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Valorization of Pb 340 rubberwood into liquid smoke as an alternative latex coagulant for Ribbed Smoked Sheet

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ABSTRACT
Formic acid, commonly used as a coagulant, has been criticized for its adverse environmental impact, leading to the search for sustainable alternatives. Additionally, the rubber processing industry generates a significant amount of unproductive rubber wood during replanting. A promising path to environmental sustainability is to utilize this potential for liquid smoke production. This study examines the use of liquid smoke from rubber wood Clon PB 340 as a latex coagulant and its effect on RSS quality. The findings indicate that RSS adhered to the P0 standard criteria for all tested liquid smoke concentrations. The 5% liquid smoke introduction to RSS, stored for 7 days, achieved the SRI 5 standard. Additionally, liquid smoke additions effectively managed dirt content, meeting or surpassing control criteria at concentrations of 5%, 20%, and 25%. Although the volatile matter content occasionally met SRI 5 standards at specific concentrations (10%, 15%, 20%, and 25%), the ash content across all treatments, including the control, did not meet the SRI 5 quality benchmarks. Using liquid smoke from non-productive rubber wood Clon PB 340 as a natural coagulant holds promise for eco-friendly latex processing. This study may advance the rubber industry's adoption of liquid smoke, promoting higher-quality, environmentally sustainable products.

Keywords:
Ribbed smoke sheet rubber, sustainability, coagulant, liquid smoke.

Introduction

Indonesia possesses extensive rubber plantations. The rubber sector plays a significant role in the national economy, with North Sumatra being the leading province in Indonesia, known for having the largest natural rubber plantations, covering 43.11 thousand hectares. Natural rubber is a valuable resource with diverse applications across many sectors. There are two principal types of rubber: natural rubber latex and synthetic rubber. Processing natural rubber latex has attracted considerable interest among farmers (Boon et al., 2022). This processing can provide substantial economic benefits to the local rubber industry by increasing farmers' utilisation of natural rubber, adding value, supporting exports of processed products, creating employment opportunities, and promoting regional economic growth (Syarifa et al., 2023).

The processing of rubber into rubber sheets, commonly known as Ribbed Smoked Sheet (RSS), is a key part of the rubber industry, particularly for automotive applications. In this process, the quality of the latex used as the raw material plays a crucial role in determining the final product's quality. Therefore, careful selection of rubber clones is essential to ensure optimal performance. The PB 340 rubber clone has been recommended as a superior clone capable of producing high-quality latex (Zaini et al., 2017).

In addition, the latex coagulation stage is a critical step in rubber latex processing. This stage involves adding a coagulant to separate the latex from water and form a solid mass that can be further processed. One of the most commonly used coagulants is formic acid (Achmad et al., 2022; Praharnata et al., 2018). However, concerns about toxicity, environmental safety, and relatively high costs have driven the search for sustainable, efficient, and environmentally friendly alternative coagulants.

Moreover, the rubber industry faces the challenge of large amounts of unutilised rubberwood generated when rubber trees are replanted to maintain latex yield. Sinaga et al. (2023) reported that rubberwood from the PB 340 clone contains significant amounts of structural components: 19.01 % lignin, 12.16 % hemicellulose, and 57.78 % cellulose, as determined by chemical analysis. Lignin and other constituents in rubberwood can be transformed into phenolic compounds during processing, and these phenolics have potential as natural coagulants in the latex coagulation process.

Therefore, the utilization of non-productive rubberwood to produce liquid smoke as a natural coagulant in rubber processing represents an attractive alternative. This study aims to investigate the potential use of liquid acid derived from PB 340 rubberwood as a substitute for formic acid in rubber latex coagulation and its application in the production of ribbed smoked sheet. Thus, this research not only provides new insights into the sustainable and innovative utilization of natural resources but also contributes to improving the efficiency and quality of the rubber latex processing industry in Indonesia.

Methods

Materials

The raw materials used in this study consisted of fresh latex obtained from PB 340 rubber clone trees planted in 2009 at PTPN IX Merbuh Plantation, Kendal Regency, Central Java, Indonesia, and rubberwood from PB 340 rubber clone trees planted in 2010 at PTPN IV Sei Lindai Plantation, Kampar Regency, Riau Province, Indonesia.

The chemicals used in this study included 2,4-dinitrophenylhydrazine (CV Nitra Kimia), sulfuric acid (H_2SO_4), acetone (Merck Mallinckrodt, USA), phenol, sodium carbonate (Na_2CO_3), Folin–Ciocalteu reagent, phenolphthalein indicator, potassium hydroxide (KOH), sodium hydroxide (NaOH), hydrochloric acid (HCl) (Merck KGaA, Germany), and formic acid (PT BASF-YPC, China).

