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Observation of Leaf Characteristics of Spineless Sago Palm (*Metroxylon sagu*) at Different Phenological Stages

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Abstract: The aim of this study was to characterize sago palm leaves at different phenological stages. Eleven palms representing the entire life cycle of sago palm were selected from local gardens in West Kalimantan, Indonesia. Length of leaf, number of leaves, and number of leaflets for each unfolded leaf were measured. The results showed that sago palm carried maximum leaves in and around the bolting stage. The average leaf length and the number of leaflets were relatively high around the late trunk-formation stage. The generalization of these characteristics into equations should facilitate their integration into the crop simulation model in order to estimate the leaf area index (LAI) or specific leaf area (SLA) more simply.

Key words: leaf length, leaflet, phenological stage, sago palm

生育ステージが異なるサゴヤシにおける葉形質の特徴

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本研究の目的は、生育ステージが異なるサゴヤシの葉の形態的な特徴を明らかにすることである。インドネシア西カリマンタンのサゴヤシ農園で、全生育ステージにわたるサゴヤシ11個体を対象とした。各個体の展開葉について、葉長、葉数、小葉数を計測した。その結果、最大葉数は花芽形成期ごろに認められた。葉長、小葉数は幹立ち期後半で比較的多かった。これらの特徴は、葉面積指数（LAI）や比葉面積（SLA）をの推定を容易にし、それをもとに構築する生育シミュレーションモデルに有用であると考えられた。

キーワード　葉長、小葉、生育ステージ、サゴヤシ

Introduction

Leaf is the plant organ that plays the most important role in biophysical processes, especially in determining water and energy exchanges between the land surface, vegetation, and atmosphere. It directly influences important processes such as canopy interception, evapotranspiration, and net photosynthesis.

Leaf area index (LAI, defined as leaf area per unit ground projected area) is the most common variable usage to characterize leaf. In addition to LAI, several terms can be used to describe leaf functions, such as specific leaf area (SLA, leaf area per unit dry mass of leaf), specific leaf weight (SLW, leaf weight per unit area), leaf area ratio (LAR, leaf area per total aboveground weight), and leaf dry matter content (LDMC, leaf dry mass per unit fresh mass) (Lee and

Heuvelink 2003; Li et al. 2005; Pierce and Running 1994).

As large-scale sago palm plantations are continuously being expanded in Indonesia, it is necessary to calculate and evaluate the optimum plant density to ensure continuous harvesting. Thus, the study of the sago palm leaf area is becoming increasingly important. However, methods of estimating the leaf area of sago palm using the length and width of the largest leaflet and the number of leaflets are time-consuming (Flach 1997; Nakamura et al. 2005).

In this study, we observed leaf characteristics of sago palms at different phenological stages representing the entire life cycle of sago palm. Instead of growth, phenology was used to derive simple equations of leaf characteristics that are useful in the crop simulation model.

Materials and Methods

Sampled Palms

Several palms from sago palm gardens of local farmers in Pontianak, West Kalimantan, Indonesia, were selected. They consisted of 11 spineless-type sago palms (local name, *sagu bemban*) from the rosette stage through the fruit-ripening stage.

Estimation of Phenological Stage

The life cycle of sago palm consists of four stages: rosette, trunk formation, flowering, and fruit ripening. The stages are aligned on a scale ranging from 0 to 1 with the same portion of each stage (0.25 each), where 0 corresponds to the sucker planting stage and 1 corresponds to the time of death (Fig. 1). Development within a stage is stated in thermal units and is calculated as the accumulation of the difference between air temperature (°C) on day i (Ti) and the base or critical temperature of the crop (Tb) divided by the total thermal units (TU) required for the completion of each stage (Equation 1). Given that sago palm tolerates temperatures around 17 °C (Flach, 1997) and the minimum tolerable temperature is 15 °C (Notohadiprawiro and Louhenapessy, 1992), Tb in this model is assumed to be equal to 15 °C, similar to that of oil palm (Djufri, 2000). The TU values may differ from one variety to another. In this study, the TU values are based on Jong's (1995) and Flach's (1997) observations of the developmental sequences of spineless-type sago palm, which were converted into thermal units with temperature data (Table 1).

Table 1. Thermal units of each phenological stage.

