Wind-Resistant Characteristics of Native and Indonesian Tissue-Cultured Sago Palms (*Metroxylon sagu* Rottb.) in Leyte, Philippines

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Abstract: Native sago palms were transplanted from Dulag to a Pangasugan experimental field, Leyte, Philippines in 2005 and tissue-cultured sago palms from Indonesia were transplanted to Pangasugan in 2007. The growth of native Dulag Philippines (NDP) and Indonesian tissue-cultured (ITC) sago palms was evaluated using the growth rate for palm height and number of leaves. The tissue-cultured sago palms (2.13 m/year) had a higher growth rate than that of the native sago palm (1.38 m/year) until 2012. The recovery of ITC sago palm (1.48 m/year) after wind damage by Typhoon Yolanda (maximum wind velocity: 65 m/s) in 2013 was slower than that of NDP (2.14 m/year) from 2014 to 2016. The development of living leaves of both NDP and ITC sago palms increased from 2 to 16 before Typhoon Yolanda hitting. Typhoon Yolanda teared off leaves, resulting in 2 for NDP and 4 for ITC. Until 2016 thirteen living leaves were observed for both NDP and ITC. The bending moment (*Mb*) at the height of palm trunk breaking by Typhoon Yolanda varied from 141 to 342 k*N*m for NDP sago palms and from 37.7 to 183 k*N*m for ITC sago palms. These *Mb* values show the strong wind resistant properties of sago palms. Both NDP and ITC sago palms, after being hit by Typhoon Yolanda were characterized by quick regrowth from the growing point of the trunk. We can conclude that the strong wind-resistant characteristics of sago palms lend considerable support to their survival in typhoon-prone areas of the Philippines.

Keywords: bending moment, Indonesia, native, Philippines, tissue-cultured

Introduction

Okazaki and Kimura (2015) showed the areas and numbers of typhoons in the Pacific Ocean from 1970 to 1997. Seventy-seven typhoons occurred within the sago growing areas 35° north latitude from the equator and 100 to 190° east longitude. Six to nine typhoons out of twenty typhoons in the Philippine territory and territorial waters directly affect the Philippines, and five of these storms are destructive (InterRisk Asia, 2017; Asian Disaster Reduction Center, 2019). Strong winds from October to December have caused serious damage to the economy and people of the Philippines.

A standing plant must have a strong trunk and root system to withstand wind damage, such as breakage and other injuries. Fujita (2014) insisted that tree forms are an important factor in withstanding strong wind. Severe plant damage from strong wind takes the form of uprooting, trunk breaking, inclination, curving and so on. Uprooting and trunk breaking are important damages from the viewpoint of occurrence frequency and influence (Suzuki, 2012). Uprooting occurs when the base foundation for the root system is defeated, in the decreasing effect order of bending strength of trunk > bending stress and bending moment produced by wind load > resistance of root system. On the other hand, trunk breaking is observed with the failure of trunk bending moment against wind load, in the decreasing effect order of resistance of root system > bending stress and bending moment produced by wind load > bending strength of trunk (Suzuki, 2012).

The bending moment of the trunk (*Mb*) is introduced by the equation

$$Mb = 1/2 \varrho \mathrm{Cd} A V^2 H$$

where *Mb* is the bending moment (kg m^2/s^2), ϱ is the air density (kg/m^3), Cd is the drag coefficient (0.3 to 0.6 for tree species), *A* is the lateral cross section of the tree crown (m^2), V is the wind velocity (m/s), and *H* is the height from the ground to the wind center (m).

Drag is a crucial factor in determining the forces on a tree in high wind (Vogel, 1989). The drag coefficient (Cd) indicates the conversion percentages of wind energy to wind load (Mayhead, 1973). The bending moment (James, 2010) of palms determines the wind resistance of trunks and leaves. Until 2015, the maximum wind velocity in building standards was 30 to 46 m/s (Information Center for Building Administration, 2015) in Japan. However, much higher maximum wind velocities have been observed in Japan recently, for example, 85.3 m/s in Miyako Island, Okinawa (Japan Meteorological Agency, 2019). Accordingly serious damage by much higher maximum wind velocities should be estimated. Typhoon Yolanda (Haiyan) (895 hPa in the center, 65 m/s maximum wind velocity, 90m/s maximum instantaneous wind velocity), one of the strongest tropical typhoons, directly hit the sago field in Pangasugan, Leyte in November 8, 2013 (Ministry of Land, Infrastructure, Transport and Tourism, 2014).

