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Agronomic Characteristics and Harvest Time as Determinants of Starch Production in Smallholder Sago Palm Plantations

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ABSTRACT

Smallholder sago plantations generally use simple technology, resulting in the determination of harvest time based solely on the physical appearance of plants. This study aims to identify the agronomic characteristics of sago that influence starch yield. The research was conducted on smallholder sago plantations, and samples of sago plants were collected at four harvest phases based on local customs: Dewasa, Jantung, Rusa, and Bunga. Observations on agronomic characteristics included the number of suckers, plant height, pith diameter, number of leaves, number of leaf scars, number of leaflets, leaflet length, and leaflet width. ANOVA and multiple comparisons were utilized to identify differences between treatments in starch yield. Regression analysis was employed to establish the relationship between starch yield and agronomic characteristics, while path analysis determined the direct/indirect effects of agronomic characteristics on starch yield. The results indicated that the optimal harvest time is during the Jantung and Rusa phases. The agronomic components that significantly influence sago starch yield are pith diameter and leaf scars. According to the coefficient of determination value, the production model can be expressed as $Y = -63.26 + 2.44x1$ ($R2=37\%$). To enhance starch yield, it is crucial to improve plant spacing. When the plant spacing is too close, with a population density exceeding 200 clumps/ha, overlapping leaves occur, negatively impacting sago starch formation. This negative effect intensifies with an increase in the number of leaves and the size of leaflets in terms of length and width.

INTRODUCTION

Sago, a long-standing staple alongside rice in the archipelago kingdom's history, became the primary staple by the 2nd century AD, enduring through the Sriwijaya Kingdom and Palembang Sultanate until the early 16th century AD. With food security crucial for sustaining the kingdom for up to 5 centuries (Vita, 2017), sago is now a key ingredient in traditional foods and has evolved into modern dishes through technological advances (Naim

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et al., 2016). Anticipated to be a vital future food source, sago addresses challenges like limited land, climate change, and raw material needs for the food industry. Public awareness positions sago as a low-gluten, beneficial food for individuals with autism and diabetes (Zhu, 2019). Sago processing produces versatile waste, serving as animal feed, compost, and a medium for edible mushroom growth. Sago caterpillars, a protein source, can be cooked with spices for dishes like satay or consumed raw (Hastuty, 2016; Taskirawati *et al.,* 2020).

The productivity of a sago stalk aged 8-10 years can yield 200 kg of dry starch per tree, sufficient to meet a person's carbohydrate needs for a year. The starch content extracted from sago plants ranges from 18% to 38.8%, surpassing that of the arenga plant, which falls between 10.5% and 36.7% (Bujang, 2010). Sago plays a crucial ecological role, including preventing riverbank erosion, conserving peat, maintaining clean river water, and serving other hydrological functions (Botanri, 2010). Additionally, sago serves as a building material, with its leaves used for thatched roofs and stem shoots utilized as a vegetable (Anggraeni and Ngantung, 2018; Bintoro *et al.,* 2018; Ahmad *et al.,* 2016).

The multitude of roles and benefits associated with sago, coupled with its excellent adaptability to peatlands, makes it imperative to consider this plant for cultivation. However, few companies engage in professional sago cultivation. Typically, sago plants are cultivated in people's plantations over generations, lacking the touch of cultivation technology, including maintenance, spacing, and varieties (Fatah *et al*., 2015). Harvest time for sago plants is traditionally determined by the plant's physical appearance. In West Kalimantan, local communities base harvest time on plant characteristics categorized as Dewasa, Jantung, Rusa, and Bunga stages (Flach, 1997). Recent advancements in cultivation information, such as spacing arrangements, seeding methods, fertilization, and sago processing technology, have been reported (Naim *et al*., 2016). This study aims to: 1) identify agronomic characteristics affecting sago starch production, 2) establish a regression model between agronomic characteristics and sago starch production, and 3) enhance cultivation techniques based on plant performance in the field.

MATERIALS AND METHOD

Experiment site description and plant sampling

The study focused on smallholder sago palm plantations in Desa Mengkalang Jambu, Kubu district, Kubu Raya Regency, West Kalimantan, situated at Longitude 9944092 and Latitude 0302004, with coordinates 0°30′ 0”S and 109°18′0”E. The study area, 1.3 m above sea level, features peat soil with a high organic matter content (>30%), exceeding 0.5 m in depth, and a soil pH of approximately 6.0. The climate is primarily tropical rainforest, with an average annual temperature of 27.1 °C and an average annual rainfall of 1608 mm. The region comprises weathered peatlands, swamps, and tidal flats with a flat surface (Badan Restorasi Gambut, 2018).