Phenological stage	Total Thermal Units (day / degree / ˚C)
Rosette	23000
Trunk formation	25000
Flowering	5000
Fruit-ripening	9000
Total	**62000**

$$s = \frac{\sum_{i=1}^{n}(T_i - T_b)}{TU} \qquad (1)$$

In Equation 1, n is the age of the plant from the time of planting as estimated by the farmers. The n value was converted into days after planting. The estimated phenological stage of each palm (s) was obtained by executing Equation 1 with temperature data over n days.

Measurement

In this study, we adopted the procedure and terminology of Nakamura *et al.* (2004) to analyze sago leaves in terms of the number of leaves on a palm, the leaf length, and the number of leaflets. The sago leaves were numbered, starting with the youngest unfolded leaf or spear leaf as Number 1. The lower leaves were numbered sequentially (2, 3, and so on) basipetally.

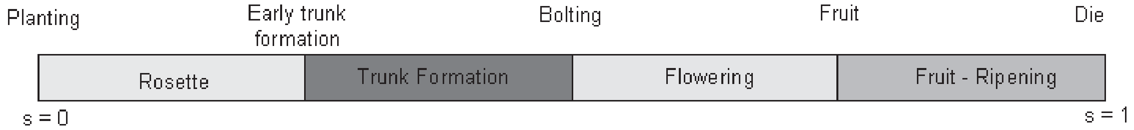

Fig. 1. Phenological model of sago palm

Characteristics such as length of leaf, number of leaves, and number of leaflets on the left and right sides of each leaf were measured. Details of the terminology can be found in Nakamura *et al*. (2004).

Results and Discussion

Phenological Stages

The estimation of the phenological stages of sampled sago palms is shown in Table 2. The values represent the entire life cycle of sago palm, from 0.121 to 1.000. The crop age, which is the basis of phenological stage estimation, was given by the farmers and may have been biased since the farmers gave quite a wide interval of ages in most cases. The middle values of the crop age range were considered the crop ages of the palms sampled in this study.

Number of Leaves

The number of living leaves, shown in Fig. 2, ranged from 8 (rosette stage) to 23 leaves (bolting stage) per plant. The number of leaves tended to be low in the rosette stage and gradually increased during trunk formation. The number of leaves was fitted to the linear equation, as shown in Fig. 3. When the crops proceeded to the reproductive stages, the dry matter allocation for leaf formation stopped, and the number of leaves tended to decrease non-linearly.

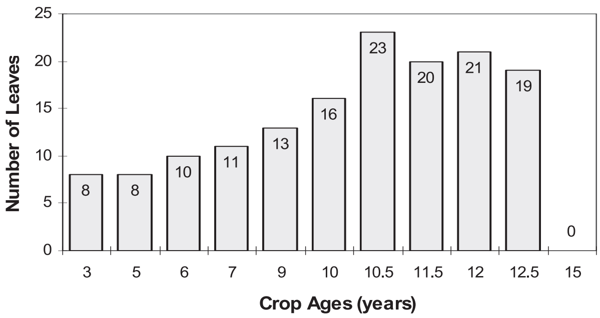

Fig. 2. Number of sago palm leaves at different ages.

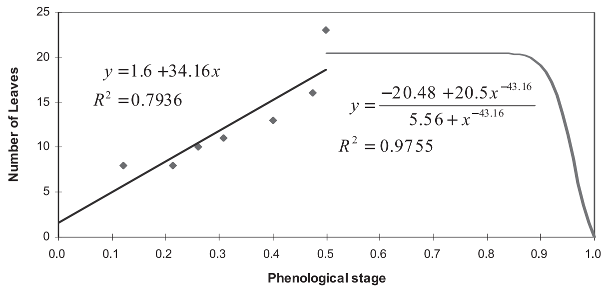

Fig. 3. Number of sago palm leaves at different phenological stages.

Length of Leaves

We divided the sago palms into two groups according to leaf length: s < 0.5 and s ≥ 0.5. The sago palms in the first group had unemerged leaves, while the leaves in the latter group had all emerged. There was an exception for the palm at s = 0.498, which was in the adjacent period from the vegetative stage to the reproductive period but still had unemerged leaves. The palm was placed in the second group.

