 20,000 m^3 of processed timber per year (average 100 m^3/ha according to Woelan et al., 2012), not including other biomass that can be processed into various products with high economic values.

Other parts of the plant that can be utilized are flowers and leaves. Rubber flowers are a source of nectar that can be used for beekeeping (Wongsiri et al., 2000; Razak et al., 2016). However, on an industrial scale, this business is considered unsustainable due to the short flowering period, so the beekeeping has to be moved to follow the seasonal flowering pattern. Several studies also reported the use of rubber leaves as compost and briquettes (Maghfirah et al., 2021; Ismail et al., 2021), but this effort will affect soil fertility in rubber plantations, as leaf litter is a source of organic material so this business is considered unsustainable.

Table 3. Utilization of rubberwood

Part of plant	Product	Method	Utility	Literatures
Wood	Timber	Industrial process	Structure, furniture	Arsad (2009)
	Activated carbon	Retort method	Fertilizer	Dharmakeerthi et al. (2012)
	Briquettes	Heating, grinding	Bio-energy	Nurhayati (2018)
	Lignocellulose	Hydrolysis, pyrolysis	Bio-oil	Admojo and Setyawan (2018)
	Medium Density Fiberboard	Industrial process	Pulp and paper	Vachlepi (2015)
	Liquid smoke	Pyrolysis	Anti-fungal, bio-coagulant	Vachlepi and Ardika (2019)
Sawdust	Activated carbon	Steam-activation processes	Bio-absorbent	Kumar et al. (2005)
	Activated carbon	Chemical treatments	Bio-absorbent	Baral et al. (2006)
	Sawdust pellets	Grounding	Bio-energy	Kan et al. (2013)
	Sawdust pellets	CO_2 activation	Bio-energy	Taer et al. (2010)

Opportunities, Challenges, and Strategies

Parts of rubber plants have been described that can be processed into high economic value products and become a potential source of income for rubber plantation The strengths, weaknesses, opportunities, and threats were identified (Figure 3). The main advantage is the abundance of raw materials, some of which are even considered as waste (e.g. skim waste) or weeds (e.g. seeds left in the field). Processing these raw materials means reducing costs on rubber plantations.

Establishing a processing factory for rubber derivative products does not have to be done from scratch as it has been widely researched. Several studies have been published for one type of product; it is only necessary to select the proper and efficient method. Under low rubber prices and increasing costs conditions, labor efficiency is a rational policy. Establishing a processing factory for rubber by-products is one option to avoid employees' layoffs by allocating non-essential labor to this new business unit.

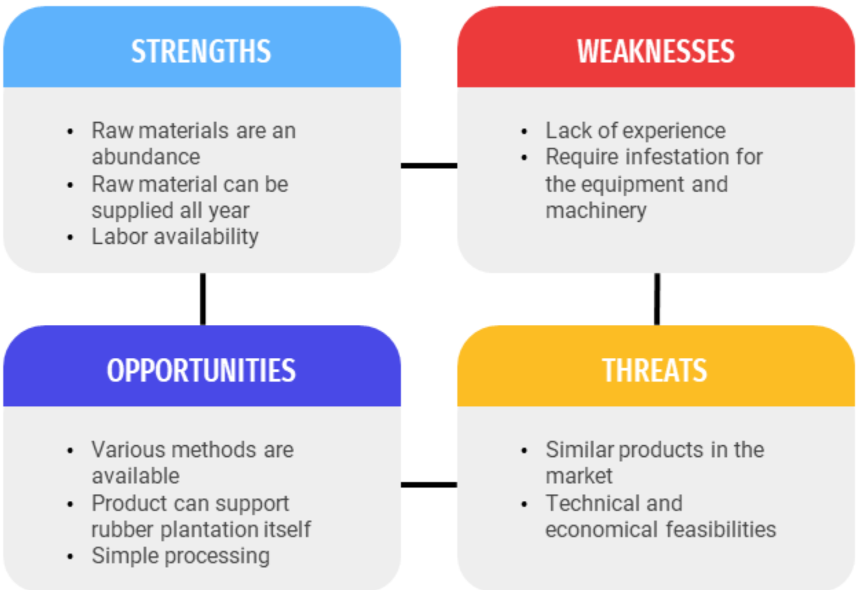

Figure 3. Strengths, weaknesses, opportunities, and threats of rubber ancillary products utilization

The method used for each product is generally still on a research scale, except for the processing of rubberwood, which is already familiar; therefore, the transition process from a research scale to an industrial scale must be carried out carefully. Another challenge is marketing, as sometimes selling is more complex than manufacturing. A careful market assessment is strongly advised in this business plan. The experience of processing rubber by-products is still minimal; it can be overcome with training and assistance by experts.

As a first step, generating products that can support rubber plantation such as biodiesel or organic fertilizers is a wise choice. Processing one type of product is riskier, than processing one type of raw material and producing several derivative products. For example, processing rubber seeds not only for biodiesel but also to produce feed and activated carbon would be more feasible. Therefore, building one factory in one place that can process all types of materials will be more efficient than building several factories of each kind of raw material.

To summarize, seven steps are proposed for initiating the rubber by-products industry as follows:

1. Problem to solve. This step questioning why the industry is needed. Given the rubber low prices and increasing costs, another source of income is indispensable to maintain rubber agribusiness sustainability.
2. Refine the idea. The idea is to utilize parts of rubber plant, non-latex, that are unexploited and generate income
3. Market research. Some products can be used to support rubber plantations. However, official and deep market research is required.
4. Business plan. This step includes the feasibility study of each product and its processing method.
5. Funding. It can be self-funded or involving investors.
6. Business location. The best option is to attach this unit to existing rubber factories.
7. Prepare for growth. It can be carried out by increasing industry capacity or opening new factories.

CONCLUSION

The ancillary products of rubber plants can be exploited to support rubber agribusiness competitiveness and sustainability. Latex serum could produce bio-energy and pharmaceutical raw products. The skim waste can be processed for hydrolases, fungi, and bacteria growing media and fertilizer. At least three parts of the seed can be exploited included the seed kernel, shells, and pericarp for bio-oil, protein, biomass, and activated carbon. Besides furniture and light-structure materials, rubberwood can be processed to produce bio-oil, bio-energy, and fertilizer; even sawdust can be processed to become activated carbon and pellets. The main advantage of the rubber by-products industry is the abundant raw materials that can be supplied all year long. The main challenge is to adopt a research-scale method to an industrial scale. Therefore, market research and feasibility studies are required.

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