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Research article

Recovery of *Sterculia quadrifida* R.Br. bark: A guide to sustainable bark harvesting for traditional medicine

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Abstract

Importance of the work: Traditionally, the bark of *Sterculia quadrifida* R.Br. has been used to treat hepatitis in Indonesia. However, information on bark recovery is lacking.

Objectives: To determine the levels of regrown bark of *S. quadrifida* under different debarking strip sizes and intensities.

Materials & Methods: In total, 120 trees were debarked in Kupang, Indonesia based on three diameter at breast height (DBH) classes, using two strip-debarking intensities: partial (periderm and phloem) and total (periderm, phloem and cambium). Periodically, bark recovery was observed visually and by weighing the recovered bark at the end of the observation period.

Results: Visually, at 21 mth, the recovery for all strip sizes in the three DBH classes had reached more than 80%, while only the small diameter class had more than 100% regrowth bark weight, as had the recovery of the strip size of 5 cm × 25 cm in the medium DBH class. All diameter classes reached 100% strip recovery by month 21. The recovered bark weight was 76.91 ± 21.80% of the total debarking treatment and was 67.51 ± 69.64% for the partial debarking treatment. The recovery rate differed significantly between diameter classes, with the wider the strip, the longer the recovery process.

Main finding: A small strip size on trees with a small DBH produced the fastest bark recovery. Debarking the outer and inner bark resulted in better recovery than from partial debarking, as indicated by the higher percentage of recovered bark weight for the former.

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Introduction

Plants from the *Malvaceae* family are traditionally used for medicinal purposes (Pieme et al., 2010; Abat et al., 2017; Ajagbonna et al., 2019). The species *Sterculia quadrifida* R.Br., also known as 'Peanut tree', is a member of this family and is naturally found in various countries including Indonesia, India, Pakistan, Australia, Timor Leste and Papua New Guinea (Hill and Baird, 2003; Cowie and Palmerston, 2006; Karthikeyan et al., 2014; Akter, 2016; Saragih and Siswadi, 2019). The species is called 'faloak' by the Timorese in eastern Indonesia, where they consume the bark decoction of *S. quadrifida* as a traditional medicine to treat hepatitis (Siswadi et al., 2014). *S. quadrifida* bark is available in traditional markets and online markets. The bark is harvested from trees on roadsides and in domestic gardens and yards, particularly in Kupang, East Nusa Tenggara province, Indonesia. The bark harvesters usually debark trees that are easily accessible without applying any specific selection criteria. Hence, 98% of *S. quadrifida* in Kupang City has been debarked, indicating that the demand for the bark is high (Siswadi et al., 2021b). The locals randomly harvest the bark down to the cambial layer without considering the strip size, intensity or tree diameter. Some trees are even ring-barked due to their bark being frequently harvested. This condition can potentially trigger the overharvesting of some trees, especially those whose bark is valued for medicinal purposes. In addition, habitat conversion that has removed the trees has been a major threat to this species.

In total, 15 compounds were detected in the ethanol bark extract of *S. quadrifida* originating from Kupang, East Nusa Tenggara (Siswadi and Saragih, 2021). Another study indicated the strong antioxidant activity of *S. quadrifida*, with a value of 4.8101 parts per million for the half maximal inhibitory concentration in ethanolic solvent (Amin et al., 2016). In addition, the water extract of the bark of this species contains epicatechin, which has a potent antiviral activity for the hepatitis C virus (HCV JFH1) (Dean et al., 2019).

The bark on a tree is essential for tree growth, protection, water storage and structure (Poorter et al., 2014; Vergílio and Marcati, 2017). Bark recovery ability is usually different for each plant species and the level of damage determines the recovery process of tree bark, whether the bark has been removed down to the cambial layer or only partially detached leaving the cambium untouched (Pandey and Kori, 2009; Stewart, 2009). In addition, the removal affects the survivability of the plant; if the debarking does not extend to the vascular cambium, it is unlikely that the tree will die (Stewart, 2009), whereas debarking that removes the cambium increases the tree's susceptibility to insect and fungal attacks and its mortality risk, which can be compounded by the additional inhibition of photosynthetic transport (Guedje et al., 2016). Bark recovery ability and the applicable sustainable harvesting system are species-specific, since the rate of bark regrowth varies and is strongly correlated to intrinsic factors (Romero and Bolker, 2008; Guedje et al., 2016). Therefore, this study was the first that investigated the recovery ability of *S. quadrifida* bark following the bark removal of different strip sizes, tree diameter classes and intensities.