Liquid smoke production

Rubberwood blocks measuring 3 cm×3 cm×3 cm, with a total mass of 3 kg, were placed into a pyrolysis reactor equipped with multiple condensers and condenser cooling units. The total production time was approximately 3 hours, with the pyrolysis process conducted for 90 minutes at a temperature of 400 °C, until no further liquid smoke flowed into the collection tank.

The smoke vapors generated during pyrolysis were passed through the condensers, where the vapors condensed from the gaseous phase into liquid and flowed through condenser pipes immersed in cooling water. An Erlenmeyer flask was positioned at the outlet of the condenser to collect the resulting liquid smoke. The collected liquid smoke was subsequently distilled at 120 °C.

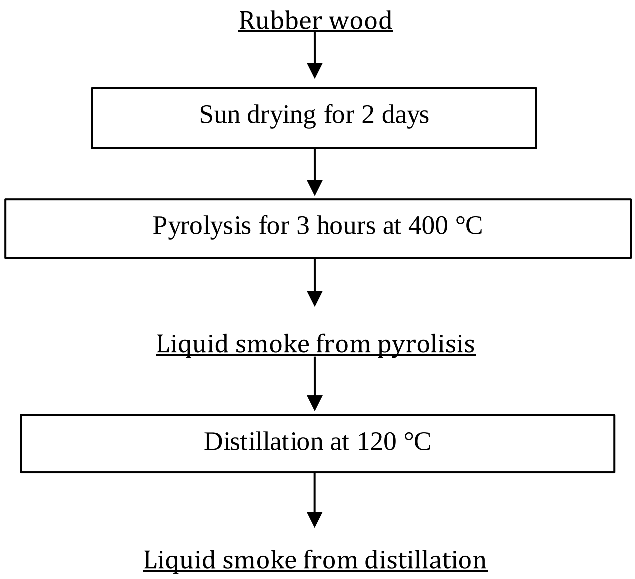

Figure 1. Flow chart of rubber wood liquid smoke preparation

Identification of liquid smoke components

The chemical composition of liquid smoke was analyzed using gas chromatography coupled with mass spectrometry (GC-MS) at LPPT, Gadjah Mada University. Component identification was performed using a Thermo Scientific Trace 1310 gas chromatograph equipped with a Thermo Scientific ISQ LT single quadrupole mass spectrometer. For sample preparation, 0.1 mL of liquid smoke was diluted with 1.0 mL of methanol in a GC vial and vortexed until homogeneous prior to injection. The injector temperature was set at 260 °C, with a split injection mode using a split ratio of 50:1 and a split flow rate of 50 mL/min. The front inlet flow rate was maintained at 1.00 mL/min. Chromatographic separation was carried out using an Agilent DB-1 capillary column (30 m length × 0.25 mm internal diameter). Ultra-high-purity helium (He) was used as the carrier gas at a pressure of 12 kPa, with a total flow rate of 25 mL/min, column flow rate of 0.51 mL/min, and linear velocity of 26 cm/s. The mass spectrometer was operated in electron impact (EI) ionization mode at 70 eV. The MS transfer line temperature was set at 250 °C, the ion source temperature at 200 °C, purge flow at 3.0 mL/min, gas saver flow at 5 mL/min, and gas saver time at 5 min. Identification of compounds in liquid smoke was achieved by comparing the obtained mass spectra with reference spectra from mass spectral libraries.

Liquid smoke application as coagulant in the production of ribbed smoked sheet

This procedure was conducted with modifications based on the methods reported by Ulfah et al. (2017) and (Hartati et al., 2015). A total of 1000 mL of fresh latex was poured into coagulation troughs, after which varying concentrations of pure liquid smoke (5, 10, 15, 20, and 25% v/v) were gradually added. A 5% formic acid solution was used as the control treatment. Following coagulation, the rubber coagulum was stored for 1, 7, and 14 days. Each coagulum was subsequently passed through a crepper to form rubber sheets, facilitating the drying process and subsequent analyses. Drying was carried out at ambient temperature for 5–6 days, or until the rubber sheets were completely dry.

