Wind damage and yield recovery in rubber (*Hevea brasiliensis*) plantation

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Abstract. The recent study observed the damage type and the effect on the yield and dry rubber content (DRC) of wind damaged and one-year recovery of rubber trees. The observation covered 11 sites consisted of 8, 11, 12, and 15 years of PB 260 clone. The damage type was distinguished into curved, cracking curved, broken branch, broken stem, and uprooted. Latex samples were collected from each damage type and compared with normal trees. The observation exhibited that the broken stem and uprooted trees were found in the center of the impacted area, whereas curved and broken branch trees were located in the outer. The proportion of curved, broken branches and uprooted trees increased by plant age, while the proportion of broken stem decreased. The wind damage inflicted a significant yield loss and DRC decrease. The curved trees showed the least impact on the yield, yet it was reduced by nearly 50 %, and the DRC lower around 4.92 %. Nevertheless, when the curve was accompanied by cracking, the yield loss and the DRC decrease were more severe. The one-year recovery trees indicated that the trees did not fully recover.

1. Introduction
Para rubber (*Hevea brasiliensis*) is mainly cultivated in the Southeast Asia region. *H. brasiliensis* is mostly cultivated on the large scale of the monoculture systems for its latex, which can be processed for various products. In 2018, world natural rubber production reached 13.87 million tons with a total consumption of 13.81 million tons [1]. Although the world rubber demand is mostly supplied by synthetic rubber, it cannot replace the unique characters of natural rubber, so that this commodity remains important for many industrial products [2,3]. *H. brasiliensis* is cultivated around 12 million hectares, mainly in South and Southeast Asia (91 %), the rest (6 %) was cultivated in tropical Africa and 3 % in tropical America [4].

In large-scale plantations, yield per area is the main concern of the planters, which is determined by individual yield and plant density [5]. Rubber breeding program in the last decades has managed to produce high yield clones [6,7], which is the main factor of world natural rubber production increase besides the rubber plantation expansion [8][9]. The severe wind damage is one of the major factors resulting in the loss of tapping trees, inflicted a detrimental yield loss [10]. The previous study by [11] exhibited that the wind velocity had a negative regression coefficient to the yield.
The heavy canopy of the mature plant leads *H. brasiliensis* vulnerable to wind damage. In certain areas, strong wind blow may damage hundreds or even thousands of trees causing permanent damage. To the managerial extent, a drastic decline of plant density oftentimes drives the company to expedite the replanting program before reaching a planned economic lifespan. Therefore, wind speed parameters should be considered in the evaluation of suitability for rubber cultivation \[12\] and planting management \[13\]. The selection of planted clones is crucial in a sub-optimal environment including high wind velocity \[14\].

Some researchers emphasized the necessity of a wind resistance breeding program \[15,16\]. However, rubber breeding works are mostly dedicated to yield improvement, while wind damage has not been received adequate attention so that the information about this topic is still limited. This article reported the characteristics of wind damage and recovery of *H. brasiliensis* tree. The reduction of the yield and dry rubber content (DRC) was discussed.

2. Material and Methods

2.1. Material

The observation was carried out at Sei Putih Estate, North Sumatra, Indonesia from November 2017 - April 2018. The plant assessed consisted of 11 sites of mature plants damaged by strong wind blow from 8, 11, 12, and 15 years of PB 260 clone (Figure 1) and a one-year recovery site. The impacted sites were tagged using GPSMAP 78s (Garmin Ltd., Kansas - USA) to draw the impacted areas. The numbers of impacted trees were counted manually according to the damage type i.e. curved, cracking curved, broken branch, broken stem, and uprooted. A total of 2,336 trees was observed in this study. The proportion of damage type was calculated by dividing the number of trees in each group with total impacted trees in each site.

Site 1 = 2,026.12 m²
\(a = 14; n = 75\)

Site 2 = 733.75 m²
\(a = 14; n = 27\)

Site 3 = 460.71 m²
\(a = 14; n = 20\)

Site 4 = 3,800.68 m²
\(a = 12; n = 190\)

Site 5 = 5,070.12 m²
\(a = 12; n = 185\)

Site 6 = 2,773.88 m²
\(a = 12; n = 98\)

Site 7 = 14,010.34 m²
\(a = 11; n = 512\)

Site 8 = 1,428.6 m²
\(a = 11; n = 51\)

Site 9 = 30,624.90 m²
\(a = 11; n = 1,108\)

Site 10 = 1,318.00 m²
\(a = 8; n = 48\)

Site 11 = 1,659.55 m²
\(a = 8; n = 61\)
Figure 1. The pattern of impacted areas observed in this study. $a =$ age of the plant, $n =$ number of impacted trees

2.2. Methods
For the yield assessment, latex samples were collected at noon from each damage type then compared to normal trees on the same site. The normal trees were selected based on the visual observation that showed normal growth and crown without any sign of wind damage. The normal trees were receiving double-cut S/2 d3 + S/4 d3 ET2.5%(2w) tapping system, while in a one-year recovery site, the normal trees were harvested using a single cult S/2 d3 ET2.5%(2w) tapping system. The tapping notation followed [17].