Materials and Methods

Site description

The study was conducted in Oelatsala village (10°14'154"S, 123°41'139"E), Taebenu sub-district, Kupang regency, East Nusa Tenggara province, Indonesia, located at 412 m above mean sea level. The location was approximately 1 km from residential areas, where most trees have never been debarked. The *S. quadrifida* plot in this study no longer exists due to land conversion in 2021 (Fig. 1). *S. quadrifida* was the most common species on this site. Other species identified were Java olive (*Sterculia foetida* L.), Shrub sandalwood (*Exocarpus latifolia* R.Br.), Rosary pea (*Abrus precatorius* L.), Cassod tree (*Sanna siamea* Lamk.), Lac tree (*Schleichera oleosa* Lour. Oken) and Teak (*Tectona grandis* L.f.).

Fig. 1 Study location map showing canopy cover changes during the wet and dry seasons (images in bottom-left corner and center, respectively), with study area after clearing in 2021 for a residential area (image bottom-right corner)

Kupang is a semi-arid region with a hot, dry climate (Tjoe et al., 2019). The rainfall and temperature data in the area from 2010 to 2020 were obtained from the Central Bureau of Statistics of Kupang Regency. The minimum and maximum temperatures were 17.3°C and 38.4°C, respectively, with the relative humidity in the 48–88% range. The rainy season occurs from November to March and peaks in December or January, with an average rainfall of 444 mm. The dry season is from May to September, with an average rainfall of 14 mm.

Debarking experiment

Two individuals collected all the samples to ensure consistency in the debarking method and the quantity of bark remaining on the trunk for all trees. Two experiments were carried out to determine the recovery ability of the bark of *S. quadrifida*. In both treatments, the trees were grouped into three DBH classes, namely small (<15 cm), medium (15–30 cm) and large (>30 cm), according to Siswadi et al. (2021a). The selected trees had no signs of previous debarking. The removed bark was stored in a Ziplock clip bag and weighed using a set of digital scales.

Strip size treatments

The outer bark (periderm), inner bark (phloem) and cambium were removed in treatments using different strip sizes. The debarking treatment refers to total debarking as described by Delvaux (2009). The length of the strip was 25 cm with three width variations (5 cm, 10 cm and 15 cm). The debarking was applied to 10 trees in each DBH class. In total, 90 trees were debarked. The elongated strip shape and debarking intensity were similar to the technique applied by traditional bark harvesters. This treatment was conducted in March 2018.

Strip intensity treatment

The second treatment was conducted in November 2018 as a follow-up study to the strip size treatments. The strip intensity treatment was conducted to determine the bark recovery at two debarking intensity levels (total and partial). Outer bark, inner bark and cambium were removed in total debarking, while in partial debarking, only the outer bark and some of the inner bark were removed. The treatments were applied to three diameter classes using a strip size of 5 cm × 25 cm, because this strip size had the highest recovery rate in the strip-size treatment. In total, 30 trees were debarked from the three DBH classes with 10 replicates. Since the strip was narrow, two strips were taken from the opposite sides of each tree.

Bark recovery observation

Recovery observation was conducted visually based on measuring the area of recovered bark using a square grid printed on white folio paper. The regrowth bark weight was determined by weighing the initial and subsequent debarking yields. Observations were carried out in September 2018, April 2019, November 2019 and June 2020 (at 7 mth, 14 mth, 21 mth and 28 mth after debarking). In the strip intensity treatment, the surface of the extracted part was closed entirely at 21 months after stripping. Therefore, the recovered bark of the strip intensity treatment was weighed earlier than for the strip-size treatment. The recovered bark from both experiments was weighed (wet weight), and the regrowth bark was expressed as a percentage.

