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Socioeconomic effects of *Pestalotiopsis* rubber leaf fall disease on smallholders in South Sumatra, Indonesia

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Abstract Since 2017, *Pestalotiopsis* leaf fall disease affecting para rubber trees has spread across Southeast Asia and South Asia. This novel disease represents a new risk to the livelihoods of rubber smallholders. The present study aims to investigate the impact of *Pestalotiopsis* leaf fall disease on the livelihoods of rubber smallholders in Indonesia. We adopt the sustainable livelihood framework for analyzing data. We first identified the context in which Indonesian rubber smallholders are situated drawing on secondary sources. Second, to understand smallholders' livelihood situations, we conducted a household survey in Banyuasin and Muara Enim Regencies of South Sumatra Province. Vulnerability of Indonesian rubber smallholders has been increasing particularly since the 2010s, due to low rubber prices, diseases, and declining government support. Due to *Pestalotiopsis* leaf fall disease, latex production had decreased on average by 47.7% compared to normal conditions. Few measures had been attempted by smallholders against leaf fall disease. Whereas 60.2% of the households had income sources other than rubber, 38.8% were dependent on rubber income. Households with greater income, often owing to sources other than rubber, were more proactive in taking action to address a given situation. Our findings confirm that *Pestalotiopsis* leaf fall disease has significantly increased the vulnerability of rubber smallholders' livelihoods. Although rubber smallholders are not monolithic, overall, enduring the impact was the most common response among rubber smallholders. Households heavily reliant on rubber may face greater vulnerability if issues like leaf fall disease and low rubber prices persist. For future implementation of control and prevention measures currently under development, it is necessary to design methods that do not leave ordinary households behind. Additionally, some government support would be essential.

Keywords: livelihoods, vulnerability, income diversification, price fluctuation, government support

1. Introduction

Natural rubber, produced from para rubber trees (*Hevea brasiliensis)*, is one of the most renowned and significant agricultural commodities worldwide. Although para rubber trees originate from Brazil, Southeast Asia has become the primary production region. As of 2022, Thailand leads the world in natural rubber production, accounting for approximately 30.2%, followed by Indonesia (19.6%) and Vietnam (8.4%) (FAO, 2024). Natural rubber is obtained through manual tapping, where a cut is made on the bark of the rubber tree via a tapping knife along half the circumference of the trunk. Tapping typically begins at the highest accessible point on the trunk and proceeds downward at a 30-degree angle from left to right. This versatile raw material is used in the production of tires, rubber gloves, latex threads, footwear, condoms, rubber hoses, conveyor belts, seismic rubber bearings, rubber asphalt, gas seals, etc. Natural rubber can be sourced from large-scale plantations managed by companies or from smallholder farmers, resulting in diverse production structures across producing countries. In the present study, the term 'plantation' refers to rubber trees managed on a large scale by companies, whereas 'garden' refers to those managed by smallholders. We refer to farmers who own and manage their own rubber gardens as rubber smallholders.

Indonesia, the focus of the present study, is characterized by a high presence of smallholder rubber production. As of 2022, smallholders account for 92.3% of dry rubber production, with 4.2% produced by state-owned enterprises and 3.5% produced by private enterprises (Statistics Indonesia, 2023). A greater proportion of smallholder production underscores the significant role of natural rubber in local livelihoods.

Since 2017, a novel leaf fall disease affecting rubber trees has spread across Southeast Asia and South Asia (Febbiyanti and Fairuzah, 2020; Kusdiana and Saputra, 2022; Damiri et al., 2022; Manessa et al., 2023; Hadi Ismail et al., 2024). On the basis of current knowledge, fungi belonging to the genus *Pestalotiopsis* cause this leaf fall disease. Brown spots appeared on

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the infected leaves (Figure 1). Under normal conditions, rubber leaves fall once a year during the dry season. However, when rubber trees are infected, leaves may fall three or four times annually, including outside the dry season (Figure 2). Presently, there is limited evidence that this disease leads to the complete drying and death of rubber trees. Frequent leaf fall and extended periods without leaves reduce photosynthetic activity, thereby decreasing latex production. This decline can significantly impact rubber smallholders, as it affects the production of their primary income source.

Figure 1 Rubber leaves infected by *Pestalotiopsis* sp.
*Source:*Tri Rapani Febbiyanti.

Figure 2 Rubber trees without leaves due to *Pestalotiopsis* leaf fall disease.
Source: Tri Rapani Febbiyanti.