Tissue culture technology will change sago biomass production. Sago-growing countries have tried to introduce tissue culture to sago seedlings by somatic embryogenesis (Alang and Krishnapillay, 1987; Hisajima et al., 1991; Tahardi et al., 2002; Ogita and Yamaguchi, 2003, Sumaryono et al., 2009; Novero et al., 2010; Sumaryono et al., 2012; Ibrahim et al., 2014). In 2007 eight tissue-cultured sago seedlings in the Biotech Center of the Agency for the Assessment and Application of Technology, Indonesia were transplanted in Pangasugan (Okazaki et al., 2012; Nishiyama et al., 2014) to elucidate whether Indonesian tissue-cultured (ITC) sago seedlings were able to grow in a different environment. The mean height of eight palm seedlings was around 30 cm at transplanting time. The growing speed and strength of tissue-cultured sago palms should be compared to those of native Dulag Philippines (NDP) sago palms in Leyte, because there is no data on the growth of ITC sago palms under field conditions.

The growing points and leaves of 8-year-old native and 6 year-old tissue-cultured sago palms were damaged and partially separated from the apical parts of the palms by Typhoon Yolanda (Nishiyama et al., 2014; Nishiyama et al., 2015). The damaged apical part of the sago palms had recovered gradually (Nishiyama et al. 2018).

The objectives of this study are to show the wind-resistant property of native (NDP) and Indonesian tissue-cultured (ITC) sago palms in Leyte, Philippines and to evaluate the successful regrowth of sago palms in typhoon-prone areas of the Philippines.

Materials and Methods

1. Native and Indonesian tissue-cultured sago palms

Native (NDP) sago palm seedlings were collected from Dulag, Leyte, Philippines in 2005 and transplanted to Pangasugan. The tissue-cultured (ITC) sago seedlings were transported from the Biotech Center of the Agency for the Assessment and Application of Technology, Jakarta, Indonesia to Pangasugan in 2007. The explants were provided by means of sanitization and pretreatment after washing suckers. The explants were planted in polyethylene buckets containing a medium (soil, compost and fertilizers) and incubated in an air-conditioned greenhouse for 6 to 8 weeks until two leaves developed, and adapted to the environment until development of the fourth leaf. The explants were grown to a seedling weight of 500 g. Then they were transported by air to the Philippines and acclimated for 5 days and transplanted to the sago field at Pangasugan. At the time of transplanting in the field, the sago seedlings had a fourth leaf.

2. Experimental field and plots

The sago experimental field was located in a 0.4 ha lowland area of Pangasugan, Leyte, Philippines. The area is in an Af climate (Köppen climate classification) with over 2200 mm of precipitation/year. The soil has a silt loam texture (Lina et al., 2009), a slightly acidic pH of 6.3 to 6.5, and electrical conductivity of 46 to 51 μS/cm and 1.97 ± 0.40 to 2.13 ± 0.50 gN/kg (Table 1). Twelve NDP sago seedlings from Dulag, in the eastern part of Leyte were transplanted to Pangasugan in 2005 in a 4m x 2m plot trial without fertilization; two 4m x 2m plots were combined to form one 4m x 4m plot in 2007; and finally, three palms were produced for use in starch production. In 2007, eight ITC seedlings with the fourth leaf were planted in a 4m x 4m plot without fertilization. Suckers were controlled to make one mother palm and one sucker per plot.

