# Optimizing sodium metabisulfite in pale crepe rubber processing: toward cleaner and consistent product quality for agroindustrial applications

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**Abstract.** Pale crepe rubber, a premium-grade natural rubber product, requires high visual quality, brightness, and uniformity to meet export and medical-use standards. Conventional bleaching agents used to enhance color often pose challenges related to cost, odor, or safety. This study evaluates the use of sodium metabisulfite (SMBS) as an alternative bleaching agent in pale crepe rubber production to achieve optimal product quality while considering practical and environmental aspects. Fresh field latex was bleached with SMBS at varying concentration and the quality of crepe rubber was characterized and compared to international standard. The results show that SMBS effectively improves brightness and visual consistency when applied at an optimal concentration, producing crepe rubber that meets international quality specifications. Compared with conventional agent, SMBS offers a safer and more affordable approach suitable for small to medium scale processing. Overall, the study highlights a context-appropriate innovation that supports cleaner production practices and promotes sustainable value addition in the natural rubber agroindustry.

## 1 Introduction

Natural rubber (*Hevea brasiliensis*) plays a critical role in tropical agricultural economies, with field latex serving as the primary raw material for a wide range of industrial applications. Among its processed rubber grades, pale crepe rubber is highly valued for its cleanliness, brightness, and uniform quality, making it suitable for medical equipment, hygiene products, and premium industrial products. To meet these stringent quality demands, the production of pale crepe rubber requires careful control of impurities, pigmentation, and oxidation reactions, all of which significantly affect the visual and physical properties of the final product.

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Conventional pale crepe processing involves multiple washing, milling, and drying steps to remove contaminants and enhance brightness [1-3]. However, these physical treatments are often insufficient to eliminate natural pigments or oxidation residues, necessitating the use of chemical bleaching agents. Aromatic mercaptan-based agents, such as sodium para-toluene thiophanate (commercially knows as Nexo-Bleach, Rupepa, RPA-4, or Poly Bleach), have long been employed for high-grade crepe rubber in Sri Lanka [4]. While effective, these compounds are associated with strong odors, handling risks, and environmental concerns, limiting their sustainability for decentralized or smallholder-scale operations. Similar limitations were reported by Singthuen *et al*. (2011), who found that although thiophenol and alkylthiol effectively enhanced color, their odor and toxicity restricted industrial applicability [5].

In response to these challenges, Sodium metabisulfite (SMBS) has emerged as a promising alternative due to its established use as a safe antioxidant and preservative in food and agricultural industries. SMBS is readily available, cost-effective, and relatively low in toxicity, making it suitable for small and medium-scale rubber processors. However, despite anecdotal use in sole local trials, systematic evaluation of SMBS concentration effects on pale crepe quality remains limited particularly concerning its influence on visual brightness and physicochemical parameters relative to international quality standards.

This research builds upon and differs from previous research on crepe rubber, which primarily focused on clone variation and renewable energy utilization for drying processes [6, 7]. Instead of addressing post-coagulation factors or energy systems, this study isolates SMBS bleaching concentration as a specific processing parameter, allowing for targeted assessment of its impact on both visual clarity and critical physicochemical attributes, namely initial plasticity (Po), plasticity retention index (PRI), volatile matter, ash, and dirt content. By emphasizing a practical and safer chemical approach, the study contributes to the development of cleaner and more sustainable bleaching practices for the rubber agroindustry. Its findings are intended to support context-appropriate innovations that improve product quality while advancing environmental and occupational safety in plantation-based production systems.

## 2 Materials and methods

### 2.1 Materials

Pale crepe rubber was produced using fresh field latex obtained from the Experimental Field of the Indonesian Rubber Research Institute (IRRI), Sembawa, Banyuasin Regency, South Sumatra, Indonesia. The latex was collected under standard tapping practices and process immediately after collection to maintain stability. Sodium metabisulfite (SMBS) was used as the bleaching agent, and technical-grade formic acid served as the coagulant. Both materials were sourced from domestic suppliers in Indonesia.