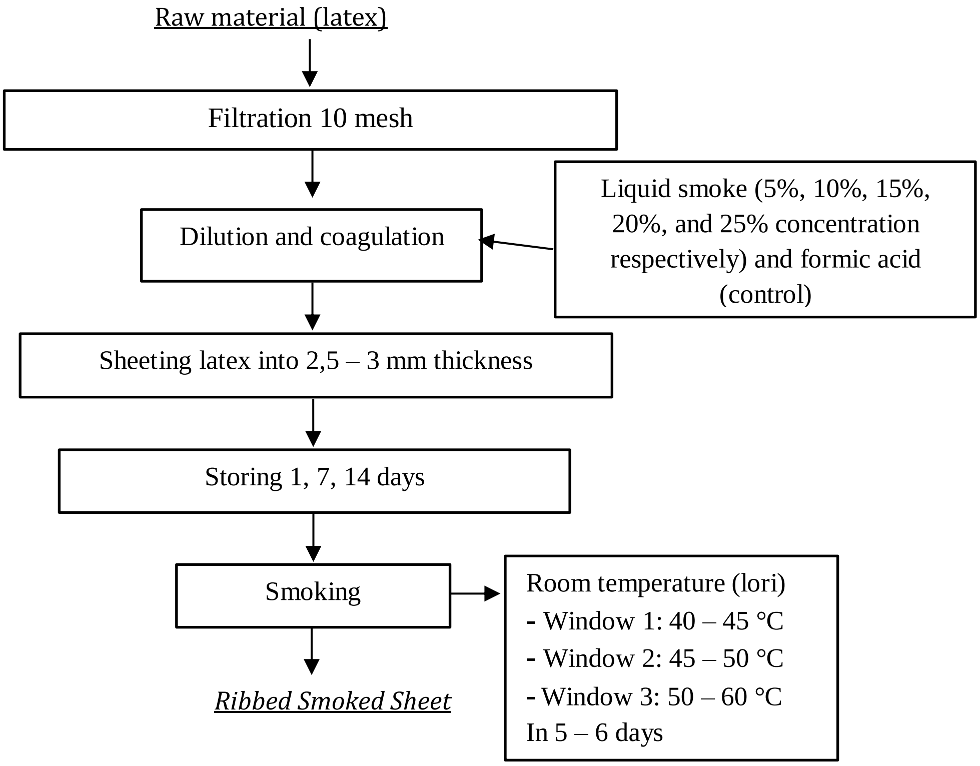

Figure 2. Flow chart of liquid smoke application into rubber smoked sheet

Quality characterization of resulting Ribbed Smoked sheet

Quality evaluation of ribbed smoked sheet (RSS) was conducted to ensure that the produced rubber met the required quality standards. Rubber quality standards in Indonesia are regulated under SNI 1903:2011 concerning technical specifications for rubber. The rubber sheets (RSS) were required to comply with the Indonesian Rubber Standard (SIR) 5 classification for sheet rubber.

Prepared RSS samples were subjected to testing for Plasticity Retention Index (PRI) (ISO 2930), initial plasticity (P_0) (ISO 1795), dirt content (ISO 249), ash content (ISO 247), and volatile matter content (ISO 248). To meet the quality requirements of SIR 5, RSS must exhibit a minimum

PRI value of 70, a minimum P_0 value of 30, a maximum ash content of 0.50% (w/w), a maximum dirt content of 0.04% (w/w), and a maximum volatile matter content of 0.80% (w/w).

Statistical analysis

The quality data of the ribbed smoked sheet (RSS) were statistically evaluated using analysis of variance (ANOVA) to identify significant differences among treatments. Statistical significance was further assessed using Duncan's Multiple Range Test (DMRT) at a 95% confidence level ($p < 0.05$).

Result and discussion

Production of liquid smoke from rubber wood as latex coagulant

This study utilized rubberwood as the raw material for the production of liquid smoke, which was subsequently applied as a latex coagulant. Rubberwood contains polyisoprene as its primary component, along with proteins, holocellulose (67%), cellulose (40%), hemicellulose (20%), lignin (20.68%), various organic compounds, and relatively low moisture content. These characteristics indicate that rubberwood has substantial potential for conversion into liquid smoke suitable for use as a latex coagulant (Vachlepi & Ardika, 2019). The conversion of rubberwood into liquid smoke was achieved through a pyrolysis process, which is a method of organic material preservation involving natural pH adjustment under controlled conditions. During pyrolysis, rubberwood pieces were heated at high temperatures in the absence of oxygen. This heating process weakened the chemical bonds within the rubberwood structure, causing the organic compounds to decompose and form new compounds through depolymerization and fragmentation reactions. These processes led to the breakdown of cellulose, lignin, hemicellulose, and other long-chain organic molecules present in rubberwood. Pyrolysis resulted in the formation of gaseous, liquid, and solid products. At elevated temperatures, the volatile organic compounds generated during pyrolysis condensed into liquid smoke. The overall process of liquid smoke formation is illustrated in Figure 3.