The research focuses on plants at various harvest ages, categorized by Flach (1997) as follows: a) the Dewasa phase, the final stage of stem elongation marked by flag leaves' appearance; b) the Jantung phase, with the emergence of flower wrapping sheath; c) the Rusa phase, characterized by the maximum appearance of flower stalks of order two; and d) the Bunga phase, where the flower stalk appears from order two until it blooms/fruits.

Samples were gathered from a sago population density of 200 clumps/ha, with spacing applied in the range of 7 x 7 m^2. Subsequently, samples were collected from four different plants at each harvest phase, totaling 16 plants. The selected trees were felled using an axe and then assessed for the number of suckers, plant height, pith diameter, number of leaves, number of leaf scars, number of leaflets, leaflet length, leaflet width, and starch yield.

Agronomic characteristics

The measurement of agronomic characteristics, according to Novarianto *et al.* (2020), was as follows: Suckers were counted when they appeared to produce leaves. Plant height (m) was measured from the base of the stem to the top of the leaf. Pith diameter (cm) was measured at the height of 1 m from the stem. The number of leaves was counted as all green leaves on the sago crown. The number of leaf scars was calculated from 1 m plant height until the lowest leaf, excluding the base of the stem during the rosetting phase. The number of leaflets (cm) was measured from the last leaflet to the tip of the leaf. The length of the leaflets (cm) was measured from four leaflets taken from the center of the leaf, namely two leaflets each from the left and right. The width of the leaflets (cm) was measured at the center of the leaflets.

Sago starch extraction

Sago starch was extracted from the tree's pith at the top, middle, and bottom using a tubular drill (6 cm diameter, 10 cm high) to ensure a uniform sample. Sago starch extraction took place at the Food Technology Laboratory, Faculty of Agriculture, Tanjungpura University. Each sago stem sample weighed approximately 100g. Subsequently, the sample was crushed with a blender in 500 ml of water and filtered using a filter cloth. The filtrate was left to settle for 24 hours. The precipitate, wet sago starch, was then dried in an oven at 50°C for 24 hours. The dried sago starch was weighed, and the starch yield (%) was calculated as the dry starch weight (g) divided by the sample weight (g) multiplied by 100%.

Data analysis

Observational data underwent analysis using ANOVA, Multiple Comparisons, Regression, and Path Analysis. ANOVA and Multiple Comparisons were employed to identify differences in agronomic characteristics at each harvest phase. The Regression test aimed to establish the close relationship between starch yield, the dependent variable (y), and independent variables (x) represented by agronomic characteristics. Path Analysis sought to determine the direct or indirect interrelationships between variables. Path Analysis involves correlation coefficients divided into path correlation coefficients, indicating direct and indirect effects. Examining correlation values across various variables helps identify agronomic characteristics with positive or negative relationships with starch yield. Consequently, the analysis output can be utilized to enhance negative characteristics through the application of improved cultivation technology (Sari *et al.,* 2020).

RESULTS AND DISCUSSION

Agronomic Characteristics of the Harvest Phase

The results presented in Table 1 indicated that the sago harvest phase at different times exhibited varying agronomic characteristics and starch yield. Distinct agronomic features encompassed plant height, the number of leaves, leaf length, and leaf width. According to the agronomic analysis, the Jantung harvest phase stood out as the optimal time, yielding the highest starch (51.37%). It was characterized by favorable agronomic traits, including 22 strands of leaves and leaflets measuring 146.5 cm in length and 7.8 cm in width, respectively. The Rusa harvest phase also demonstrated a high starch yield (47.24%), with a plant height reaching 10.3 m, although other agronomic characteristics were lower than those in the *Jantung* phase. The dimensions of the leaflets remained consistent in size from the *Dewasa* to *Jantung* harvest phase, ranging between 147 x 8.0 cm and 146 x 7.6 cm. As the harvest progressed to the *Rusa* and *Bunga* phases, the leaf size diminished, measuring 124 x 6.9 cm and 124 x 6.8 cm, respectively.