Pestalotiopsis leaf fall disease represents a new risk to the livelihoods of rubber smallholders. However, systematic social scientific research is lacking regarding the extent to which rubber smallholders have been affected by this disease and how they are attempting to cope with this external shock. Currently, only fragmented information from news reports is available (Kompas, 2023). Reseach in terms of social sciences, particularly about the situations of and perceptions among farmers, is key to consider possible solutions for plant diseases and pest (Bianchi et al., 2006; Mills et al., 2011; Zang et al., 2018; Gwada et al., 2021) or climate change (Masud et al., 2017; Thinda et al., 2020; Khan et al., 2024). Against this backdrop, the present study aims to investigate the impact of *Pestalotiopsis* rubber leaf fall disease on the livelihoods of rubber smallholders in Indonesia.

There have been various studies on the livelihoods of rubber smallholders in Southeast Asia. Southeast Asia enjoyed a rubber boom until 2011 but has since experienced a decline in rubber prices. Given these circumstances, many studies have focused on the effects of low rubber prices on rural livelihoods (Syarifa et al., 2016; Andriesse and Tanwattana, 2018; Nicod et al., 2020; Sari, 2020; Mara and Sativa, 2022) as well as risk perceptions among rubber smallholders (Imelda et al. 2023a; Imelda et al. 2023b). For example, Nicod et al. (2020) analyzed the livelihood strategies of rubber smallholders in Thailand amidst market uncertainties, particularly the downward trend in rubber prices, by comparing data sets from 2011 (the peak of rubber prices) and 2017 (a period of low rubber prices). They reported various types of adaptation strategies ranging from minor adjustments to fundamental changes. Nevertheless, a significant number of farmers persisted with the "status quo" even during times of low rubber prices, and the conversion of rubber plantations was uncommon.

Previous studies suggest the necessity of understanding the livelihood effects of *Pestalotiopsis* leaf fall disease in the broader context in which Indonesian rubber smallholders are situated, paying careful attention to the actions (or inactions) taken by each household. To address this, we adopt the sustainable livelihood framework (SLF); several previous studies on

rubber smallholders have also applied the SLF with some modifications (Andriesse and Tanwattana, 2018; Nicod et al., 2020; Wang et al., 2023).

The most common version of the SLF (DFID 1999) consists of three main components: the vulnerability context, transforming structures and processes, and livelihood assets. The vulnerability context refers to "the external environment in which people exist," encompassing trends in population, resources, and the economy, as well as shocks related to disasters, human or crop/livestock health, conflicts, and seasonal variations in prices, production, or employment. Transforming structures and processes are “the institutions, organizations, policies and legislation that shape livelihoods,” encompassing governmental, private, and civil sector conditions, as well as policies, legislation, institutions, culture, and power relations. Generally, factors within the vulnerability context are beyond the control of local people. However, some elements of the vulnerability context can be addressed through transforming structures and processes, such as through policy initiatives.

Livelihood assets consist of five elements: human capital, social capital, natural capital, physical capital, and financial capital. Human capital represents “the skills, knowledge, ability to labor and good health that together enable people to pursue different livelihood strategies and achieve their livelihood objectives.” Social capital refers to “the social resources upon which people draw in pursuit of their livelihood objectives,” including networks, membership in groups, and relationships characterized by trust, reciprocity, and exchanges. Natural capital encompasses “the natural resource stocks from which resource flows and services (e.g., nutrient cycling, erosion protection) useful for livelihoods are derived.” Physical capital includes “the basic infrastructure and producer goods needed to support livelihoods.” Financial capital denotes “the financial resources that people use to achieve their livelihood objectives.” Livelihood assets are significantly influenced by the vulnerability context and transforming structures and processes. On the basis of the available livelihood assets and resources, local people make decisions to cope with external changes, referred to as livelihood strategies. The decisions made and strategies implemented result in various livelihood outcomes, ranging from successful adaptation to minor changes in response to challenges.

With respect to the purpose of the present study, recent significant events and policy developments in the Indonesian natural rubber sector are summarized and presented to provide insights into the vulnerability context and transforming structures and processes. The recent outbreak of leaf fall disease is considered a new shock that impacts vulnerability. Data from a household survey will be utilized to clarify livelihood capital assets and the strategies employed for livelihood maintenance.

1. Materials and Methods

1.1. Study site

We focused on South Sumatra Province (Figure 3), which is the largest rubber-producing province in Indonesia, accounting for 29% of the country's total rubber production (Statistics Indonesia, 2023). South Sumatra Province boasts approximately 885,697 ha of rubber gardens and plantations, making it the leading province in Indonesia for rubber cultivation. The rubber plantations in South Sumatra are predominantly smallholdings (97%), with private estates accounting for 2% and government estates accounting for 1% (ibid).