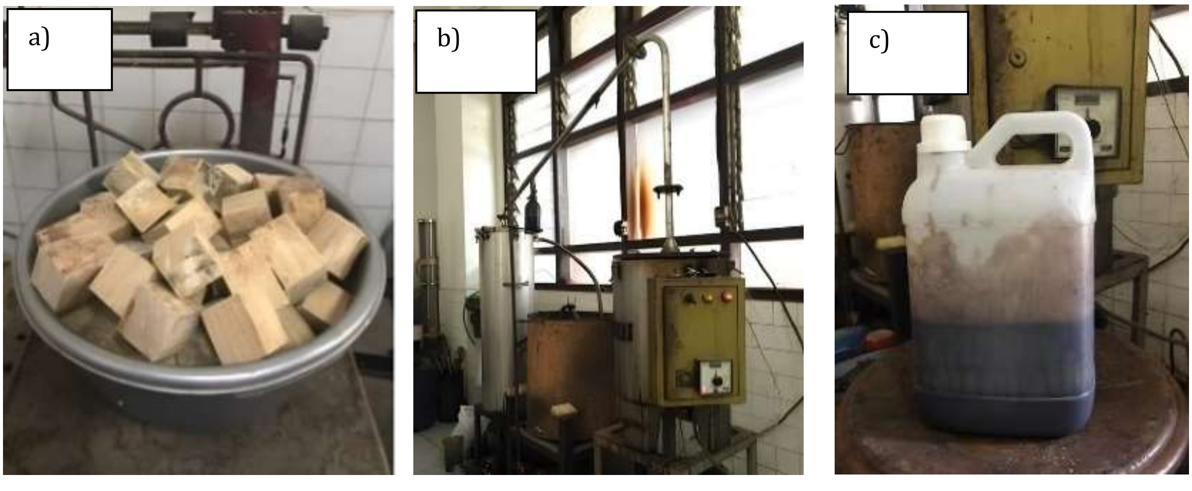

Figure 3. Processing liquid smoke a) rubber wood, b) heating at 400 °C, c) resulting liquid smoke.

The rubber coagulation process represents the initial stage in the purification of natural rubber latex obtained from rubber trees (Hevea brasiliensis). Following latex harvesting, a coagulant is added to facilitate the coagulation process. Generally, coagulating agents induce the aggregation of proteins present in the latex, resulting in the formation of a solid rubber mass. Rubber latex is derived directly from natural rubber sap. According to Rosmainar et al. (2020) , the use of liquid smoke as a coagulant provides several positive impacts for rubber farmers, including environmental friendliness, inhibition of bacterial growth and oxidation, and reduction of unpleasant odors. Its application as a coagulating agent in latex processing also promotes faster coagulation, higher elasticity, increased dry rubber content, and improvements in rubber quality and market value (Rosmainar et al., 2020). The rubber coagulation process is illustrated in Figure 4.