Statistical analysis

Before the analysis, homogeneity and normality tests were conducted for the recovery rate and recovered bark weight data. The recovery data from the strip size treatment had non-normal distributions. Therefore, it was tested using the nonparametric Kruskal-Wallis tests ($p < 0.05$) and the *post hoc* Mann-Whitney test ($p < 0.05$). The data for regrowth bark weight were normally distributed, with homogeneous variance across groups, so analysis of variance was applied, followed by *post hoc* Tukey tests. Analyses were performed using the IBM SPSS Statistics version 27 software (IBM Corp. Armonk, NY, USA).

Results and Discussion

Sterculia quadrifida trees profile

The branch-free height indicates the amount of bark that can be harvested from the ground upward. Thus, it is important to consider having a higher yield while considering the recovery ability. The traditional bark extraction technique generally harvests up to the clear-bole height because it is accessible, has a smooth surface and is easy to debark. The trees in the strip intensity treatment had better canopy health scores than those in the strip-size treatment. However, in general, most of the *S. quadrifida* trees in this study had healthy crowns, especially trees in the medium and large DBH classes.

Evidence of insect attacks was identified in one-half of the trees after the debarking treatment. One tree in the small DBH class in the strip-size treatment suffered from severe ant attack and died four months after debarking. Ant and termite nests were observed in the strip treatment area. It was possible that the ants had been attracted by the fresh layer of cambium of the *S. quadrifida* that may have had a sweet taste. Another effect of debarking is gum secretion, with the stripped stem of *S. quadrifida* sometimes excreting gum, while a small number of strips also produced new shoots after debarking.

Tree growth, bark recovery and the effect of debarking on *S. quadrifida* are poorly understood. Some *S. quadrifida* trees suffer from insect attacks after debarking treatment. Termites and ants were observed on the exposed parts of *S. quadrifida* stem. Studies have shown similar results, with bark stripping causing pest and disease attacks on trees (Delvaux et al., 2009; Mariot et al., 2014). Despite plant species and stem parts having different chemical constituents for defense, plants are prone to pest attacks after debarking (Ataç and Eroğlu, 2013). Insects nesting in the bark layer are among the causes of tree death (Tiberi et al., 2016). Some species have sweet, edible inner bark and cambium that can attract insects (Turner, 2020) as was the case in the current study with *S. quadrifida*.

S. quadrifida bark secrets transparent gum after debarking as a result of a protection mechanism upon mechanical damage (Barak et al., 2020). Many plants that grow in semi-arid regions exude gum, whose functions are protection, wound closure and protection against hydration loss (Licá et al., 2018). The genus *Sterculia* is known to produce gum called karaya (Prachi and Bhogaonkar, 2016; Prasad et al., 2022). *Sterculia foetida* and *Sterculia urceolata* are two gum-producing species found in Indonesia (Malabadi et al., 2021), where the gum is used in the pharmaceutical and food industries (Lujan-Medina et al., 2013; Sukhadiya et al., 2019; Prasad et al., 2022). *S. quadrifida* is a potential gum producer.

After debarking, several *S. quadrifida* trees also showed the development of new shoots near the debarked area, which has been described as a survival mechanism (Delvaux, 2009). New shoots have been reported after bark extraction in *Bombax buonopozense* (Mohammed et al., 2022) and *Uapaca togoensis*, *Parkia biglobosa* and *Maranthes polyandra* (Delvaux, 2009).

Recovery determination based on visual observation

Strip-size treatment

The bark recovery of *S. quadrifida* started from the edge of the strip (edge growth) (Fig. 2). The bark regeneration percentages with respect to DBH class, strip size and observation period are represented in Table 1.