Harvest time was an essential factor in determining the starch yield of sago stalks. The results of observations in Table 1 showed that the highest starch yield was evident at the harvesting age of Jantung and Rusa phases, with starch yields ranging from 47 to 51%. The previous phase (Dewasa) and the subsequent one (Bunga) showed a lower starch yield. The low starch yield in the mature stage of the sago palm was attributed to the starch-filling process in the trunks at that time. Meanwhile, the decrease in starch content at the flowering stage was caused by the dismantling of food reserves to support fruit filling. Thus, the maximum starch content occurred when the starch reserves stored in the trunks had not been used for fruit filling. According to Flach (1997), sago is a perennial plant that is a hapaxanthic plant and dies soon after the reproducing phase. Flowers appeared at the terminal stem and were inflorescent, then produced fruit. Its life cycle took 8-11 years through four growth phases, namely rosetting, stem elongation, flowering, and fruit ripening. The carbon allocation or biomass accumulation into plant organs differed among the growing phases. In the flowering and fruit ripening stage, most of the biomass photosynthate production was allocated to flower or fruit organs.

Relationship between Starch Yield and Agronomic Characteristics

Figure 1 showed that the production component of sago starch was closely related to the diameter of the stem and the number of leaf scars. The relationship between the two agronomic characteristics and starch yield followed the equations Y= -63.26 + 2.44x with a coefficient of determination (R2) of 37% and Y= -2.28 + 0.84x with a coefficient of determination (R2) of 34%. Based on these equations, it can be explained that the model could only explain the formation of starch content determined by pith diameter by 37%, and 63% was determined by other factors of diameter. The results of the regression analysis provided additional information that had been described in Table 1. The agronomic characteristics that were always superior, as shown at harvest age during the Jantung phase, were not necessarily a component of sago starch production. Even the number of leaves, leaflet length, and leaf width did not significantly contribute to starch production.

The best sago harvest time was accompanied by some of the best agronomic characteristics, as shown in Table 1, in the form of tall trees, many leaves with more prolonged and broader leaves. At first glance, this conclusion seemed reasonable because superior agronomic characteristics were expected to be followed by more starch production. However, when compared to the results of the regression test, as shown in Figure 2, it was revealed that the mentioned agronomic characteristics that affected starch yield (Table 1) did not significantly determine starch production. The regression test results indicated that starch yield was correlated with the pith diameter and the number of leaf scars. These results certainly created confusion about which agronomic character supported starch production. The starch content increased from Dewasa to Rusa phase and continued to decrease until the Bunga phase. The delay in harvesting until the plant flowering stage caused a decrease in starch content between 21 -27%. The starch accumulated in the trunk of the palm until the flowering stage, with the maximum starch content taking place just

Table 1. The agronomic characteristics of sago plants at several harvest phases

Characteristics	Harvest phase			
	Dewasa	Jantung	Rusa	Bunga
Starch yield (%)	40.04±3.87^{b}	51.37±5.08^{a}	47.24±2.36^{a}	37.10±2.65^{b}
Number of suckers	12.75±7.4^{a}	11.75±1.8^{a}	12.5±5.45^{a}	17.5±8.10^{a}
Plant height (m)	9.84±0.84 ^{a}	8.30±0.87 ^{b}	10.20±0.34 ^{a}	8.90±0.72 ^{b}
Pith diameter (cm)	43.22±2.31^{b}	45.70±1.26^{b}	43.90±0.65^{b}	42.99±1.07^{b}
Number of leaves	21.50±1.00 ^{a}	21.75±3.20 ^{a}	17.50±1.00 ^{b}	11.75±1.26^{c}
Number of leaf scars	52.25±7.54^{a}	58.25±2.87^{a}	55.25±1.89^{a}	54.75±4.35^{a}
Number of leaflets	70.38±1.25^{a}	66.63±3.07^{a}	68.63±5.79^{a}	61.00±9.27^{a}
Leaflet length (cm)	147.49±5.58 ^{a}	145.61±4.24 ^{a}	124.45±6.83 ^{b}	124.42±13.36 ^{b}
Leaflet width (cm)	8.15±0.40 ^{a}	7.80±0.28 ^{a}	6.87±0.51 ^{b}	6.78±0.88 ^{b}

Note: Different letters within the same row show significant differences according to the DMRT at5% level.