### 2.2 Methods

#### *2.2.1 Pale crepe rubber production*

Fresh field latex was diluted with clean water to achieve a dry rubber content (DRC) of approximately 15%. SMBS was then added as the bleaching agent at concentrations of 2.5, 5, 7.5, and 10 g per kg dry rubber, while a control sample was prepared without any SMBS. The latex mixture was gently stirred to ensure uniform dispersion of the bleaching agent.

Coagulation was initiated by adding formic acid under gentle stirring and allowed to proceed naturally at room temperature for 1-2 hours. After coagulation, the rubber mass was removed, rinsed with clean water to eliminate residual acid, and processed using a crepe machine to produce thin, uniform sheets. The sheets were air-dried for 1 hour, followed by oven drying at 80 $^{o}$C until no visible white spots remained.

### *2.2.2 Visual and physicochemical quality analysis*

The visual colour of the pale crepe was observed visually. Physicochemical properties including initial plasticity (Po), plasticity retention index (PRI), volatile matter content, ash content, and dirt content, were determined according to the Indonesian National Standard (SNI 06-1903-2000) for natural rubber quality testing.

All measurements were performed in triplicate (n = 3) for each treatment to ensure reproducibility. Data were analyzed using one-way analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) at a significant level of $p < 0.05$ to identify differences among treatments. Statistical analysis were conducted using SPSS version 25.0 (IBM Corp., USA).

## 3 Results and discussion

### 3.1 Visual appearance of pale crepe rubber

The visual color of crepe rubber is a key determinat of product quality, particularly for export and medical-grade applications that require a bright and uniform appearance The color variation is influenced by pigment content, impurities, proteins, and oxidation reactions during coagulation and drying [8].

Figure 1 shows the visual differences among pale crepe rubber treated with various SMBS concentrations. The untreated (control) samples exhibited a brownish tone with dull surface. This indicates that without bleaching treatment, color-causing compounds in the rubber, such as carotenoid pigments, proteins, dan organic impurities, are not significantly degraded [8]. Creped treated with 2.5 g/kg dry rubber of SMBS produced slightly brighter but uneven coloration. At 5 g/kg SMBS, the crepe appeared light yellow, uniform, and clean, indicating an effective bleaching concentration. Treatments with 7.5 g/kg maintained brightness but tended toward a deeper yellow hue, whereas 10 g/kg resulted in non-uniform brownish coloration, likely due to over-bleaching or partial degradation.

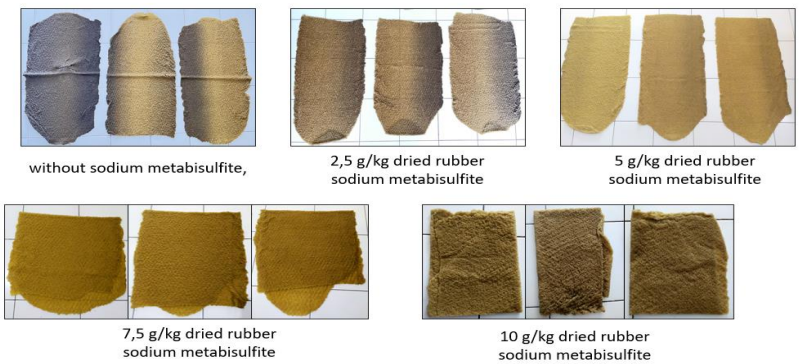


**Fig. 1.** Visual appearance of pale crepe rubber.

These differences are explained by the reducing action of SMBS, which dissociates into bisulfite ($HSO_3^-$) and sulfite ($SO_3^{2-}$) ions in water. These ions selectively reduce chromophoric groups (e.g., conjugated double bonds, quinones, and aldehyde groups) responsible for pigment coloration, convertong the into colorless form [9]. The general reaction can be expressed as:

$$\text{Pigment–oxidized} + HSO_3^- \rightarrow \text{Pigment-reduced (colorless or less colored)} \quad (1)$$

This mechanism not only decolorizes pigments but also prevents oxidantive browning by inhibiting enzymatic or auto-oxidative reactions. This mechanism aligns with reported reducing bleaching modes in both food and dental applications, where SMBS showed faster whitening than peroxide-based agents [10].