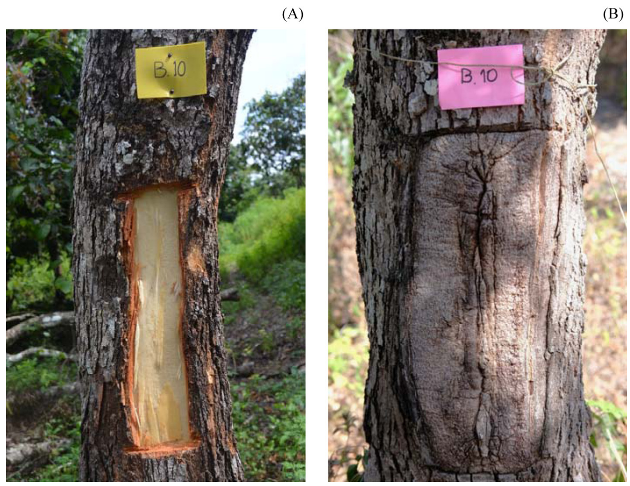

Fig. 2 Total debarking treatment using strip size 5 cm × 25 cm: (A) medium diameter class, with outer bark, inner bark and cambium being removed; (B) regrown bark after 20 mth

Table 1 Average recovery rate in strip size-treatments based on visual observation

DBH class	Strip size (cm)	Recovery over time after treatment (%)			
		7 mth	14 mth	21 mth	28 mth
Small	5×25	83.44±19.70^{a}	95.67±9.50^{a}	98.78±3.46^{a}	100.00±0.00^{a}
	10×25	58.60±18.73^{b}	69.50±1.50^{bcd}	92.20±9.22^{a}	97.00±4.65^{a}
	15×25	46.00±7.38^{c}	66.50±3.50^{cd}	91.50±7.09^{a}	98.75±2.17^{a}
Medium	5×25	77.18±16.73^{b}	94.91±10.87^{ab}	98.82±3.74^{a}	99.09±2.87^{a}
	10×25	54.56±19.20^{b}	65.00±3.00^{cd}	89.67±14.38^{a}	95.67±7.97^{a}
	15×25	49.90±16.54^{c}	50.50±10.50^{d}	88.60±13.62^{a}	93.80±13.18^{a}
Large	5×25	70.40±15.80^{b}	98.20±2.14^{a}	100.00±0.00^{a}	100.00±0.00^{a}
	10×25	60.50±21.52^{b}	73.33±12.68^{abcd}	91.90±10.34^{a}	96.70±5.92^{a}
	15×25	62.10±25.59^{b}	80.50±5.50^{abc}	93.40±11.43^{a}	99.30±1.00^{a}
Average		62.61±17.74^{B}	77.01±6.58^{B}	94.29±7.85^{A}	97.81b±3.91^{A}

Values (mean ± SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different; for the average row, values (mean ± SD) superscripted with different uppercase letters are significantly ($p < 0.05$) different.

The smallest strip size had the highest recovery (more than 90%) in all DBH classes at month 14. The mean (±SD) bark recovery after debarking was high in month 7 (62.61±17.74) and continued to increase to month 14 (77.01±15.53%), before leveling off in month 21 (94.29±3.92%) and month 28 (97.85±1.94%). Conversely, the largest strip size (15 cm × 25 cm) had the lowest bark recovery. A similar recovery pattern occurred in all diameter classes. However, the smallest diameter class trees had a faster and higher recovery rate than those of medium and large. At this point (21 mth or 28 mth after debarking), the recovery rate was not significantly different based on either strip size or DBH class.

Generally, the *S. quadrifida* bark had almost fully recovered within 21 mth. The recovery ranged from 88.60 ± 13.62% to 100%, reaching 93.80 ± 13.18 to 100% in the adjacent observation at 28 mth. The speed of bark recovery has been reported to be species-specific (Mohammed et al., 2022); however, in the current study, the bark recovery of *S. quadrifida* was similar to that of *Holarrhena antidysenterica* R. Br. whose repeated bark harvest was recommended using an 18 mth cycle between harvests (Singh and Singh, 2022), while *Terminalia arjuna* bark needed 2 yr to recover (Pandey and Mandal, 2012). Other studies reported that bark occlusion was not complete on some debarked trees after 1 yr (Vermeulen, 2004; Akhter et al., 2012.

Strip intensity treatment

The experiment involving bark regrowth following partial debarking did not penetrate far below the hardened exposed stem area (Fig. 3). Based on visual observation, the recovery in the total debarking experiment was 59.23 ± 18.22% in month 7. After 14 mth, the recovery rate was 85.20 ± 9.70% to 100%, with the exposed area being fully closed at 21 mth (Table 2).