The lengths of sago leaves from palms in the first group (Fig. 4a) were relatively similar, as indicated by the small standard deviation values except for those for the 5-year-old palm (s = 0.214), which had a standard deviation of 1.60 (Table 3). Among the palms within

Table 2. Estimated phenological stages 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	Near death, no leaves	1.000

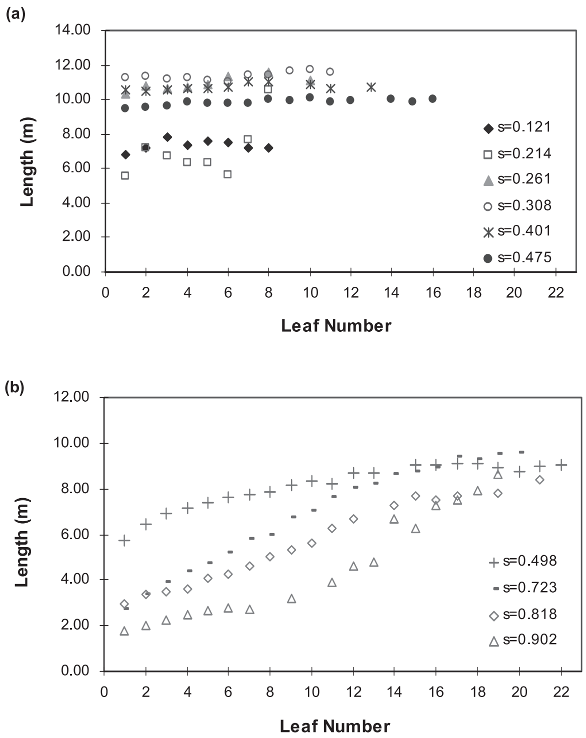

Fig. 4. Length of sago palm leaves at s<0.5 (a) and s≥0.5 (b)

this group, leaf length was found to have the highest value (11.70 m) in the palm at s = 0.308, which was also the highest value of leaf length for all palms observed in this study. The exception was a 5-year-old palm with abnormal growth performance of its crown, probably due to competition with adjacent palms.

The pattern of the leaf length of palms in the second group is shown in Fig. 4b. The younger leaves were shorter than the older ones, making the standard deviation values of this group relatively higher than those of the first group (Table 3). The length of the shortest leaf was s = 0.902 (1.8 m), while that of the longest one was s = 0.723 (9.6 m).

The leaf length of the second group of palms, in which all of the leaves had emerged, changed exponentially from the younger leaves to the older ones. Similar results were reported by Nakamura et al. (2004), who indicated that the rapid elongation process of unemerged to emerged leaves occurred exponentially.

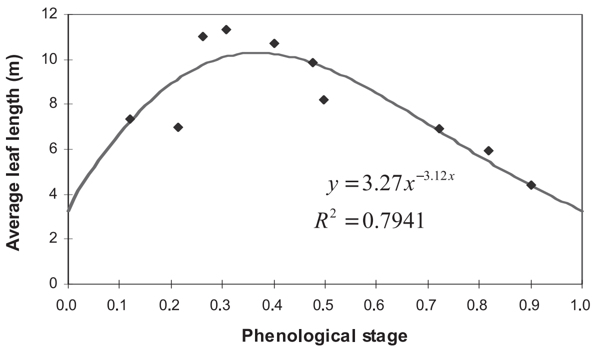

Fig. 5. The average length of sago palm leaves at different phenological stages.

Table 3. Leaf length of sago palm leaves at different phenological stages.