The optimum concentration of 5 g/kg dry rubber of SMBS provides sifficient reducing strenth to achieve derirable brightness while maintaining rubber matrix stability. At lower concentration, pigment reduction is incomplete, while higher concentration may cause oxidation reversal or polymer degradation.

### 3.2 Quality characteristics of pale crepe rubber

Crepe rubber is not yet standardized in Indonesia, therefore, the Sri Lankan specification for latex crepe was used as a reference (Table 1). The results of quality analysis across SMBS treatments are summarized in Table 2.

**Table 1.** Standard specification latex crepe (Sri Lanka standard).

| Properties | Specifications |
|---|---|
| Initial plasticity (Po) | Min 30 |
| Plasticity retention index (PRI) | Min 60 |
| Volatile matter content (%, w/w) | Max 0.50 |
| Ash content (%, w/w) | Max 0.20 |
| Dirt content (%, w/w) | Max 0.02 |

Source: RRISL, 2016

Overall, all samples met the minimum Po standard (≥ 30), indicating adequate elasticity. The highest Po was observed at 10 g/kg SMBS, while 5-7.5 g/kg treatments provided consistent and stable values, suggesting that moderate bleaching supports rubber strength. PRI, which reflects thermal-oxidative stability, increased with SMBS concentration up to 7.5 g/kg (78%), then slightly decreased at 10 g/kg (69%). Despite the minor decline, both 5 g/kg and 7.5 g/kg treatments exceeding the standard PRI threshold (≥ 60%), confirming their suitability for high-quality crepe rubber.

Volatile matter and ash contents remained within acceptable limits across treatments, with the lowest value recorded at 5 g/kg SMBS, indicating reduced residual moisture and inorganic impurities. Meanwhile, dirt content showed minimal variation and no significant difference among treatments, suggesting that SMBS mainly affects chemical brightness rather than mechanical cleanliness.

These results collectively indicate that 5 g/kg SMBS offers the best balance among color, elasticity, and purity, consistent with both the visual evaluation and quality analysis.

**Table 2.** Quality parameters of pale crepe rubber treated with different SMBS concentrations.

| Properties | Initial plasticity (Po) | Plasticity retention index (PRI) | Volatile matter content (%, w/w) | Ash content (%, w/w) | Dirt content (%, w/w) |
|---|---|---|---|---|---|
| Control 1 | 31 | 90 | 0.44 | 0.30 | 0.06 |
| Control 2 | 40 | 95 | 0.46 | 0.18 | 0.09 |
| Control 3 | 41 | 95 | 0.56 | 0.22 | 0.06 |
| Average | 37 | 93 | 0.49 | 0.23 | 0.07 |
| 2.5 g/kg KK SMBS | 34 | 53 | 0.48 | 0.14 | 0.06 |
| 2.5 g/kg KK SMBS | 36 | 50 | 0.57 | 0.20 | 0.08 |
| 2.5 g/kg KK SMBS | 34 | 56 | 0.48 | 0.18 | 0.05 |
| Average | 35 | 53 | 0.51 | 0.17 | 0.06 |
| 5 g/kg KK SMBS | 36 | 61 | 0.43 | 0.14 | 0.08 |
| 5 g/kg KK SMBS | 38 | 66 | 0.44 | 0.14 | 0.02 |
| 5 g/kg KK SMBS | 38 | 66 | 0.42 | 0.14 | 0.02 |
| Average | 37 | 64 | 0.43 | 0.14 | 0.04 |
| 7.5 g/kg KK SMBS | 40 | 80 | 0.26 | 0.20 | 0.03 |
| 7.5 g/kg KK SMBS | 42 | 79 | 0.26 | 0.30 | 0.03 |
| 7.5 g/kg KK SMBS | 41 | 76 | 0.22 | 0.30 | 0.03 |
| Average | 41 | 78 | 0.25 | 0.27 | 0.03 |
| 10 g/kg KK SMBS | 45 | 76 | 0.30 | 0.24 | 0.04 |
| 10 g/kg KK SMBS | 42 | 62 | 0.22 | 0.20 | 0.05 |
| 10 g/kg KK SMBS | 42 | 69 | 0.20 | 0.20 | 0.04 |
| Average | 43 | 69 | 0.24 | 0.21 | 0.04 |

### 3.3 Stastitical analysis

One-way ANOVA confirmed that SMBS concentration had a statistically significant effect on most quality parameters of pale crepe rubber (Table 3). The analysis indicated significant differences in initial plasticity (Po) ($F = 4.44$, $p = 0.025$), plasticity retention index (PRI) ($F = 43.82$, $p = 0.001$), volatile matter content ($F = 24.88$, $p < 0.001$), and ash content ($F = 4.35$, $p = 0.027$). in contrast, the effect of SMBS concentration on dirt content was not statistically significant ($F = 2.38$, $p = 0.122$).

