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Specific Leaf Area of Sago Palm (*Metroxylon sagu*) in Relation to Phenological Stages

Evi Gusmayanti[1], Takemi Machida[2] and Masao Yoshida[2]

[1] United Graduate School of Agricultural Sciences, Tokyo University of Agriculture and Technology, 3-5-8, Saiwaicho, Fuchu, Tokyo 183-8509, Japan

[2] Faculty of Agriculture, Ibaraki University, 3-21-1, Ami, Inashiki, Ibaraki 300-0393, Japan

Abstract: As large-scale sago palm plantations expand, the study of the sago palm leaf area will assume increasing importance to manage the optimum density in sago plantations. In order to calculate the specific leaf area (SLA), which is one of the simple leaf area features, ten spineless-type palms at different phenological stages representing the entire life cycle of sago palm were selected. The analyses consisted of the calculation of the specific leaf area of individual leaves (SLA_L) and whole plants (SLA_P). The results showed that the SLA_L varied with the leaf number within a phenological stage without a consistent trend. However, the average SLA_L based on the leaf number showed a slight decreasing trend from younger to older leaves. The SLA_P also showed a decreasing trend from younger plants to older plants, which satisfactorily fitted a linear regression model.

Key words: sago palm, specific leaf area of individual leaves (SLA_L), specific leaf area of whole plants (SLA_P)

異なる生育ステージにおけるサゴヤシの比葉面積

エヴィグスマヤンテイ[1]・町田武美[2]・吉田正夫[2]

[1] 東京農工大学大学院連合農学研究科　〒183-8509　東京都府中市幸町　3-5-8

[2] 茨城大学農学部　〒300-0393　茨城県稲敷郡阿見町中央　3-21-1

要旨　近年、サゴヤシにたいする関心がますます高くなってきており、サゴヤシのプランテーション開発も拡大してきている。このような中、サゴヤシの葉面積に関する研究は、プランテーションにおける適正な個体密度決定の観点などから、ますます重要になってきている。本研究では、個体の葉面積を把握するうえで容易な指数である比葉面積（SLA）を計測するために、サゴヤシの全生育ステージから生育が異なるトゲなしの10個体を選んで検討した。個葉の比葉面積（SLA_L）および個体全体の比葉面積（SLA_P）を算出した。その結果、個葉の比葉面積（SLA_L）は、個体内で一定の傾向がなく葉ごとに異なった。しかしながら、個葉の比葉面積（SLA_L）は、若い葉よりもageが進んだ葉で低い傾向があった。また、個体全体の比葉面積（SLA_P）も、若い個体よりもageが進んだ個体で低く、直線回帰モデルに合致した。

キーワード：サゴヤシ、個葉の比葉面積（SLA_L）、個体全体の比葉面積（SLA_P）

Introduction

The specific leaf area (SLA) is defined as the total leaf area divided by the total leaf dry mass. It has been studied in many plants, e.g., Meziane & Shipley (1999) studied 22 herbaceous plants, Vile et al. (2005) studied 136 species, and Shipley (2006) analyzed the

614 species compiled from 37 different studies. The results showed correlation with various components in plant growth. The SLA has been found to correlate with net photosynthesis, as in Reich et al. (2003), who found that the maximum capacity of photosynthesis can be predicted from the SLA. Related results were reported by Shipley and Vu (2002), Arredondo and Schnyder (2003), Metcalf et al. (2006), and Shipley (2006), who found the correlation of the SLA with the relative growth rate.

The SLA, by definition, may also indicate the leaf thickness (LT). Vendramini et al. (2002), who analyzed the association between the SLA and LT in 77 species, found that the SLA and LT were significantly correlated. These results led them to the conclusion that the SLA appears to be a good indicator of general plant resource-use strategies. Furthermore, leaf thickness is highly related to leaf structure, namely, the leaf carbon assimilation rate, leaf optical density, total leaf chlorophyll concentration, leaf tissue density, and nitrogen concentration, as studied by White and Montes-R. (2005).

In plant ecology, the SLA is associated with many critical aspects of plant growth and survival. Recent studies in controlled environments have demonstrated the important roles of the SLA and leaf dry matter content (LDMC) in explaining variation in the potential relative growth rate and ecological behavior of plants. Other roles involve the trade-off between rapid biomass production and efficient conservation of nutrients (Li et al. 2005). On the other hand, in agronomic modeling, the SLA has been widely used as a key parameter in estimating the crop yield. It has been used to derive the Leaf Area Index (LAI), as in Lintul (de Wit, 1997), Cropsyst (Stockle *et al.* 2003), and ORYZA2000 (Bouman and van Laar 2006).