The observations at 7 mth showed that the recovery had reached over one-half of the extracted surface. The fastest recovery from total stripping in the first and second observations was seen in the small DBH class and was significantly different from the medium and large DBH classes. However, after 21 mth, recovery had reached 100% in all three DBH classes.

Recovered bark weight

Strip size

Recovery reached more than 100% for all strip sizes in the small DBH class and the 5 cm x 25 cm strip size in the medium DBH class. In addition, the highest recovery was in the small DBH class of the 5 cm × 25 cm strip size, with 139.02±36.74% and a regrowth bark weight of 306.29±52.90 g (Table 3). For the strip sizes of 10 cm × 25 cm and 15 cm × 25 cm, the bigger the DBH class, the lower the recovery rate. The highest recovery in the strip size 10 cm × 25 cm was in the small DBH class (133.57±21.97%), while the lowest was in the large DBH class (71.06±22.39%). For the strip size 15 cm × 25 cm, the highest recovery was 132.83±17.35% in the small DBH class, while the lowest was 62.68±11.97% in the large DBH class.

(A) (B)

Fig. 3 Partial debarking (removal of outer and inner bark) of small diameter tree: (A) inner bark exposed after debarking; (B) surface of inner bark after hardening with no bark regrowth apparent.

Table 2 Average recovery rate in strip intensity treatment based on visual observation

DBH class	Recovery after total debarking over time after treatment (%)			Recovery after partial debarking over time after treatment (%)		
	7 mth	14 mth	21 mth	7 mth	14 mth	21 mth
Small	67.43±19.29^a	92.74±7.64^a	100±0.00^a	0±0.00	0±0.00	0±0.00
Medium	57.34±17.98^b	83.32±2.62^b	100±0.00^a	0±0.00	0±0.00	0±0.00
Large	52.92±17.40^b	79.53±18.85^b	100±0.00^a	0±0.00	0±0.00	0±0.00
Average	59.23±18.22^C	85.20±9.70^B	100±0.00^A	0±0.00^D	0±0.00^D	0±0.00^D

Values (mean ± SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different; for the Average row, values (mean ± SD) superscripted with different uppercase letters are significantly ($p < 0.05$) different.

Table 3 Bark recovery of *S. quadrifida* based on regrowth bark weight

DBH class	Strip size (cm)	Initial debark weight (g)	Recovered bark weight 28 mth after debarking (g)	Total harvested bark (g)	Bark recovery yield (%)
Small	5×25	128.14±34.89	178.12±26.25	306.29±52.90	139.02±36.74[a]
	10×25	276.25±30.50	396.00±9.90	645.25±53.03	133.57±21.97[a]
	15×25	329.00±39.00	437.00±16.97	766.00±72.12	132.83±17.35[a]
Medium	5×25	195.25±41.36	220.13±71.66	415.38±105.80	112.74±31.10[ab]
	10×25	392.14±98.53	336.14±67.22	728.29±157.86	85.72±17.22[bc]
	15×25	542.00±91.14	444.17±67.22	986.17±148.60	81.95±28.76[bc]
Large	5×25	311.75±42.70	229.00±59.38	540.75±83.37	73.46±21.08[c]
	10×25	533.88±72.93	379.38±87.75	913.25±93.76	71.06±22.39[c]
	15×25	816.00±36.21	511.50±75.76	1.327.50±56.78	62.68±11.97[c]

Values (mean ± SD) in the bark recovery yield column superscripted with different lowercase letters are significantly ($p < 0.05$) different.

The bark recovery of *S. quadrifida* reached more than 90% 14 mth after bark removal but only for the 5 cm × 25 cm strip size. The strip width of 5 cm resulted in better recovery than wider strip sizes, although for strip widths of 10 cm and 15 cm, the stripped part was generally fully occluded by 21 mth. The same finding has been reported in a study of three medicinal plants in South Africa that recommended strip sizes of less than 10 cm for greater recovery (Vermeulen and Geldenhuys, 2004).