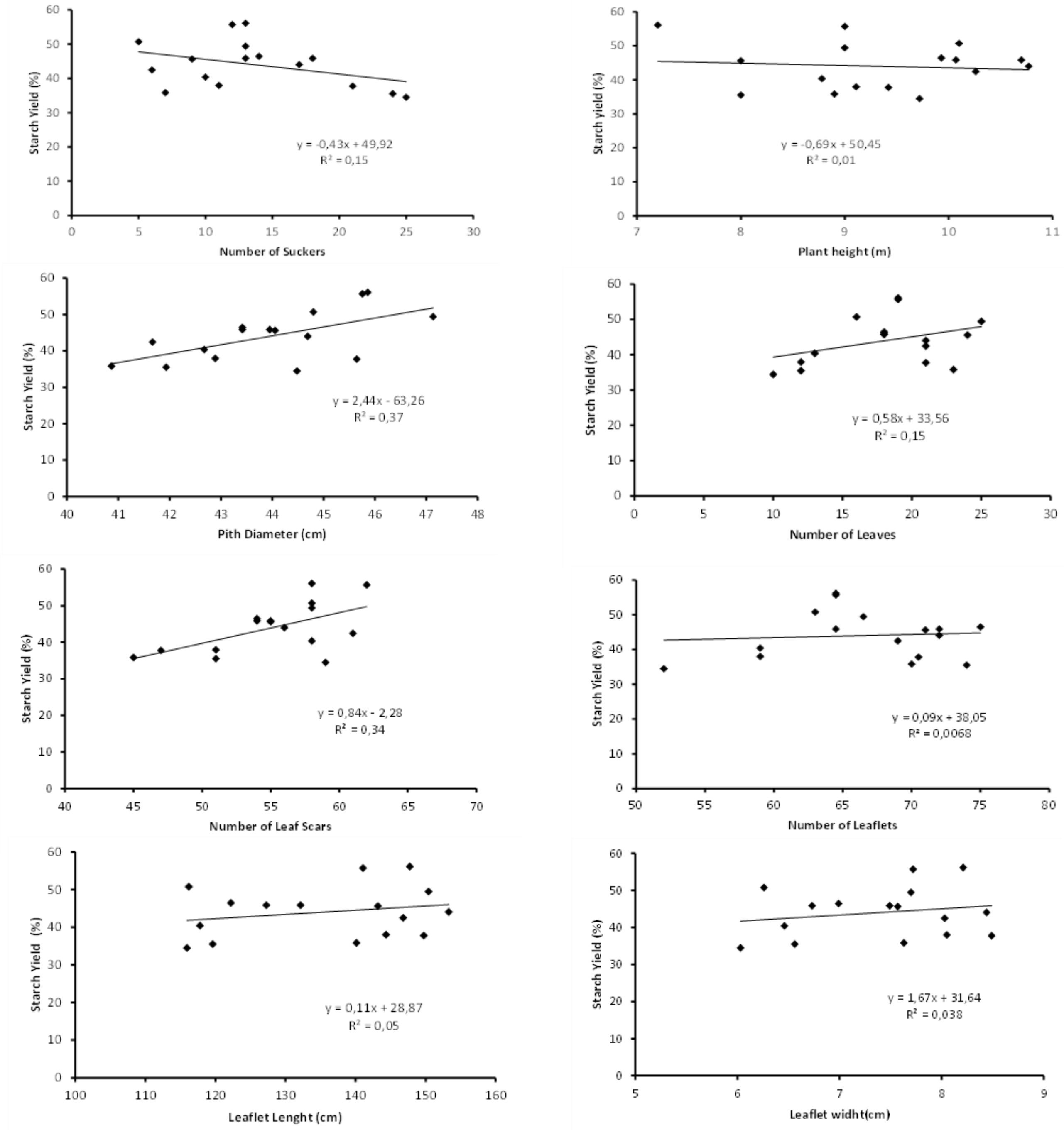

Figure 1. Relationship between agronomic characteristics and starch yield

before the onset of the flowers. The starch left unharvested would then be used to form flowers and seeds before the trunk died (Flach and Schuiling, 1989).