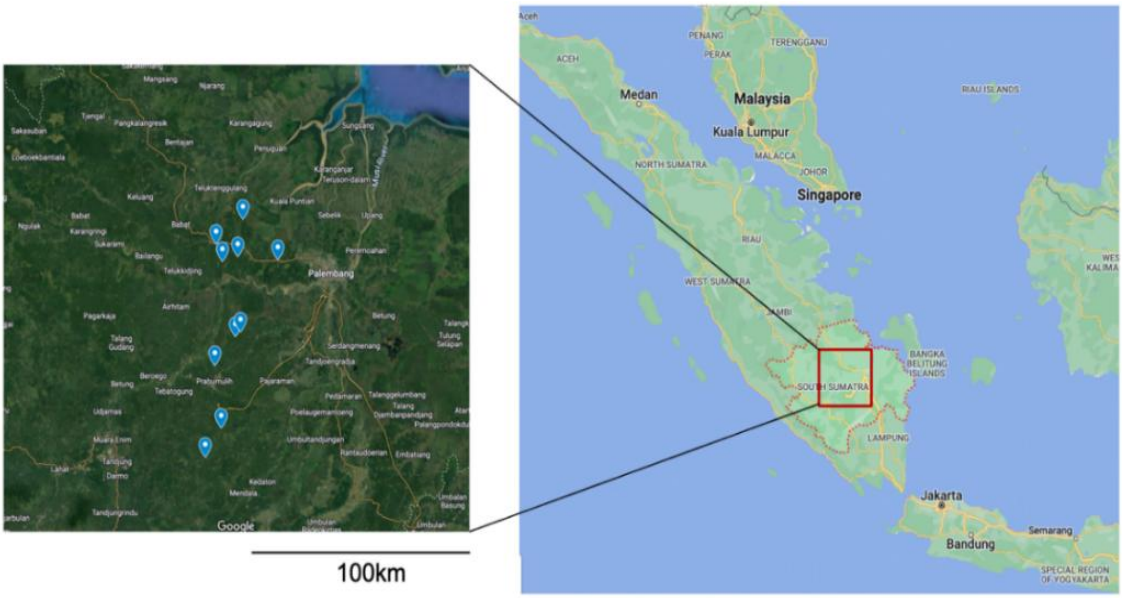

Figure 3 Locations of the 10 villages in South Sumatra, Indonesia.
Source: Google Maps.

South Sumatra Province is divided into 13 regencies (*kabupaten*) and 4 cities (*kota*). For our study, we targeted the Banyuasin and Muara Enim Regencies because of their importance as major rubber-producing areas.

2.2. Data collection and analysis

We employed multiple data collection methods for this study. First, we reviewed the current situation and recent policy issues related to natural rubber production, local marketing, diseases and pests, and global markets. Our data sources included global, national, and regional statistics; official documents at the national and regional levels; and local information provided to the Indonesian Rubber Research Institute, where five of the authors are affiliated. The information gathered through these procedures was analyzed to confirm the vulnerability context and the transforming structures and processes under the SLF.

Second, to understand the livelihoods and perceptions of rubber smallholders, we conducted a household survey based on in-person interviews. The survey took place in September 2023 in Banyuasin and Muara Enim Regencies of South Sumatra Province. We selected 10 villages: five from Banyuasin Regency and five from Muara Enim Regency. Basic information about these villages is presented in Table 1. The population and population densities varied among the villages, with nine villages having densities ranging from 50 to 250 persons/km^2, with the exception of one outlier (Petanang). All villages are located in lowland areas. Six villages actively engaged in the collective selling of rubber materials through auctions facilitated by rubber processing and marketing units (RPMUs: *units pengolahan dan pemasaran bokar*), as detailed in the results section.

Table 1 Basic information of the 10 villages surveyed.

Regency (Kabupaten)	District (Kecamatan)	Village (Desa)	Population	Population density (person/km^2)	Topography	Functioning of Rubber Processing and Marketing Units (RPMU)	Number of respondents
Banyuasin	Banyuasin III	Petaling	1,894	169.1	Lowland	Active	11
		Regan Agung	1,574	162.3	Lowland	Active	10
	Betung	Pulau Rajak	865	64.1	Lowland	Active	11
	Suak Tapeh	Meranti	2,915	119.5	Lowland	Active	10
	Sembawa	Pulau Harapan	7,361	220.9	Lowland	Active	10
Muara Enim	Gelumbang	Sebau	2,977	238.2	Lowland	Active	10
		Karta Mulia	1,712	100.7	Lowland	Not active	10
	Lubai Ulu	Karang Agung	8,133	85.0	Lowland	Not active	5
	Lubai	Sukamerindu	2,772	51.0	Lowland	Not active	15
	Lembak	Petanang	2,245	695.0	Lowland	Not active	11
Total							103