The dry rubber content (DRC) was measured according to ASTM International (2002). As much as 10 g of fresh latex was collected in each damage type accordingly then added by 1 ml of 2% acetic acid. The coagulum was pressed between rolls in running water to produce a +2 mm thickness of the rubber sheet. The samples were oven-dried at 55 °C temperature overnight. The DRC was calculated using the following equation:

$$DRC = \frac{Dw}{FW} \times 100\%$$

- DRC : Dry rubber content (%)
- Dw : Dry weight (g)
- FW : Fresh weight (g)

The same procedures of yield and DRC assessment were applied on the one-year recovery site. The data were summarized using Microsoft Excel Program (Microsoft Inc., Washington-USA).

3. Results and Discussion
3.1. The damage type
Our result suggested that the damage extent was determined by many factors, in accordance with [19] that identified factors affecting the vulnerability and level of wind damage i.e. tree height, crown weight, stem strength and flexibility, tree spacing, and root strength. The area and number of impacted trees varied in each site and did not show a particular pattern. In the observation sites, the planting space was 3 m x 6 m with east-west row direction. The curving and falling direction of the tree indicated that wind blew from south to north as showed in sites 4, 6, 7, and 8.

Wind damage could inflict both internal and external wounds [20]. The trees could be twisted and resultant stress crushes the internal tissues including wood, splitting, and cracking the bark. In the recent study, the type of damage was distinguished into curved, cracking curved, broken branch, broken stem, and uprooted (Figure 2). A curved tree changed in visual form as the main stem was curved but no crack was found on the stem (Figure 2A), this type of tree could be tapped normally yet the yield was lower than a normal tree. Some of the curved trees had a crack on the stem (Figure 2B) allowing the latex to flow out continuously. A broken branch tree (Figure 2C) might not be impacted directly by the wind but was struck by neighboring trees lead to the canopy volume reduction. The trees that could not resist wind damage experienced a broken stem (Figure 2D) or uprooted (Figure 2E). These two types of damage were found in the center of the impacted area suggested that they received the most severe impact, while curved and broken branch trees were found in the outer area.

The curved and broken stem might be due to the heavy crown so that the stem could not resist the wind blow. Our result was in accordance with [21] that suggested that the middle of the trunk is more vulnerable to wind and crown asymmetry. Furthermore, [22] suggested that the critical wind speed at which trees break was constant (~42 m/s), regardless of tree characteristics. The uprooted trees were suspected due to the combination of heavy crown and low root strength. In the root disease area, rubber plantation is more vulnerable to plant density decrease.
Our further investigation showed that the proportion of damage type varied over plant age (Figure 3), which was in line with [23] that found a variation in the crown ratio of the among trees in the rubber plantation. It suggested that the vulnerability to wind damage might vary over clone and plant age. The proportion of curved, broken branches and uprooted trees increased by plant age. In the 8, 11, 12, and 15 years old of the tree, the proportion of curved tree was 24.15 %, 29.72 %, 39.92 %, and 47.33 % respectively, the broken branch was 5.68 %, 5.25 %, 8.18 %, and 27.33 % respectively, while uprooted trees were 0.85 %, 0.36 %, 1.55 %, and 6.00 %. The increase in the proportions might be due to the crown architecture. The older trees possessed heavier crown, thus were more susceptible to wind damage. The proportion of broken stem decreased by plant age. In the 8, 11, 12, and 15 years old of the tree, the proportion of broken stem was 69.32 %, 64.68 %, 45.42 %, and 16.67 % respectively. The increase of plant girth and lignin accumulation was suspected to be the main factors of stem strength [24,25].