These results were consistent with the study on *Drimys brasiliensis*, which showed that the smallest strip has better bark regrowth (Mariot et al., 2014), with the higher recovery rate being due to the existing network at the edges of the former stripping, as debarking can trigger an increase in new tissue formation (Delvaux et al., 2010).

Strips from small-diameter trees had higher recovery rates, which was consistent with the reported higher regeneration capacity in younger *Prunus* trees (Lagarde-Betti et al., 2019). The small and medium diameters should be a priority for debarking, not only due to the faster bark regeneration in young trees with smaller diameters (Delvaux et al., 2010; Pandey and Mandal, 2012) but also because the debarking cycle is more likely to be faster in the smaller diameter classes. There was a tendency for a decrease in recovery rate as the tree matures, with bigger trees having a slower recovery response (Stewart, 2009). However, in contrast, Vermeulen et al. (2012) reported that the smaller the tree diameter, the lower the recovery rate.

In the current study, the large-diameter trees yielded a much higher harvested bark weight due to their thicker bark. However, the recovered bark weight was less than the initial bark harvest. Based on the Tukey *post hoc* test results, there are no significant differences among the recovery levels for all strip sizes. The large DBH class had the lowest recovery rate, which was significantly different from the small DBH class but not significantly different from the medium class. The recovery of the small DBH class differed significantly from the medium and large DBH classes.

Strip intensity

Recovery following partial debarking was expressed as zero because only the hardened inner bark was visible on the debarked stem. The inner bark had hardened and discolored evenly over the entire surface, with no apparent new bark growth as occurred following total debarking. However, based on the regrowth bark weight, some bark recovery also occurred following partial debarking (Table 3).

With total debarking, visually, the fastest recovery occurred in the small DBH class. At 7 mth after stripping, one-half of the stripped surface had occluded. The recovery rate between the small DBH classes significantly differed from the medium and large diameter classes at 7 mth and 14 mth. At the end of observation period, the debarked part in all DBH classes had completely occluded.

With total debarking, the initial bark harvest for the large DBH class weighed 237.67 ±62.66 g (Table 4). After 21 mth, it had only produced regrowth of 170.00±21.19 g (a recovery rate of 71.53±32%). Initially, for the small DBH class, the debarked mass was 146.02±2.04 g; after 21 mth, the recovery had reached 82.20±6.6%. There was better recovery from debarking by the small-diameter trees than the large-diameter trees, as indicated by the higher percentage of recovered bark weight for the former.

The average recovery rate for total debarking across the three diameter classes was 76.91 ± 4.91% and significantly differed from the 58.54±3.76% value for partial debarking (Table 4). At the same time, the total bark yield (initial plus subsequent) was 340.93±58.13 g and only 156.15±27.31 g for total and partial debarking, respectively, with these values being significantly different. For *S. quadrifida* debarking, it is suggested to use the total stripping method because the recovery was significantly higher than for partial debarking.

Table 4 Recovered bark weight following total and partial debarking

DBH class	Total debarking				Partial debarking			
	Initial stripped bark weight (g)	Recovery bark weight (g)	Total (g)	Bark recovery yield (%)	Initial stripped bark weight (g)	Recovery bark weight (g)	Total (g)	Bark recovery yield (%)
Small	146.02±2.04	120.04±8.00	266.00±6.00	82.20±6.60	77.50±4.50	48.28±27.50	125.78±23.41	62.30±59.87
Medium	197.22±38.69	151.89±12.06	349.11±34.02	77.08±26.80	94.22±14.50	56.45±24.45	150.67±16.64	59.91±49.00
Large	237.67±62.66	170.00±21.19	407.67±62.11	71.53±32.00	125.17±23.46	66.84±35.27	192.01±51.19	53.40±28.29
Average	193.63±37.49	147.30±20.65	340.93±58.13	76.91±4.36^{A}	98.96±19.75	57.19±7.60	156.15±27.31	58.54±3.76^{B}

A comparison is made between the bark recovery yield of Total debarking and Partial debarking; for the average row, the means superscripted with different uppercase letters are significantly (p < 0.05) different.