Prior to visiting each village, we contacted key individuals involved in natural rubber production, primarily presidents of RPMUs, and requested their assistance in arranging in-person interviews with approximately 10 rubber smallholders during our visits. The actual number of respondents per village is detailed in Table 1, totaling 103 respondents across all villages. Our study specifically targeted rubber smallholders, excluding farmers who do not cultivate rubber. We utilized a standardized questionnaire format during the interviews. The questions addressed basic household characteristics, land holdings, details of rubber production activities, impacts of and responses to leaf fall disease, sources of income apart from rubber tapping, and perspectives on future livelihoods. The respondents were briefed by key village individuals prior to the survey. Before commencing the interviews, we provided a comprehensive explanation of the survey's background and objectives to all the participants and obtained their informed consent.

Additionally, following the interviews conducted via the questionnaire, we undertook two further activities. First, we conducted explanatory sessions on leaf fall disease. Scientific knowledge regarding *Pestalotiopsis* sp. and its potential impact on rubber trees was presented in a manner accessible to ordinary farmers. Key points explained to smallholders included the identification of *Pestalotiopsis* sp. as a fungus suspected to cause abnormal leaf fall patterns, its widespread impact across Southeast Asian and South Asian countries, ongoing research efforts by the University of Indonesia and the Indonesian Rubber Research Institute to develop control measures, and the essential cooperation needed from smallholders to implement these solutions. Second, we provide guidance on how to photograph leaves affected by the disease via smartphones. We planned to gather comprehensive information on the spread of leaf fall disease from farmers by connecting with them through a messaging application (WhatsApp) to create infection maps. Additionally, we intended to offer timely advice on plant protection measures via the app upon request. While these activities primarily aimed to collaborate with rubber smallholders by imparting knowledge, they also facilitated relaxed communication sessions where informal information about their lives was gathered.

The data collected from the household survey were tabulated and analyzed via JMP® Pro 17 for statistical analysis. To align with the SLF, we represented each livelihood asset with some of the household survey data as follows.

a) Human capital: Experience in rubber garden management (years) and knowledge of rubber production and management.

b) Social capital: Participation in auctions facilitated by RPMUs.

c) Natural capital: Size and condition of natural rubber gardens and other types of land use.

d) Physical assets: Availability of fertilizers and pesticides.

e) Financial capital: Amount of savings and income sources other than rubber.

Since we did not collect detailed livelihood and income data before the onset of leaf fall disease, the present study does not facilitate direct comparisons of conditions before and after the disease outbreak. Nevertheless, by synthesizing all the collected information, we present the impacts of leaf fall disease on livelihood assets and strategies for discussion.

3. Results and Discussion

3.1. The vulnerability context where Indonesian rubber smallholders are situated

Figure 4 presents changes in rubber prices on the basis of TSR (Technically Specified Rubber) 20 on the SICOM (formerly the Singapore Commodity Exchange) market, which is generally consulted to understand trends in natural rubber prices. Many studies indicate that rubber prices in Southeast Asian countries experienced a boom from 2008-2011 (except for 2009, which was due to the bankruptcy of Lehman Brothers). However, after 2012, rubber prices significantly decreased and have generally remained low.

Figure 4 Rubber price changes (SICOM TSR 20).
Source: https://www.investing.com/commodities/rubber-tsr20-futures-historical-data.

Recent issues related to lower rubber prices include the trade and political war between China and the US, each imposing import tariffs, which has led to a decline in the consumption of goods from China to the US. Consequently, this has reduced the demand for raw materials, the main users of rubber, in the tire industry. In response, Thailand, Indonesia, and Malaysia agreed to reduce export volumes to increase rubber prices. As a result, rubber prices increased by approximately 4% in 2019 compared with those in 2018. Additionally, improved relations between China and the U.S. led to increased investor confidence in the rubber market. Furthermore, the increase in rubber prices was triggered by an outbreak of *Pestalotiopsis* leaf fall disease, which reduced the global rubber supply. However, in 2020, the COVID-19 pandemic caused prices to sharply decline. Following the lifting of lockdown policies, rubber prices began to rise again until 2021, with the average price reaching US$ 1.68. However, by September 2022, the price of rubber had declined to US$ 1.33 per kg, possibly due to a global recession (Syarifa et al., 2023). After experiencing low prices in 2023, slight improvements can be observed in 2024.

International price situations affect rubber selling prices at the local level. For smallholders, regardless of the selling method, low international prices result in low local prices. The hardships faced by smallholders, as reported in previous studies, continue to persist.