**Table 3.** One-way ANOVA results for the effect of SMBS concentration on pale crepe rubber quality parameters.

| Properties | F-value | p-value | Significance ($\alpha = 0.05$) | Interpretation |
|---|---|---|---|---|
| Initial plasticity (Po) | 4.44 | 0.0255 | Significant | SMBS affects Po |
| Plasticity retention index (PRI) | 43.82 | <0.001 | Highly significant | Strong effect of SMBS |
| Volatile matter content (%, w/w) | 24.88 | <0.001 | Highly significant | SMSB reduces volatility |
| Ash content (%, w/w) | 4.35 | 0.0270 | Significant | SMBS influences ash content |
| Dirt content (%, w/w) | 2.38 | 0.1216 | Not significant | No effect of SMBS |

The statistical results confirm that moderate SMBS concentrations (particularly around 5 g/kg dr rubber) provide the optimal balance between plasticity, stability, and purity of pale crepe rubber. Higher concentrations tend to cause oxidative discoloration and slight degradation, as reflected by decrease in PRI dan increase in volatile matter. The absence of significant variation in dirt content suggests that bleaching primarily improves color dan polymer stability rather than physical cleanliness.

### 3.4 Sustainability and processing implications

The application of SMBS as a bleaching agent aligns with the principles of sustainable and cleaner agroindustrial processing. SMBS is inexpensive, readily available, and requires no specialized handling or equipment, making it particularly suitable for smallholder and medium-scale crepe rubber producers. Compared with aromatic mercaptan-based bleaching agent commonly used in export-oriented industries, SMBS offers a safer and less odorous alternative, reducing occupational exposure risks and improving workplace conditions.

At an optimal concentration of 5 g/kg dry rubber, SMBS provides effective color improvement and quality enhancement, supporting eco-efficient production systems that meet international standards for pale crepe rubber. Its use can help reduce product rejection rates, lower production costs, and strengthen the competitiveness of local agro-industries through cleaner production practices. From a biosystems engineering perspective, the process is easily scalable and adaptable to existing crepe production units with minimal modification, making it feasible for decentralized rubber processing networks.

However, certain trade-offs should be considered for broader industrial adoption. Long-term storage stability of SMBS-treated rubber needs to be monitored, as residual sulfite compounds may gradually oxidize, potentially affecting color stability during storage.

Additionally, residue monitoring is important to ensure that trace levels of sulfite remain within safe limits, particularly for applications in medical or food-contact materials. These considerations highlight the need for continued optimization of post-bleaching handling and drying conditions to maintain both product integrity and environmental safety.

Overall, this study reinforces SMBS as a context-appropriate innovation for sustainable crepe rubber production, balancing chemical efficiency, economic practicality, and environmental responsibility within the agro-industrial value chain.

## 4 Conclusions

The application of sodium metabisulfite (SMBS) as a bleaching agent significantly improves the visual appearance and overall quality of pale crepe rubber. Among the tested concentrations, 5 g/kg dry rubber of SMBS provided the best balance between bleaching effectiveness and product stability, producing bright, clean, and uniform sheets that meet international standards.

This study demonstrates that SMBS offers a practical, safe, and environmentally compatible alternative to conventional aromatic bleaching agents. Beyond its laboratory performance, SMBS-based bleaching can be readily integrated into local agroindustrial practices, particularly among smallholder and medium-scale processors, due to its low cost, accessibility, and minimal equipment requirements. Its adoption contribtes to be broader transition toward cleaner and more sustainable rubber processing technologies, supporting the development of eco-efficient value chains in plantation-based industries.

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