In *S. quadrifida,* total debarking resulted in a better recovery rate. However, Delvaux et al. (2010) concluded that removal of the cambium resulted in poor recovery because partial stripping was only carried out on the outer layer of the bark, allowing the tree to recover more rapidly (Guedje et al., 2016). The outer bark (rhytidome) is the outer layer of the stem that protects against wind, microorganisms, fire and herbivores (Rosell et al., 2014; Morris et al., 2016). The inner bark (phloem) transports carbohydrates (Rosell et al., 2015), nutrients, such as sugars and fatty acids (Morris et al., 2016; Masendra et al., 2020), and replenishes the dead outer bark (Eberhardt, 2013). The immature xylem forms bark regrowth and is seen as sheet growth on the surface of the extracted part (Shigo, 1984), while the cambium will form edge growth (Vermeulen et al., 2012). However, the ability of a species to regenerate after debarking is also related to the anatomy and tissue structure of its bark. Unfortunately, at this time, no information is available on the bark anatomy of *S. quadrifida*.

Each species has a different bark recovery pattern (edge growth or sheet regrowth). However, in the current study on *S. quadrifida* bark recovery, both these patterns were evident due to the difference in the thickness of the bark harvested, where total debarking produced edge regrowth, while partial debarking resulted in sheet regrowth. Total debarking resulted in a better recovery process than partial debarking. Several possible physiological reasons can be suggested. First, bark is essential for transporting nutrients, sugars and water within a tree and total debarking disrupts the transportation system, leading to severe interruption in the circulation of essential resources. This severe action might trigger the tree to allocate resources more efficiently to aid in recovery. Second, trees have stress response mechanisms that can be activated in extreme situations; total debarking might induce a more robust stress response in a tree, prompting the activation of a defense mechanism and the production of secondary metabolites that could aid in recovery. Third, trees can compartmentalize wounds and initiate a wound response process, with total debarking perhaps triggering a more extensive distinguish response throughout the tree. This situation focuses on sealing off the entire exposed area, preventing the entry of pathogens, as well as promoting healing.

Tree bark is known to have antimicrobial (Akhtar et al., 2017), antioxidant (Elansary et al., 2019) and anticancer (Burlacu and Tanase, 2021) properties. The extract yield and flavonoid content of *S. quadrifida* bark were obtained optimally when harvested from trees with a 15–30 cm diameter (Siswadi et al., 2021a). Debarking also results in regrowth bark with higher levels of antioxidants than the initially harvested bark of *S. quadrifida* (Saragih and Siswadi, 2019). However, intensive harvesting can reduce the life expectancy of the tree (Gaoue et al., 2013). One way of overcoming this is to apply techniques that can accelerate recovery. The application of Bordeaux paste and neem seed kernel has resulted in a noticeably greater bark recovery by *Cinnamomum zeylanicum* (Hanumantha and Vasudeva, 2022). In addition, it has been observed that covering the exposed part with a transparent plastic sheet after debarking enhanced recovery (Zhengli et al., 1982). Covering the wound site with mud helps to protect the tree from insects (Chungu et al., 2007; Beltran-Rodriguez et al., 2021), as does applying disinfectant (Mohammed et al., 2022). Research on techniques to increase *S. quadrifida* bark regrowth is necessary. In the meantime, the application of periodical harvesting will maintain the sustainability of using the bark from this species.

Conclusion

With *S. quadrifida*, recovery of the smallest strip size, based on visual observations, was approximately 94.21% at 21 mth. The recovery of the other strip sizes reached 100% at 28 mth. For the strips where the visual inspection indicated there had been complete occlusion, the weight of the bark regrowth could be more or less than the original bark weight. Based on the current results, total debarking is recommended using a strip size of 5 cm × 25 cm on trees with DBH less than 30 cm. Combining the narrowest strip size and small diameter trees class resulted in the fastest bark recovery. The larger the diameter class, the greater the regrowth bark obtained; however, the recovery process was slower. Total debarking resulted in better recovery than from partial debarking, as indicated by the higher percentage of recovered bark weight for the former.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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