Leaf No.	Leaf length (m)									
	s=0.121	s=0.214	s=0.261	s=0.308	s=0.401	s=0.475	s=0.498	s=0.723	s=0.818	s=0.902
1	6.80	5.57	10.31	11.29	10.58	9.46	5.72	2.72	2.94	1.80
2	7.20	7.22	10.80	11.34	10.50	9.52	6.42	3.35	3.35	2.03
3	7.82	6.74	10.65	11.16	10.55	9.62	6.90	3.90	3.48	2.27
4	7.34	6.30	10.70	11.24	10.60	9.87	7.18	4.40	3.60	2.50
5	7.60	6.33	10.90	11.12	10.65	9.76	7.40	4.75	4.07	2.65
6	7.50	5.65	11.31	11.06	10.70	9.80	7.65	5.20	4.25	2.80
7	7.23	7.64		11.41	11.05	9.80	7.76	5.80	4.60	2.70
8	7.20	10.55	11.55	11.42	11.00	9.98	7.88	5.95	5.00	
9				11.64		9.96	8.14	6.73	5.31	3.17
10			11.10	11.70	10.90	10.12	8.32	7.05	5.63	
11				11.54	10.60	9.86	8.24	7.60	6.25	3.90
12						9.91	8.71	8.02	6.70	4.63
13					10.70		8.69	8.24		4.78
14						10.00		8.65	7.30	6.70
15						9.87	9.02	8.74	7.70	6.25
16						9.99	9.07	8.95	7.50	7.30
17							9.12	9.40	7.70	7.50
18							9.11	9.30		7.90
19							8.93	9.50	7.80	8.66
20							8.74	9.60		
21							9.00		8.40	
22							9.03			
23										
Average	7.34	7.00	10.92	11.36	10.71	9.83	8.14	6.89	5.64	4.56
S.D.	0.31	1.60	0.39	0.21	0.19	0.18	0.97	2.24	1.81	2.34