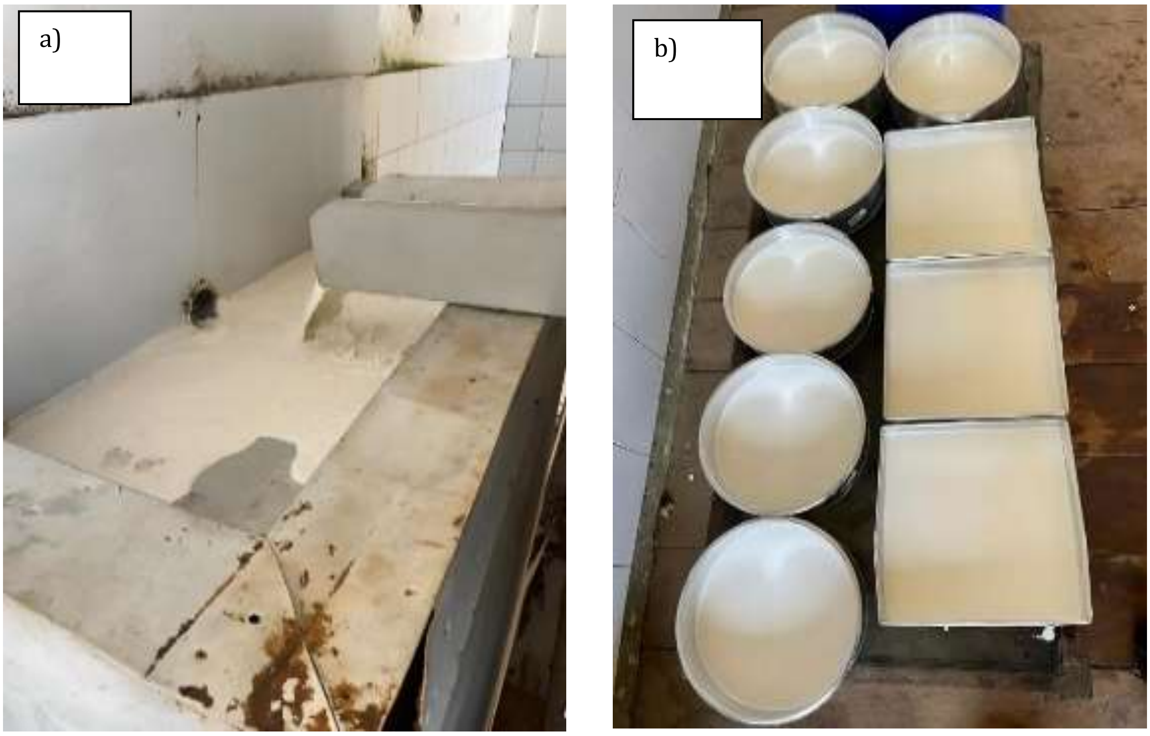

Figure 4. Rubber latex coagulation process (a) Rubber latex collection; (b) latex coagulation

Production of rubber ribbed smoked sheet

The application of rubber latex into ribbed smoked sheet (RSS) represents a key stage in natural rubber production. Rubber sheets are formed through a milling process that breaks the coagulated rubber into thin sheets with a thickness of approximately 2.5–3.0 mm. These sheets are subsequently subjected to a smoking process to produce RSS. The smoking process facilitates drying and preservation, enhances the physical strength of the rubber, and imparts the characteristic aroma and color of RSS that are preferred in both local and international markets (Hairiyah et al., 2022; Iurp et al., 2017). The resulting RSS products are presented in Figure 5.

Figure 5. Rubber ribbed smoked sheet

Composition of liquid smoke from rubber wood

The composition of compounds present in liquid smoke derived from rubberwood plays a crucial role in determining its effectiveness as a coagulant during latex coagulation and its impact on the final rubber product. Compounds that contribute to the coagulating properties of liquid smoke include phenolic compounds, organic acids, and degradation products resulting from the thermal decomposition of lignin, hemicellulose, and cellulose.Identification of compounds in liquid smoke produced from PB 340 rubberwood using gas chromatography revealed a total of 48 compounds. Among these, 2-methoxymethylfuran exhibited the highest relative abundance, accounting for 26.52% of the total detected compounds. As shown in Table 1, several phenolic derivatives were identified, including 2-methoxyphenol, 4-ethyl-2-methoxyphenol, 2-methoxy-6-methylphenol, and 2-methoxy-4-propylphenol. Phenolic compounds play an important role in facilitating latex coagulation. In particular, 2-methoxyphenol (commonly known as guaiacol), which is formed from the depolymerization of lignin into phenolic derivatives, influences the adhesive properties of rubber and affects its elasticity as well as the overall quality of the final product (Feng et al., 2019; Puspitasari et al., 2020). Therefore, liquid smoke derived from PB 340 rubberwood demonstrates strong potential for application as a natural coagulant in the production of ribbed smoked sheet (RSS).