Table 1. Chemical properties of soils (control) in Pangasugan, Leyte, Philippines

	$pH(H_2O)$	Electrical conductivity μS/cm	Total nitrogen g N/kg
August, 2007	6.3	46	1.97 ±0.40
January, 2008	6.5	51	2.13 ±0.50

control: plot without fertilizer application

3. Palm height and number of leaves

The sago palm growth rate is regulated by the number of developing leaves per year and the size of the petiole. The palm height was measured and the leaves counted at the short interval during the early growth stage. Gradually, however, longer intervals were used. The height of the sago palms and the trunk diameter at breast height were measured using a measuring pole (Senshin Kogyo 10m), a measuring tape (Sekisui Jushi Eslon 12-50HRW 50m) and a digital clinometer (Haglof ECIID), and the number of leaves was counted with the naked eye. These three factors are closely related to the growth of trees (Editorial Board of Forest Ecology and Conservation, 2010).

4. Bending moment of the sago palm

According to the proposal (Shi-igai, 1993; Ishikawa, 2005; Suzuki, 2012), the bending moment (*Mb*) of the sago palm was calculated, based on the wind-receiving area (lateral cross section) of sago palms which was calculated by the product of living leaf length at the lowest position and palm height from the living leaf at the lowest position, and the center of wind blowing was present at the trunk breaking point. The bending moment is introduced and evaluated by the equation

$$Mb = 1/2 \rho \mathrm{Cd} A Vmax^2 Hb$$

where *Mb* is the bending moment (kg m^2/s^2), ρ is the air density (kg/m^3), Cd is the drag coefficient (0.3), *A* is the wind-receiving area (lateral cross section) of sago palms which was calculated by the product of living leaf length at the lowest position and palm height from the living leaf at the lowest position (m^2), *Vmax* is the maximum wind velocity (65 m/s for Typhoon Yolanda), and *Hb* is the height from the ground to the point of the wind center (m) .

Results

1. Palm height

The three NDP and six ITC sago palms determined in Pangasugan (two ITC sago palm seedlings died before being hit by Typhoon Yolanda) are shown in Fig. 1. The mean height of the NDP and ITC sago palms was 844 ± 202 cm and 837 ± 105 cm in 2011 and 1050 ± 280 cm and 781 ± 90 cm in 2016, respectively. The growth rate of ITC sago palms was higher than that of NDP sago palms. ITC sago palms (206 cm/year; C in Fig.1) had a higher growth rate from 2007 to 2011 than NDP sago palms (143 cm/year; A in Fig.1) did from 2005 to 2012. Typhoon Yolanda hit sago palms on November 8, 2013. The recovery rate of ITC sago palms (148 cm/year; D in Fig. 1) after wind damage was slower than that of NDP sago palms (214 cm/year; B in Fig. 1) from 2014 to 2016. The reason of decrease in the mean height of ITC sago palms measured in 2012 compared to those measured in 2011 is unknown. Figure 2 shows the damaged sago palms in the Pangasugan experimental field in April 2014. The growth point of sago palms was still alive. However, the living leaves were blown over by the strong wind.

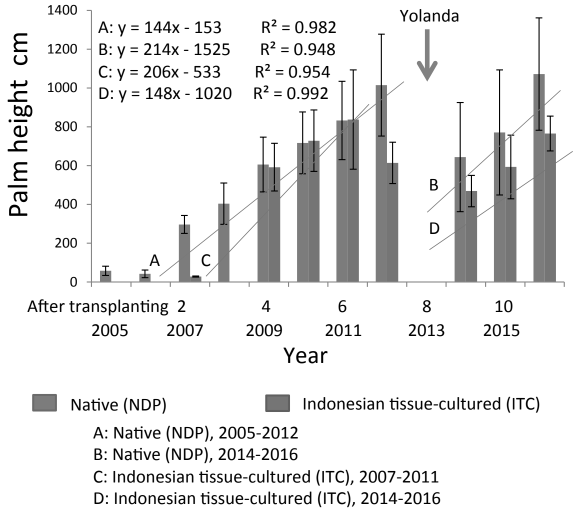

Fig 1. Mean height of native (NDP) and Indonesian tissue-cultured (ITC) sago palms

Fig 2. Sago palms damaged by Typhoon Yolanda in Pangasugan, Leyte, Philippines (April of 2014)

2. Number of living leaves

The development of living leaves of both tissue-cultured (ITC) and native (NDP) sago palms ranged from 2 to 16 living leaves during this field experiment (Fig. 3). The number of living leaves of NDP sago palms reached a maximum 5 years after transplanting. In case of ITC sago palms, unfortunately there is no record on the maximum number of living leaves, because living leaves were blown by Typhoon Yolanda.