In addition to the global trend in rubber prices, Indonesia faces its own set of challenges. Natural rubber production and exports in Indonesia have declined over the past several years (see Figure 5). This decrease in production can be attributed, at least in part, to the impact of *Pestalotiopsis* leaf fall disease. Additionally, the COVID-19 pandemic in 2020 may have further exacerbated these effects. Other contributing factors include insufficient rubber tree rejuvenation efforts and recent extreme weather events linked to La Niña. Over the long term, persistent low rubber prices have led to many rubber plantations being left unmanaged or even abandoned (Syarifa et al., 2023; The Jakarta Post, 2023).

Pestalotiopsis rubber leaf fall disease has been a relatively new phenomenon since 2017; therefore, the scientific understanding of this disease has been limited, even among researchers. Various prevention methods are currently being tested, including fogging and fungicide spraying (Ministry of Agriculture in Indonesia 2023). These methods necessitate specific tools and equipment, adding to the costs for natural rubber producers, including both companies and smallholders. Efforts to

identify and develop effective fungicides or microbial solutions for disease prevention are also ongoing (Japan Science and Technology Agency 2024).

The quality of natural rubber produced in Indonesia has faced criticism because it is low. As previously mentioned, over 90% of natural rubber is produced by smallholders. However, not all smallholders possess the necessary knowledge and skills for effective rubber garden management. Common issues in rubber gardens managed by smallholders include the lack of weed and pest control, minimal or no use of fertilizers, excessive tapping of rubber trees (overtapping), and contamination of tapped rubber materials. These factors collectively contribute to Indonesian natural rubber not being competitive in the international market, potentially leading to a decline in export volume.

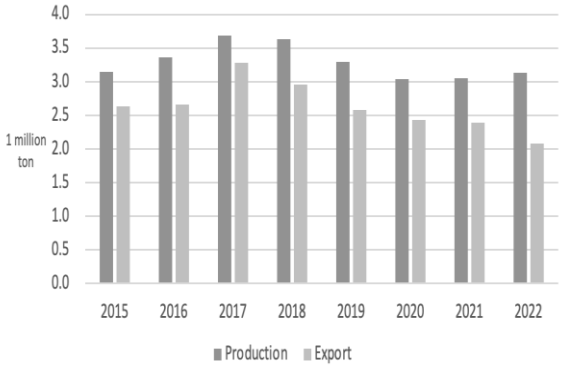

Figure 5 Production and export of natural rubber in Indonesia (Statistics Indonesia 2023).

In addition to *Pestalotiopsis* sp., para rubber trees are also affected by other diseases, such as white root disease caused by *Rigidoporus microporus*. Effective disease control in rubber plantations should ideally follow the principle of "prevention is better than cure." However, owing to a lack of adequate management knowledge among smallholders, implementing preventive measures remains challenging. Controlling white root disease typically involves clearing stumps and residual plant roots before replanting. For stem and branch diseases, the use of resistant clones and maintaining optimal planting conditions are recommended. Unfortunately, many smallholders may not be aware of these strategies. Given these circumstances, there is skepticism about whether smallholders will be willing or able to adopt preventive measures against *Pestalotiopsis* leaf fall disease in the future.

The aforementioned issues have collectively contributed to the perception that the natural rubber sector is in decline, often referred to as a sunset industry. In the Ministry of Agriculture's Strategic Plan for 2015-2019, rubber was classified as a "major plantation crop (*komoditas utama perkebunan*)." However, in the subsequent Strategic Plan covering 2020-2024, rubber was no longer categorized as a "strategic commodity (*komoditas strategis*)." Furthermore, starting in 2022, the Indonesian Government ceased providing fertilizer subsidies for rubber, as well as for oil palm and pepper, under the Ministry of Agriculture's Regulations on Procedures for Determining Allocations and Maximum Retail Prices for Subsidized Fertilizers in the Agricultural Sector. Subsidized fertilizer is now allocated only to farmers of coffee, sugarcane, and cocoa. The withdrawal of fertilizer subsidies, coupled with high fertilizer prices, has significantly hindered rubber smallholders' ability to increase productivity. Moreover, the exclusion of natural rubber from the list of strategic commodities suggests a potential reduction in overall government support. This situation poses the risk that adequate policy and financial support for prevention measures against *Pestalotiopsis* leaf fall disease may be insufficient.