The sago palm (*Metroxylon sagu* Rottb.) is considered humankind's oldest food plant. It has long been a staple food for humans in South East Asia before the introduction of rice or wheat. In the last decade, the popularity of sago palm as a research topic has been increasing significantly due to its beneficial features: sago palm is economically acceptable, relatively sustainable, environmentally friendly, uniquely versatile, and vigorous, and it promotes socially stable agro-forestry systems (Flach 1997). As the interest in sago palm continues to grow and large-scale sago palm plantations expand, the study of the sago palm leaf area will assume increasing importance, especially in managing the optimum density of sago plantations. In order to calculate the SLA, which is one of the simple leaf area features, and understand the relationship between the SLA and phenological stage, we selected ten palms from different phenological stages representing the entire life cycle of sago palm. We calculated the SLA of individual leaves (SLA_L) and that of whole plants (i.e., the mean of all leaves, SLA_P).

Materials and Methods

Sampled palms

The study was conducted in Pontianak, West Kalimantan, Indonesia (0°7'S 109°26'E). Ten spineless-

Table 1. Estimated phenological stages (s) of sampled palms.

Estimated age from planting (years)	Growth description	Phenological stage (s)
3.0	rosette stage	0.121
5.0	starting trunk formation	0.214
6.0	early trunk growth	0.261
7.0	early trunk growth	0.308
9.0	mid trunk growth	0.401
10.0	full trunk growth	0.475
10.5	bolting	0.498
11.5	flowering, stalk has been truncated	0.723
12.0	fruiting, but no fruit found	0.818
12.5	fruiting stage, stalk has dried, no fruits left	0.902
15.0	almost dead, no leaves	1.000

type sago palms (local name, *sagu bemban*) of different phenological stages, from the rosette stage to the dying stage, were selected from the sago palm gardens of local farmers (Table 1). The stages are aligned on a scale ranging from 0 to 1, where 0 corresponds to the stage of sucker planting and 1 corresponds to the stage of palm death. The procedure to calculate the estimated phenological stage (s) is described in detail in Gusmayanti et al. (2008).

Measurement

The sago leaves were numbered as in Nakamura et al. (2004, 2005), starting from the youngest unfolded leaf or spear leaf as number 1. The lower leaves were numbered sequentially 2, 3, and so on basipetally. Six to eight leaflets per leaf were taken randomly from both sides of the leaf. All samples were treated following the standard protocol for measuring the SLA (Garnier et al. 2001). Samples were rehydrated by dipping them in water for about one day until they achieved a water-saturated condition. Upon the completion of this treatment, leaves were dried with tissue paper to remove any surface water, and the projected area was measured (one side of the leaves). Samples were then oven-dried at 70 °C for at least 2 days, and their dry mass was measured. The SLA was calculated as the projected area divided by the dry mass.

Two types of SLA were calculated in this study. The SLA, which is the specific leaf area on the basis of the leaf number (SLA_L), is the projected area of the leaf divided by its dry mass. The SLA_L was calculated for each leaf found in the whole plant. When all values of the SLA_L in the same plant were averaged, the specific leaf area on the basis of the whole plant (SLA_P) was obtained:

$$SLA_L(n)=\frac{area(n)}{mass(n)}, \quad (1)$$

where n is the leaf number.

$$SLA_P=\sum_{i=1}^{n}\frac{SLA_L(i)}{n} \quad (2)$$

Results and Discussion

Specific Leaf Area on the Basis of the Leaf Number (SLA_L)

The leaf number of sago palms sampled in this study ranged from 8 to 23 leaves per plant. The calculation results of the SLA_L show the variability of the SLA_L values among leaves within a plant and among plants as well (Fig. 1). The minimum value