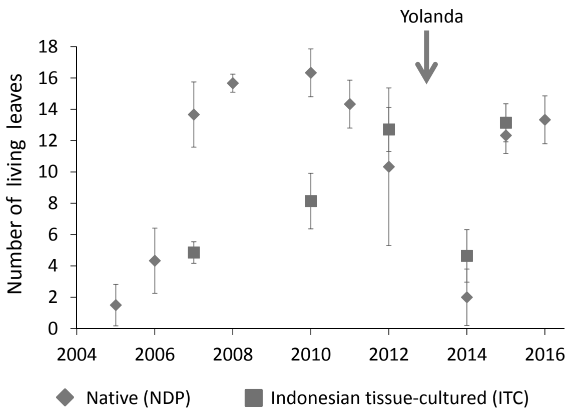

Fig 3. Number of living leaves of native and tissue-cultured sago palms

3. Wind-resistant characteristics of the sago palm

Table 2 shows the lateral cross section of sago palms (m^2), height from the ground to the trunk breaking point (m), diameter at breast height (cm), and bending moment at *Vmax* (kNm). The lateral

Table 2. Bending moment of the sago palms by wind load

	Cross-section area of palm crown m^2	Height (*Hb*) from ground to trunk breaking point m	Diameter at breast height cm	Bending moment (*Mb*) at *Vmax* k*N*m
Native (NDP)	79.5	5.7	41	342
	58.3	6.2	40	275
	64.3	2.9	38	141
Indonesian Tissue-Cultured (ITC)	10.7	4.7	35	37.7
	39.5	6.1	32	183
	32.9	4.2	35	105
	33.5	3.7	31	93.2
	47.1	4.8	33	171
	31.2	4.8	34	113

N = kg m/s^2

Bending moment of sago palm by wind load (Mb: kgm^2/s^2) = $\frac{1}{2} \rho \, Cd \, A \, Vmax^2 \, Hb$

ρ = 1.2 kg/m^3

Cd = 0.3

A = cross-section area m^2

$Vmax$ = wind velocity 65 m/s

Hb = height from ground to broken point m

cross section of three NDP and six ITC sago palm crowns varied from 58.3 to 79.5 m^2 and from 10.7 to 47.1 m^2, respectively. The wind center point estimated from the trunk breaking point was 2.9 to 6.2 m for NDP sago palms and 3.7 to 6.1 m for ITC sago palms. The diameter at breast height ranged from 38 to 41 cm for NDP sago palms and from 31 to 35 cm for ITC sago palms. The bending moment at *Vmax* ranged from 141 to 342 k*N*m for NDP sago palms and 37.7 to 183 k*N*m for ITC sago palms when Cd was 0.3, based on the calculation from sixteen trees of eight species (Mayhead, 1973). Sago palms clearly showed strong wind resistance, although there were large variations among native and Indonesian tissue-cultured sago palms.

Discussion

1. Wind resistance of the sago palm

Both unknown adverse effects on tissue-cultured sago palms observed in 2012 and the strong winds of Typhoon Yolanda in 2013 might have had negative influence on the growth of tissue-cultured sago palms thereafter. The weakness of the family of Palmae against strong wind varies, depending on the palm form, above-ground and root balance and trunk quality (Iizuka et al., 2011). It is believed that the sago palm is not strong against wind. The apical part of the trunk and large leaves of the sago palm were blown away from the experimental field (Nishiyama et al., 2014). However, the lower parts of trunk remained and recovered over the course of several years. Figure 4 shows the maximum bending moment of sago palms,