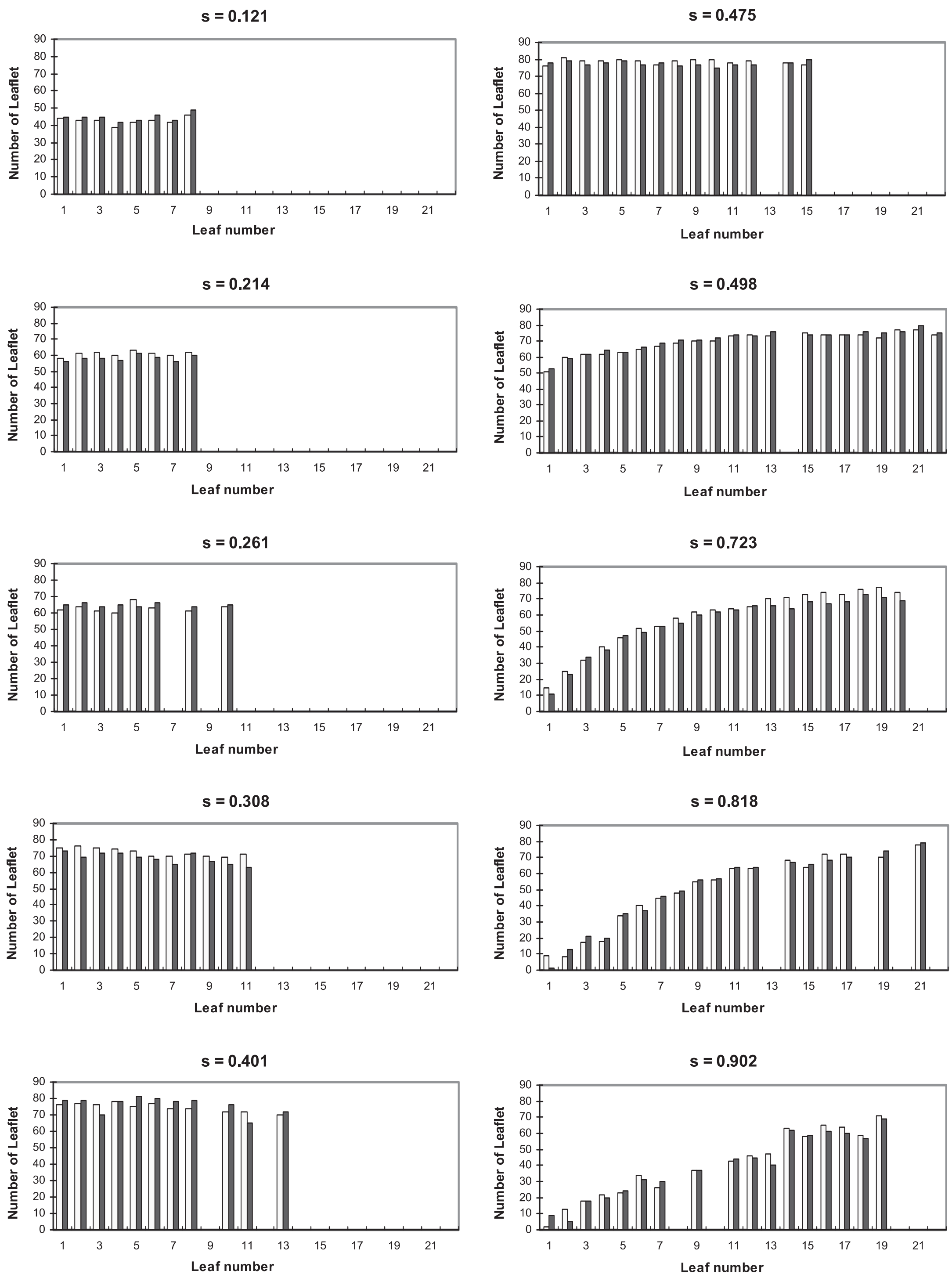

Fig. 6. The number of leaflet in left (□) and right side (■) at different phenological stage.

The average leaf length within a palm changed as the phenological stage changed. Leaf length tended to be maximum in the middle of the trunk-formation stage (Fig. 5) but changed through the geometric equation $y = 3.2676\ x^{(-3.1181x)}$, where y is the average leaf length and x is the phenological stage.

Number of Leaflets

The number of leaflets on the sago palm leaves is presented in Fig. 6 and Fig. 7. The numbers ranged from 2 (at s = 0.902) to 81 (at s = 0.475) on the left side and from 1 to 81 (both at s = 0.818) on the right side of the leaves. On the other hand, the total number of leaflets ranged from 10 (at s = 0.818) to

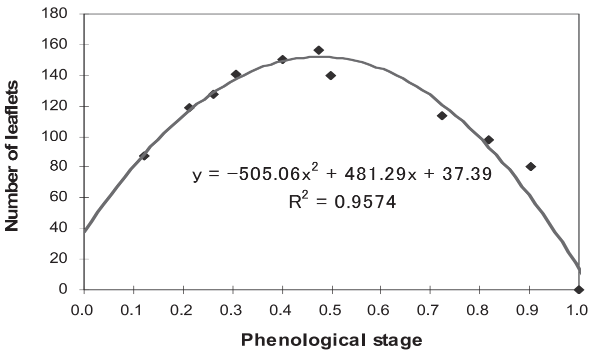

Fig. 7. The average numbers of leaflets at different phenological stages.

160 (at s = 0.475).

The number of leaflets on the left and right sides differed on most of the leaves observed. Some leaves had more leaflets on the left side, while others had more on the right side. Only 4 of 136 leaves were observed to have the same number of leaflets on both sides. This result was not in agreement with that of Nakamura *et al*. (2004), who found that the number of leaflets on the right side was always higher than that on the left side.

In crop modelling, crop development is distinguished from crop growth. Growth can be defined as an increase in the weight or volume of the total plant or the various plant organs, while development involves changes in the stage of growth and is characterized by the order and rate of appearance of vegetative and reproductive organs. Both development and growth are dynamic, often interrelated, processes.

Since the aim of this study was to apply the crop model, leaf characteristics were investigated as a function of phenological stage. Leaf area, which is usually stated as the leaf area index or specific leaf area, is an essential variable in the model. By knowing the number of leaves or leaflets per palm and the leaflet area at the corresponding phenological stage, the total area of leaf blades can be estimated. However, leaflet area was not included in this study. Plans are underway to study leaflet area throughout the phenological stages in the future so that leaf area can be estimated in the crop model more simply.

Conclusions

During this study, we observed sago palms carrying 8 to 23 leaves in their crown. The number of leaves during late trunk formation was relatively high. The younger leaves were relatively short in palms aged 10.5 years (s = 0.498) or above. The differences in the length of younger and older leaves were relatively small in palms aged 3 to 10 years (s = 0.121 to s = 0.475).

The number of leaflets ranged from 10 to 160, and the maximum leaflet number on the left and right sides was 81. Most of the leaves were found to have a different number of leaflets on each side. Only a small percentage (4 of a total of 136 leaves) had the same number of leaflets on both sides.

The estimation of leaf area by the crop model will be conducted by way of several leaf characteristics, including the parameters revealed in this study. We await further studies.

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