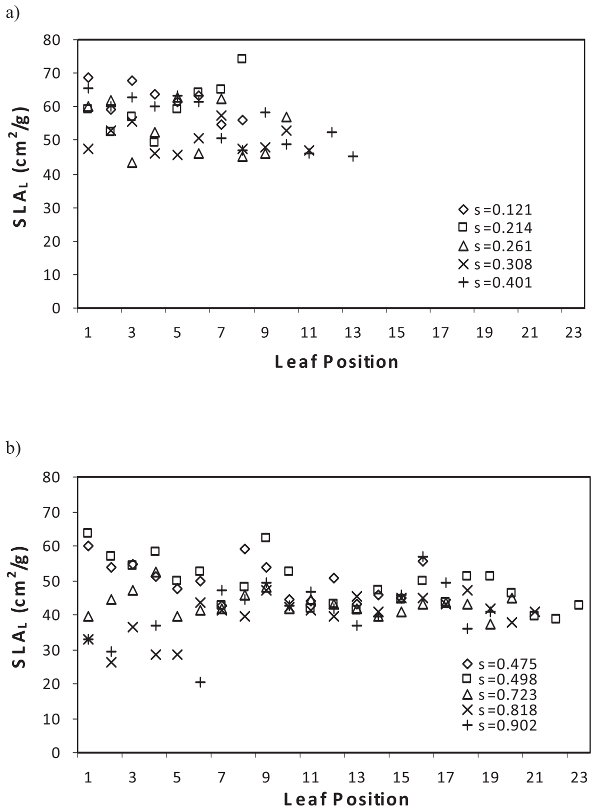

Fig. 1. Specific leaf area on the basis of the leaf number (SLA_L) at phenological stages (s)<0.45 (a) and s≥0.45 (b)

of the SLA_L (20.6 cm²/g) was observed in the sixth leaf of a palm with phenological stage s= 0.902, while the maximum value (74.0 cm²/g) was found in the eighth leaf of a palm with phenological stage s= 0.214. However, when the SLA_L values of a leaf at the same numbers were averaged, a slight decreasing trend of the SLA_L values from the younger leaves to the older ones was observed (Fig. 2).

The results show that the SLA on the basis of the leaf number within a plant varies greatly from leaf to

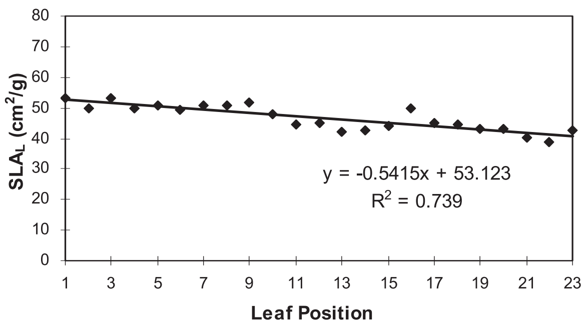

Fig. 2. Average value of the SLA_L of leaves at the same position number

leaf. The SLA may decrease as the leaf age increases; however, other factors, such as variations in radiation due to partial shading of a plant and plant density, may be involved in the determination of the SLA, as well as the location along a leaf from which the samples were taken. Rawson et al. (1987) reported that the SLA of wheat decreased from the tip to the base of a leaf by approximately 35%.

Specific leaf area on the basis of the whole plant (SLA_P)

The average value of the SLA_L within a plant is stated as the SLA_P. The calculation results of each palm based on the phenological stages are shown in Fig. 3. The maximum value (61.9 cm^2/g) was

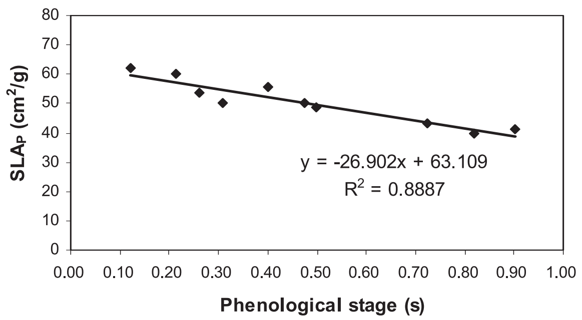

Fig. 3. Specific leaf area on the basis of the whole plant (SLA_P) at different phenological stages (s)

observed in a palm with phenological stage s=0.121, while the minimum value (39.7 cm^2/g) was found in a palm with phenological stage s=0.818. The results show that young palms have a relatively higher SLA_P than older palms. Similar results were also found by Gunn et al. (1999) in barley crop. The decreasing trend was fitted to a linear model, i.e., SLA_P=-26.902 s +63.109, which is good enough to describe the variability of data (almost 90%).

Conclusion

This study aimed to calculate the specific leaf area of individual leaves (SLA_L) and whole plants (SLA_P) in sago palm. Each unfolded leaf from ten selected plants, which ranged from 8 to 23 leaves per plant, was analyzed. The results show that the SLA_L varied from leaf to leaf within a plant without a consistent trend. However, the average SLA_L based on the leaf number showed a slight decreasing trend from younger leaves to older leaves. This indicates that increasing the number of samples in future studies may yield a significant and consistent trend of SLA_L changes from younger leaves to older leaves. In this study, the change in the average value of the SLA_L within a plant (SLA_P) was found to follow a linear regression model. The model seems to be good enough to be used in a simple crop model to estimate the influence of the phenological stage on the SLA value of sago palm.

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