Table 1. Identification of compounds in liquid smoke from rubber wood

No	Retention time (min)	Compound	Molecular Formula	Relative Area (%)
1	4,30	3-furaldehyde	$C_8H_{16}O_2$	0,82
2	4,40	4-sec-butoxy-2-butanone	C_6H8O_2	0,43
3	4,53	2-(methoxymethyl)-furan	$C_5H_4O_2$	26,52
4	4,63	furfural	$C_{14}H_{26}O_2$	0,14
5	4,68	(8E)-8-dodecen-1-yl acetate	$C_{17}H_{32}O_2$	1,00
6	4,77	10-methyl-E-11-tridecen-1-ol propionate	$C_9H_{18}O$	1,13
7	5,11	nonanal	$C_8H_{16}O_2$	1,97
8	5,18	4-isobutoxy-2-butanone	$C_7H_{14}O_4$	0,41
9	5,28	(3,4-dihydroxy-3-methylbutyl) acetate	$C_7H_{14}O$	0,33
10	5,35	(4Z)-4-hepten-1-ol	$C_5H_8O_3$	2,05
11	5,55	2-oxopropyl acetate	$C_6H_{12}O_3$	4,61
12	6,18	2,5-dimethoxyoxolane	$C_6 H_8O$	3,98
13	6,34	2-methylcyclopent-2-en-1-one	$C_6H_6O_2$	3,08
14	6,47	1-(2-furanyl)ethanone,	$C_9H_{14}O_3$	0,43
15	6,85	(Z)-3,4,4-trimethyl-5-oxohex-2-enoic acid	$C_6H_{10}O_2$	0,70
16	7,01	3-hydroxycyclohexanone	$C_9H_{18}O$	1,00
17	7,21	(Z)-5-methyloct-5-en-1-ol	$C_7H_{10}O$	0,41
18	7,54	3,4-dimethyl-2-cyclopenten-1-one	$C_7H_{10}O_3$	0,97
19	7,76	2-furanethanol, ß-methoxy-(S)-	$C_6H_6O_2$	2,77
20	7,82	2-(2-furyl)-2-methoxyethanol	$C_7H_{10}O$	0,71
21	8,11	2-methyl-2,3-divinyloxirane	$C_6H_6O_3$	0,92
22	8,48	furyl hydroxymethyl ketone	$C_6H_{10}O_3$	0,15
23	8,55	methyl 4-oxopentanoate	$C_8H_{16}O$	0,13
24	8,62	4-methyl-4-hepten-3-ol,	$C_9H_{18}O$	0,02
25	8,68	2,3-dimethyl-2-cyclopenten-1-one	$C_7H_{10}O$	1,56
26	8,87	3,4-dimethyl-3-penten-2-one	$C_7H_{12}O$	0,58
27	8,97	1,6-heptadien-4-ol	$C_7H_{12}O$	0,67
28	9,03	2-nitrohept-2-en-1-ol	$C_7H_{13}NO_3$	0,39
29	9,72	Decanal	$C_{10}H_{20}O$	0,39
30	9,76	9-oxabicyclo[3,3,1]nonan-2-one	$C_8H_{12}O_2$	0,40
31	9,88	2,3-dimethyl-2-cyclopenten-1-one	$C_7H_{10}O$	1,49
32	10,02	hexanal dimethyl acetal	$C_8H_{18}O_2$	2,51
33	10,23	10-methyl-E-11-tridecen-1-ol propionate	$C_{17}H_{32}O_2$	0,11
34	10,56	2,2-dimethyl-3-heptyne	C_9H_{16}	0,28
35	11,00	R-limonene	$C_{10}H_{16}O_3$	0,31
36	11,34	hexen-1-ylcyclohexane	$C_{12}H_{22}$	0,46
37	11,46	2-methoxyphenol,	$C_7H_8O_2$	6,56
38	11,72	(1-methylethylidene)-	C_9H_{16}	0,13
39	11,88	2,6,8-cyclohexanetrimethylbicyclo[4,2,0]oct-2-ene-1,8-diol	$C_{11}H_{18}O_2$	0,39
40	13,06	hexanal dimethyl acetal	$C_8H_{18}O_2$	2,55
41	14,01	2-methoxy-6-methylphenol	$C_8H_{10}O_2$	0,90
42	14,26	3,7,7-trimethyl-, (1a,3a,6a)-bicyclo[4,1,0]heptane	$C_{10}H_{18}$	0,42
43	14,44	creosol	$C_8H_{10}O_2$	3,11
44	15,69	3,4-dimethoxytoluene	$C_9H_{12}O_2$	0,46
45	16,83	4-ethyl-2-methoxyphenol	$C_9H_{12}O_2$	3,42
46	18,88	1,4-diethoxybenzene	$C_{10}H_{14}O_2$	0,01
47	19,02	6-methyl-5-(1-methylethyl)-5-hepten-3-yn-2-ol	$C_{11}H_{18}O$	0,37
48	19,22	2-methoxy-4-propylphenol	$C_{10}H_{14}O_2$	0,84

Characterization of resulting rubber ribbed smoked sheet

Quality parameters are essential indicators for evaluating the characteristics and overall quality of rubber products. Through the assessment of these parameters, the quality consistency of the produced rubber and its compliance with established standards can be determined. In this study, rubber quality parameters including initial plasticity (P_0), Plasticity Retention Index (PRI), ash content, dirt content, and volatile matter content were evaluated and are presented in Table 2. Rubber quality standards in Indonesia are regulated under the Indonesian National Standard SNI 06-1903-2011 for Standard Indonesian Rubber (SIR).