Meanwhile, in Indonesia, there has been an increasing adoption of collective selling methods through RPMUs among rubber smallholders. RPMUs are village-level organizations composed of rubber smallholders aimed at producing high-quality raw rubber materials (Antoni & Tokuda, 2019). Established in 2008, RPMUs typically conduct auctions for buyers of raw rubber materials to secure fair selling prices. In contrast, when smallholders individually negotiate with middlemen, selling prices tend to be lower. The collective auctioning approach of RPMUs gives smallholders greater bargaining power, leading to higher selling prices. Through RPMUs, smallholders also have access to various forms of assistance, including technical training, subsidized fertilizers or fungicides, and other necessary equipment. Reports indicate that this collective marketing system via auctions has generally improved the quality of rubber and resulted in higher selling prices for smallholders (ibid). Presently, there are approximately 413 RPMUs in South Sumatra (Alamsyah et al., 2023). However, the ratio of natural rubber production currently marketed through RPMUs is limited, indicating that the majority of rubber farmers still sell their produce through middlemen outside of RPMU structures (Antoni & Tokuda, 2019; Alamsyah et al., 2023).

In summary, the vulnerability of Indonesian rubber smallholders has increased, particularly since the 2010s, due to low rubber prices, diseases, and declining government support. *Pestalotiopsis* leaf fall disease exacerbates the challenges faced by rubber smallholders, increasing their vulnerability. Importantly, in Indonesia, transforming structures, such as government policies, have not been supportive of rubber smallholders. This lack of support is evident in the removal of natural rubber from the list of strategic commodities and the discontinuation of subsidized fertilizer for natural rubber producers.

3.2. Livelihood situations of rubber smallholders

Table 2 presents basic information on the 103 surveyed households. The average age of the respondents, average number of household members, and average experience in rubber production were 47.2 years, 3.8 years, and 21.1 years, respectively. The percentages of respondents who graduated from junior high school, high school, and university were 61.2%, 45.6%, and 6.8%, respectively. In terms of natural rubber production, 68.9% of households were involved in rubber tapping activities with the participation of both spouses.

Table 2 Basic household information of the respondents (n=103).

	Ave.	Max.	Min.	SD.	%
Age of the respondent	47.2	78	27	11.3	-
Number of household members	3.8	7	1	1.2	-
Experience of rubber production (year)	21.1	48	3	10.7	-
Graduated junior high school	-	-	-	-	61.2
Graduated high school	-	-	-	-	45.6
Graduated university	-	-	-	-	6.8
Only husband taps rubber	-	-	-	-	28.2
Only wife taps rubber	-	-	-	-	2.9
Both husbands and wife tap rubber	-	-	-	-	68.9

The respondents reported that due to *Pestalotiopsis* leaf fall disease, natural rubber latex production decreased on average by 47.7%, with values ranging from a maximum of 75.0% to a minimum of 17.0%. Most respondents noted that leaves in their rubber gardens fall three to four times annually, creating conditions akin to dry seasons throughout the year and significantly impacting rubber leaf quality. These estimates are rough approximations provided by smallholders during interviews; therefore, their accuracy may vary.

The average size of rubber gardens owned was 2.6 ha, accounting for 92.9% of the total land owned (see Table 3). Among these trees, 0.7 ha were immature, as para rubber trees generally become viable for tapping four to five years after planting. Other land uses included horticulture, bushes, and oil palm gardens, although these were relatively insignificant compared with rubber cultivation. There was occasional purchase of bush land from others for conversion into rubber or oil palm gardens. Ownership rights were clearly defined for each bush, with minimal room for clearing forests in the surveyed districts. With respect to the awareness of rubber tree clones in their gardens, smallholders generally have limited knowledge. However, PB 260 and GT 1 clones were more prevalent than the other clones.

Table 3 Land owned (ha, % in parentheses) (n=103).

Item	Ave.	Max.	Min.	SD.
Rubber garden (immature)	0.7 (25.0)	5.0	0.0	0.9
Rubber garden (mature)	1.8 (64.3)	6.5	0.5	1.1
Total rubber garden	2.6 (92.9)	7.0	0.5	1.5
Horticulture	0.0 (0.0)	1.0	0.0	0.1
Bush	0.2 (7.1)	5.0	0.0	0.7
Oil palm garden	0.0 (0.0)	1.5	0.0	0.2
Total	2.8 (100.0)	7.3	0.5	1.6

Table 4 presents the breakdown of annual gross household income. The average annual gross income among the surveyed households was Rp. 43,156,816 in 2022. In total, the average income from rubber Rp. 28,350,990, constituting 65.7% of the total income. The household survey did not inquire about rubber income or overall household income before 2017 because of potential recall uncertainties among smallholders. Therefore, insufficient data exist to precisely quantify the extent of rubber income loss. The figures in Table 4 show the situations associated with the effects of *Pestalotiopsis* leaf fall disease.