**Figure 2.** Damage type caused by wind blow on rubber tree
3.2. Effect on the yield and dry rubber content

The curved and broken branch trees remained produce latex and could be tapped normally, whilst cracking curved and broken stem was cut on the cracking/broken point allowing for recovery. For the recent study, the cracking curved and broken stem trees were tapped for data collection. The wind damage inflicted a significant yield loss and DRC decrease (Table 1). Among damage type observed, the curved trees showed the least impact on the yield, yet it was reduced by nearly 50 %, and the DRC lower around 4.92 % compared to normal trees. Nonetheless, when the curved accompanied by cracking, the yield lost and DRC decrease was more severe (31.96 % and 13.12 % lower respectively). The significant decreases were due to the latex flowed out from the cracking could not be collected properly. Our observation also noticed that the yield of the broken stem trees varied depends on the broken height. The average yield was 77.63 ml tree⁻¹ (37.41 % to the normal tree) with the DRC was 27.70 % (12.34 % lower compared to the normal three).

| Damage type         | Latex yield ml tree⁻¹ | %     | n  | Dry rubber content % | n  |
|---------------------|-----------------------|-------|----|----------------------|----|
| Normal tree         | 207.53 ± 52.70        | 100.00| 24 | 40.04 ± 2.19         | 4  |
| Curved              | 104.73 ± 53.20        | 50.46 | 24 | 35.12 ± 3.81         | 4  |
| Cracking curved     | 66.33 ± 47.56         | 31.96 | 12 | 26.92 ± 6.12         | 4  |
| Broken branch       | 96.43 ± 53.59         | 46.47 | 19 | 29.66 ± 3.25         | 4  |
| Broken stem         | 77.63 ± 52.85         | 37.41 | 30 | 27.70 ± 4.58         | 4  |

Rubber yield and leaf area index had a positive correlation suggested the importance of the canopy on latex yield [26]. Rubber particles are biosynthesized in the laticifer cells through the mevalonate (MVA) and 2-C-methyl-D-erythritol 4-phosphate (MEP) pathways [27,28]. The significant canopy volume reduction dropped the number of laticifer cells and rubber biosynthesis capacity that was reflected in the yield and DRC decrease.

3.3. Yield and dry rubber content after one-year recovery

Following the strong wind blow, the company cut the broken stem and cracking curved trees for allowing shoots to grow (Figure 4A). The observation of a one-year recovery site found that shoots have formed branches (Figure 4B) yet the curving stem seemed to be permanent (Figure 4C). Compared with the normal tree, the yield of the stem recovery tree was only 49.87 % and the DRC was 9.6 % lower. The curved trees that seemed to be the least impacted group did not improve significantly, the yield only reached 57.75 % compared to normal trees, while the DRC remained around 4 % lower. The broken branch trees showed the most significant improvement, reaching 72.17 % of latex yield compared to normal trees and DRC was only 1.49 % lower (Table 2).
Figure 4. A shoot grew from the cut stem (A) and became new branches after one year (B), photos from different trees. The wind-damaged tree remained curved after one year (C)

Although all damage types indicated an improvement in the yield and DRC, after one year the trees could not fully recover. The increase of the yield was mainly due to the recovery of the branch and the leaves as a source of the photosynthate. Our observation was in accordance with [20] which suggested that the healed trunks (from the broken and cracking stem) were generally unsuitable for tapping. The tapped trees in rubber plantation decreased with increasing tapping age mainly due to tapping panel dryness and wind damage [29].

Table 2. Latex yield and dry rubber content of one-year recovery trees, ± standard deviation

| Damage type          | Latex yield | Dry rubber content |
|----------------------|-------------|--------------------|
|                      | ml tree⁻¹   | %                  | %                  | n  | n  |
| Normal tree          | 159.90 ± 19.67 | 100.00          | 44.44 ± 2.16      | 5  | 4  |
| Curved               | 92.35 ± 27.58 | 57.75          | 40.58 ± 5.55      | 5  | 4  |
| Broken branch        | 115.40 ± 32.06 | 72.17          | 42.95 ± 1.62      | 5  | 4  |
| Broken stem          | 79.75 ± 26.81 | 49.87          | 34.84 ± 7.11      | 10 | 8  |

Minimizing the wind damage could be implemented through spatial arrangement [10], windbreaker borders [30], and traditionally-recognized resistant clones [31,32]. A study by [33] suggested that the canopy architecture was a pivotal attribute related to wind resistance. They noticed that GT1, a wind-resistant clone, developed short lateral branches, whilst PB 235 exhibited fewer axillary yet longer branches that made it susceptible to wind damage. Thus, [34] recommended the breeding of compact crown clones to overcome wind damage issues.

4. Conclusion
The area and number of impacted trees did not show a particular pattern. The proportion of curved, broken branch, and uprooted trees increased by plant age, whilst the proportion of broken stem decreased. The wind-damaged trees exhibited a significant reduction of the latex yield and DRC. After one year, the trees could not fully recover. Therefore, we highlighted the necessity of a wind-resistance breeding program in *H. brasiliensis*. 
5. References

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