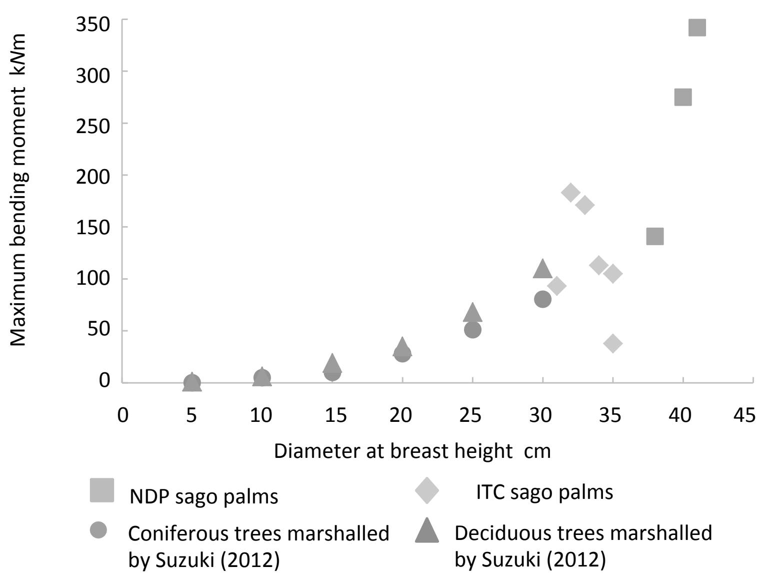

Fig 4. Relationship between diameter at breast height and maximum bending moment of sago palms and coniferous and deciduous trees

coniferous trees (Japanese cedar (*Cryptomeria japonica*) and Japanese larch (*Larix kaempferi*)) and deciduous trees (birch (*Betula*), oak (*Quercas serrata*) and Japanese cherry birch (*Betula grossa*)). The tree data were summarized by Suzuki (2012) from Mejima and Sasaki (2010), Nakabayashi et al. (2010), Torita (2009), Torita et al. (2010), and Fukami et al. (2011), although the maximum bending moment values of trees were within 30 cm of the diameter at breast height. Large maximum bending moment values for sago palms allow us to conclude that sago palms are stronger against wind even if other species of deciduous and coniferous trees have a smaller diameter at breast height.

Healthy palms under good conditions carry approximately twenty-four leaves (Flach, 1997). The larger the number of leaves the crown carries, the larger the diameter of the trunk grows. Each month, one new leaf appears out of the growing point, and the oldest one dies (Flach, 1997). However, Yamamoto (1998) reported that sago palms produced ten leaves per year on average. No difference in palm height or number of leaves was found between NDP and ITC sago palms in Pangasugan environment.

Tissue-culture technology has been applied for sago palms to accelerate seedling production suitable for the plantation (Alang and Krishnapilly, 1987). Hisajima et al. (1991) found that multiple shoots were occasionally observed from an embryo culture and that vertical halves excised from seedlings grown in vitro could grow. In addition Tahardi et al. (2002) reported somatic embryogenesis in the sago palm. Sinta et al. (2018) also revealed somatic embryogenesis of the sago palm from different origins in Indonesia. It was found that the behavior of ITC sago palms against a strong wind velocity was similar to that of NDP sago palms in Pangasugan. Tissue-culture technology is useful for developing sago production and industry in the tropical region within 10 degrees north and south from the equator.

2. Typhoon-prone and sago-growing area in Philippines

For 30 years (1981-2010) approximately twenty typhoons per year (Japan Meteorological Agency, 2019) developed in the Philippine territory and territorial waters. The east coast of the Philippines is a typhoon-prone area. Storm surge heights from Typhoon Yolanda were more than 5 m along the inner part of Leyte Gulf (Shibayama et al., 2014). One of the characteristic features of this disaster was devastating storm surge induced by a rapid change in wind direction. Sago-growing areas in the eastern part of Leyte Island (Tacloban and Dulag area) have been developed (Quevedo et al., 2005). Sago thatch is a useful material for Leyte people who utilize it as thatch of houses rather than extracting the starch from sago trunks after flowering. The thick trunk and hard bark of sago palms can survive when strong winds are attacking their large crown.

Conclusion

There is no research on the comparison of growth rate and bending moment of native and tissue-cultured sago palms. We found no difference in the wind-resistant property between native (NDP) and Indonesian tissue-cultured (ITC) sago palms in Leyte, Philippines. The strong wind-resistant characteristics supported the survival of sago palms in the typhoon-prone areas of the Philippines.

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