In terms of management practices, 73 households (70.9%) did not allocate funds, such as fertilizer, to their rubber gardens in 2022. The average and maximum expenditures were Rp. 472,767 and Rp. 10,675,000, respectively. There was a positive correlation (coefficient 0.56, $p < 0.01$) between annual income and annual expenses for rubber garden maintenance, reinforcing the earlier finding that the quality of natural rubber produced by Indonesian smallholders is compromised due to inadequate management practices. As previously mentioned, subsidized fertilizer support for natural rubber production has been largely discontinued. During the interviews, the respondents expressed concerns about the high cost of fertilizer and stated that they could not afford it. Consequently, only households with higher incomes were able to purchase fertilizer. Previous studies have also indicated that financially well-off farmers are more likely to adapt to external changes, such as climate change (Masud et al., 2017; Thinda et al., 2020; Khan et al., 2024).

When asked about measures taken to control *Pestalotiopsis* leaf fall disease, 95 households (92%) reported taking no action. Eight households (8%) had implemented some measures, including applying fertilizer (four households), fogging with

fungicide (one household), land cleaning (one household), smoking (one household), and seeking support (one household). However, all the respondents indicated that their efforts were ineffective against *Pestalotiopsis* sp. According to t tests, there was a statistically significant difference between the "measures taken" and "measures not taken" groups in terms of total annual income ($p < 0.01$) and annual rubber income ($p < 0.1$). Smallholders with higher incomes were more likely to take action against the disease. This finding is also align with previous studies such as Khan et al. (2024).

Table 4 Annual gross income (million Indonesian rupiah, % in parentheses) (n=103).

Item	Ave.	Max.	Min.	SD.
Rubber	28.4 (65.7)	87.4	3.0	14.6
Shop management	5.4 (12.5)	120.0	0.0	15.2
Salary	4.3 (9.9)	48.0	0.0	11.0
Labor	1.7 (3.8)	30.0	0.0	5.5
Others	3.5 (8.0)	78.0	0.0	10.7
Total	43.2 (100.0)	192.0	12.0	26.9

(1 USD = 15,384 Indonesian rupiah as of September 2023).

No systematic measures against leaf fall disease by RPMUs have been reported. RPMUs are crucial organizations for local livelihoods in the rubber sector. However, there appears to be little inclination among rubber smallholders to take collective action or seek government support through RPMUs.

When asked, "Do you have plans to convert your rubber gardens?", 35 households (34%) answered "yes". Of these, 13 households planned to convert 50% of their rubber gardens, whereas 7 households planned to convert their entire (100%) rubber gardens. The presence of income sources other than rubber had statistically significant effects on the intention to convert to rubber gardens ($p < 0.01$ according to the chi-square test), as did total annual income ($p < 0.01$ according to the t test). These findings suggest that households with additional income sources and higher total annual income are more likely to consider converting their rubber gardens. We can infer that affluent households with additional income sources beyond rubber are more inclined to take proactive measures to change a given situation. This observation leads to the inference that households heavily reliant on rubber may face greater vulnerability if issues such as leaf fall disease and low rubber prices persist.

For the remaining 67 households that answered "no" to the earlier question about converting their rubber gardens, we explored the reasons behind their decision. The upper part of Figure 6 illustrates negative reasons such as "lack of resources." The most common reason cited was insufficient funds for land use conversion (51%), followed by a lack of experience or knowledge outside of rubber cultivation (12%). The lower part of the figure shows positive reasons for maintaining rubber gardens. Sixteen percent of respondents expressed that rubber trees are a familial asset passed down through generations, indicating a desire to continue this traditional livelihood. This suggests that smallholders have an emotional attachment to rubber as a part of their heritage.

Previous studies have noted an increasing trend of converting rubber gardens to oil palm gardens in Indonesia for increased profitability (Syarifa et al., 2016; Mara and Sativa, 2022). However, in our study, only four households (4%) reported having oil palm gardens (see also Table 3). Large-scale conversion of rubber gardens has not yet occurred significantly. This could be attributed to the fact that the two regencies surveyed are central to smallholder rubber production in Sumatra, where there is a strong historical and cultural attachment to rubber. Nevertheless, as depicted in Figure 6, depending on future circumstances, there may be an acceleration in the conversion of rubber to oil palm.