Table 2. Quality Parameters of Ribbed Smoked Sheet

Storage	Treatment	Parameter				
		P_0	PRI	Ash content (%)	Impurity content (%)	Volatile Matter (%)
Day 1	K	39,33 ± 0,29^{a}	80,51 ± 1,9^{h}	1,45 ± 0,27^{e}	0,06 ± 0,00^{gh}	2,67 ± 0,08^{k}
	5%	43,17 ± 2,02^{b}	68,49 ± 5,11^{fg}	1,17 ± 0,06^{d}	0,03 ± 0,00^{bc}	1,50 ± 0,05^{h}
	10%	44,83 ± 0,29^{bc}	60,23 ± 2,33^{abcd}	1,59 ± 0,22^{e}	0,05 ± 0,00^{ef}	1,34 ± 0,02^{g}
	15%	43,33 ± 0,76^{b}	56,54 ± 54,54^{ab}	2,35 ± 0,22^{f}	0,05 ± 0,00^{ef}	1,67 ± 0,04^{i}
	20%	45,67 ± 1,26^{c}	62,78 ± 0,25^{cde}	2,16 ± 0,12^{f}	0,02 ± 0,00^{a}	1,85 ± 0,02^{j}
	25%	45,67 ± 0,76^{de}	65,7 ± 1,25^{efg}	2,29 ± 0,03^{f}	0,04 ± 0,00^{cd}	1,44 ± 0,05^{h}
Day 7	K	61,17 ± 1,15^{f}	70,57 ± 2,54^{g}	0,79 ± 0,13^{abc}	0,05 ± 0,01^{f}	0,85 ± 0,00^{bcde}
	5%	58,17 ± 0,58^{de}	71,92 ± 0,22^{fg}	0,81 ± 0,03^{abc}	0,06 ± 0,00^{g}	0,93 ± 0,01^{e}
	10%	58,33 ± 2,02^{de}	64,37 ± 3,79^{def}	0,78 ± 0,00^{abc}	0,04 ± 0,00^{de}	0,90 ± 0,02^{de}
	15%	58,67 ± 1,04^{de}	69,32 ± 0,59^{fg}	0,72 ± 0,01^{ab}	0,04 ± 0,00^{def}	0,89 ± 0,01^{cde}
	20%	58,50 ± 1,00^{de}	68,93 ± 1,46^{fg}	0,68 ± 0,01^{a}	0,12 ± 0,00^{i}	1,06 ± 0,08^{f}
	25%	60,00 ± 0,87^{ef}	64,44 ± 1,45^{def}	0,65 ± 0,03	0,09 ± 0,00^{k}	0,81 ± 0,02^{abc}
Day 14	K	59,50 ±1,00^{def}	62,13 ± 2,67^{a}	0,94 ± 0,04^{cd}	0,07 ± 0,00^{ab}	0,82 ± 0,02^{bcde}
	5%	58,33 ± 1,89^{de}	61,1 ± 2,06^{cde}	0,96 ± 0,01^{bcd}	0,03 ± 0,00^{hi}	0,86 ± 0,00^{ab}
	10%	57,83 ± 0,58^{d}	62,54 ± 1,64^{bcde}	0,95 ± 0,03^{cd}	0,07 ± 0,00^{j}	0,78 ± 0,03^{a}
	15%	59,17 ± 0,29^{de}	57,97 ± 2,06^{abc}	0,97 ± 0,01^{bc}	0,08 ± 0,00^{ef}	0,75 ± 0,03 ^{ab}
	20%	58,67 ± 0,58^{de}	59,87 ± 3,87^{abc}	0,93 ± 0,04^{abc}	0,06 ± 0,00^{jk}	0,78 ± 0,01^{a}
	25%	58,17± 0,58^{de}	55,76 ± 1,83^{abcd}	0,83 ± 0,04^{bc}	0,08 ± 0,00^{i}	0,76 ± 0,03^{abcd}

Notes: values shows average ± standard deviation. P_0 (initial plasticity); PRI (Plasticity retention index). Different superscript letters on the same column indicates statistically significant difference according to one-way ANOVA Duncan post hoc test ($p < 0,05$).

Initial plasticity (P_0) refers to the plasticity of raw rubber measured without any prior treatment. The elastic flexibility percentage represented by P_0 serves as an indirect predictor of the molecular chain length of elastic polymer particles. The results indicated that the use of liquid smoke and formic acid as coagulants in latex coagulation produced P_0 values that were not significantly different (Table 2). This finding suggests that liquid smoke has strong potential as an alternative to formic acid. Differences in P_0 values between liquid smoke and formic acid (control) coagulants are attributed to the chemical composition of liquid smoke, which contains organic acids and phenolic compounds that function not only as coagulants but also as antimicrobial agents.

The Plasticity Retention Index (PRI) is used to measure the resistance of polymer materials to oxidative degradation. PRI provides important information regarding rubber quality, as oxidative behavior significantly affects rubber properties during processing and subsequent applications. PRI determination involves thermal aging at 140 °C for 30 minutes to assess oxidative degradation. A high PRI value indicates strong resistance to ozonolysis and oxidative degradation (Aguele et al., 2015). As shown in Table 2, the highest PRI value was obtained from the control treatment at 1-day storage, reaching 79.7%. However, the use of liquid smoke at different concentrations did not result in statistically significant differences, except during the 1-day storage period.