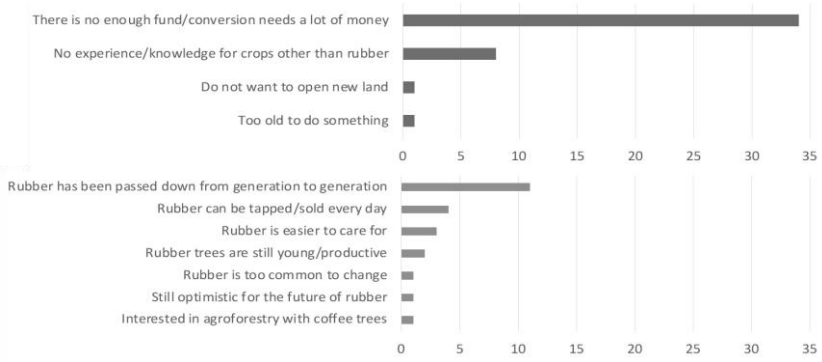

Figure 6 Reasons for not having a will to convert rubber gardens (n=67).

We summarized the situations of livelihood assets after *Pestalotiopsis* leaf fall disease in Table 5 from the viewpoint of the SLF. *Pestalotiopsis* leaf fall disease has unquestionably had a negative effect on natural capital assets, as evidenced by the occurrence of regular leaf falls (approximately four times per year) and decreased latex production. Consequently, the disease

has also negatively affected financial capital assets, specifically income from rubber and household savings. Approximately 60% of the households had income sources other than rubber. However, it would be inaccurate to view this diversification as a direct coping strategy against leaf fall disease. Income diversification had already been occurring gradually before the disease emerged. In our study, we did not observe significant shifts in income sources even with the substantial decline in rubber production due to leaf fall disease. This result is similar to Andriesse and Tanwattana (2018) and Nicod et al. (2020) about Thai cases. This lack of proactive action by rubber smallholders can be understood through Darnhofer's (2014) concept of buffer capability, which refers to "the ability to assimilate a perturbation without a change in structure or function." Rubber smallholders seemingly attempt to absorb the decrease in rubber income by depleting their savings. During the interviews, we also learned that some households increased their debt. If the current situation persists, smallholders may become more reliant on debt, increasing their vulnerability.

Table 5 Livelihood capital assets after *Pestalotiopsis* leaf fall disease.

Capital asset	Corresponding components in this study	Change due to the leaf fall disease	Note
Human	Experience of rubber garden (year) Knowledge of rubber production and management	Unchanged	There was a lack of knowledge and skills in disease management, as well as insufficient attitudes and opportunities to acquire new knowledge.
Social	Participation in auctions by RPMUs	Unchanged	There was little evidence that participation in RPMUs increased as a countermeasure against the leaf fall disease. Households participating in RPMUs had higher incomes.
Natural	Natural rubber garden owned and their conditions Other types of land use	Decreased	Continuous leaf falls and the decrease in latex production signify a significant decline in natural capital. The components of natural capital may change in the future due to the conversion of rubber to oil palm.
Physical	Availability of fertilizer and pesticide	Unchanged	The leaf fall disease itself did not affect the availability of fertilizer and pesticides. However, overall, due to declining government support, the availability of fertilizer has significantly decreased.
Financial	Saving amount Presence of income sources other than rubber	Decreased	Rubber income and savings are considered to have decreased significantly as a result of the leaf fall disease. Approximately 60% of the households had income sources other than rubber. Households with other income sources had higher incomes. Smallholders may become more reliant on debt, leading to increased vulnerability.

The disease had a minimal impact on human, social, and physical capital assets. However, there has been a notable decrease in the availability of fertilizer (physical capital) due to reduced government support, although this decline is not a direct result of leaf fall disease. With respect to human capital, smallholders' knowledge and skills related to previous rubber diseases were found to be inadequate. Furthermore, there was a lack of motivation and opportunities for them to acquire new knowledge. These factors pose challenges for implementing effective solutions against *Pestalotiopsis* in the future.

4. Conclusions

Pestalotiopsis leaf fall disease has significantly increased the vulnerability of rubber smallholders' livelihoods, primarily because of the decrease in latex production. While some households had income sources other than rubber, some were solely dependent on rubber income. Rubber smallholders are not monolithic; households with greater income, often owing to income sources other than rubber, are more proactive. Overall, smallholders' livelihood strategies have not been fundamentally transformed due to leaf fall disease; enduring the impact was the most common response.

Scientific knowledge about prevention and control measures is currently under development. Control measures will, in any case, incur high costs. In this context, it is crucial to design methods to implement control and prevention measures that do not leave ordinary households behind. Some collective arrangements at the village or regional level are key. In addition, although the Indonesian government is not currently supportive of the natural rubber sector, some government support is essential.

Ethical considerations

For the household surveys, we provided a comprehensive explanation of the survey's background and objectives to all participants and obtained their informed consent. In the process of dana tabulation, all the collected data were encrypted to ensure the anonymity of the respondents.

Conflict of interest

The authors declare that they have no conflicts of interest.

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