The PRI values also showed an increasing trend with higher concentrations of liquid smoke. This behavior is associated with the presence of phenolic compounds and organic acids that inhibit spoilage bacteria, act as antioxidants, protect rubber molecules at elevated temperatures, and maintain stable PRI values. Sinaga et al. (2023) reported that liquid smoke derived from PB 340 rubberwood contains 2.15% phenolic compounds, while Sari et al. (2019) reported that liquid smoke derived from rubber shell contains 0.84% phenols. This level is sufficient to inhibit bacterial growth in rubber. Consequently, bacterial degradation and oxidative damage in RSS can be suppressed. Oxidative processes affect rubber properties such as plasticity, elasticity, and mechanical strength by causing chemical changes, particularly molecular chain scission induced by oxygen radicals from atmospheric oxygen, leading to decreased plasticity and elasticity (Dewi et al., 2019; Novirman, 2021).

Ash content represents the total mineral content present in rubber. Rubber ash consists mainly of mineral salts such as carbonates and phosphates of potassium, magnesium, calcium, sodium, and other inorganic components in varying proportions. Storage duration influences rubber degradation, which continues throughout the storage period. As shown in Table 3, ash content generally decreased with longer storage time. However, higher liquid smoke concentrations resulted in increased ash content, particularly at Day 1. The lowest ash content was observed at H7 with 25% liquid smoke concentration (0.65%), while the highest ash content was observed at H1 with 15% liquid smoke concentration (2.35%). The ash content of the Day 1 control sample was not significantly different from that of the 10% liquid smoke treatment but differed significantly from the 5%, 15%, 20%, and 25% treatments. At Day 7 and Day 14, no significant differences were observed. This increase in ash content is attributed to the pyrolysis process used to produce liquid smoke, which generates inorganic by-products. When liquid smoke is added to latex during coagulation, these inorganic components mix with the latex and become entrapped within the rubber structure during drying, thereby increasing ash content in the final product (Vachlepi & Ardika, 2019).

Impurity content refers to the presence of foreign particles, both organic and inorganic, in rubber. High dirt content can significantly reduce rubber quality and cause processing difficulties, as impurities interfere with physical and mechanical properties, potentially leading to structural failure and reduced product performance and service life. Based on Table 2, the lowest dirt content was observed at Day 1 with 20% liquid smoke concentration (0.02%), while the highest dirt content was observed at Day 7 for both the control and 20% liquid smoke treatments (0.12%). The results indicate that longer storage duration increased dirt content, likely due to contamination during storage. Dewi et al., (2019) reported that high dirt content may also result from the addition of coagulants and the presence of contaminants such as stones, sand, twigs, mud, and insoluble solids.

Volatile matter content refers to the amount of volatile substances that can be released from rubber and transition into the gaseous phase. Rubber, as an elastic polymer, consists of long-chain organic molecules that generally retain volatile compounds. However, certain volatile components may evaporate over time or under specific environmental conditions. High volatile matter content can negatively affect the physical properties of rubber and reduce product shelf life. Based on Table 2, the lowest volatile matter content was observed at Day 14 with 15% liquid smoke concentration (0.75%), while the highest value was recorded at Day 1 for the control treatment (2.67%). Volatile matter content exceeded standard limits in most treatments, except for liquid smoke concentrations of 10%, 15%, 20%, and 25% at 14 days of storage. Elevated volatile matter levels may result from suboptimal drying conditions during rubber processing, where insufficient drying rates lead to increased volatile retention (Martrias et al., 2015).

Conclusion

The ribbed smoked sheet (RSS) produced in this study met the initial plasticity (P_0) requirements at all concentrations of liquid smoke addition. The Plasticity Retention Index (PRI) of RSS treated with 5% liquid smoke and stored for 7 days satisfied the SIR 5 standard. Similarly, the use of 5%, 20%, and 25% liquid smoke resulted in dirt content values that met, and in some cases outperformed, the control treatment.Volatile matter content met the minimum SIR 5 requirements only at 14 days of storage for liquid smoke concentrations of 10%, 15%, 20%, and 25%. However, ash content for all treatments, including the control, did not meet the SIR 5 quality standard. Overall, the utilization of non-productive PB 340 rubberwood to produce liquid smoke as a natural latex coagulant and its application in RSS production demonstrates considerable potential as an environmentally friendly alternative to conventional coagulants.

Acknowledgments

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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