Evaluation of Agronomic Characteristics of Sago Starch Yield

Table 2 showed that the production of sago starch was directly determined by the leaflet length (-0.91), the number of leaf scars (0.48), and the pith diameter (0.59). The direct effect of leaflet length was negative on starch production, meaning the leaflet length indirectly suppressed starch production through the variables leaf width and the number of leaves. In general, the results of the path analysis showed that the sago starch yield would be higher with the increase in the pith diameter and the leaf scars. However, on the other hand, the starch yield would be inhibited by the increase in leaflet length, leaflet width, and the number of leaves during the flowering stage of the sago plant.

The results of the analysis in Table 2 explained the close relationship of various variables in increasing starch yield, as simply presented in Figure 2. Path analysis is very useful in explaining this phenomenon. The results of the path analysis test (Table 2 and Figure 2) showed that the pith diameter and the leaf scars had a direct effect of 0.59 and 0.48, respectively, followed by a total effect value of 0.61 and 0.58, respectively. This result was relevant to the regression test in Figure 1. This occurred because the direct effect followed by the total effect was also high, meaning that the indirect effect of various variables did not interfere much. Hence, the value was relatively proportional to the total effect. The total value of path analysis effects was identical to the Pearson correlation coefficient, so the variable with a high total effect had a high correlation with the dependent variable of starch yield, as shown in Figure 2. The path diagram could explain the interaction of variables, with a residual amount of 0.17. It could be interpreted that the analysis model was unable to explain other influences outside the influence of the independent variable, which was standardized at 73%. In other words, the residual influence that could not be explained by the model was 17%.

On the other hand, leaflet length directly affected the formation of sago starch, with a very high correlation of -0.91, meaning that leaflet length inhibited the production of sago starch. Leaflet length also affected indirectly through the number of leaves and leaflet width of -0.61 and -0.81, respectively. The results of the path analysis on sago agronomic characteristics were thought to be related to soil fertility that was conducive to sago growth and development, resulting in large trunks and dense leaf formation. Mature sago palm did not require fertilization. Fertilization was only adequate at the time of planting seedlings.

However, applying plant spacing that was too close caused overlapping of some leaves. If the photosynthetic process in leaves was less optimal, causing a decrease in photosynthate stored in sago trunks. The decrease in photosynthate also occurred because some leaves without photosynthesis needed photosynthate to maintain leaf survival. This meant that photosynthate could be produced by leaves and would reach its maximum if it was supported by sufficient sunlight exposure to all leaves. According to Sulaiman *et al.* (2021), three characteristics of sago palm growth were significantly positive in forming trunk diameters, i.e., the number of leaves, leaflet length, and plant height. This condition could occur in plantations with a spacing of 10 x 10 m2 or a density of 100 clumps/ha. In smallholder sago plantations, plant spacing was still narrow (6 x 6 m or 7 x 7 m), so the plant density was more than 200 clumps/ha. The farmers applied narrow spacing due to the method of selling sago based on stem pieces or per tree and not by starch yield productivity. The population density would speed up the frequency of harvesting, plant denser to reduce the number of suckers, and more mature trees would be more profitable.

Table 2. Direct and indirect effects of correlation coefficient values between agronomic character and starch yield

Variable	Direct effect	Indirect effect at each variable								Total effect
		PH	PD	SK	LF	LS	LT	LL	LW	
Plant height	-0.185	-	-0.038	0.005	0.000	0.049	0.017	0.088	-0.039	-0.102
Pith diameter	0.592*	0.012	-	-0.071	0.042	0.182	-0.036	-0.284	0.174	0.611
No. of suckers	-0.378	0.003	0.111	-	-0.063	-0.081	-0.012	0.172	-0.134	-0.383
No. of leaves	0.159	0.000	0.157	0.149	-	-0.041	0.132	-0.640*	0.465	0.382
No. of leaf scars	0.479*	-0.019	0.225	0.064	-0.014	-	-0.092	0.093	-0.152	0.584
No. of leaflets	0.237	-0.013	-0.090	0.020	0.089	-0.185	-	-0.271	0.296	0.083
Leaflet length	-0.909*	0.018	0.185	0.071	0.112	-0.049	0.071	-	0.725	0.224
Leaflet width	0.758	0.009	0.136	0.067	0.097	-0.096	0.093	-0.870*	-	0.195

Note: *) path correlation significant on level 0.05$^{*)}$ or 0.001$^{**)}$ and has the highest score on direct and indirect effect; SK: suckers; PH: plant height; PD: pith diameter; LF: no. of leaves; LS: no. of leaf scars; LT: no. of leaflets; LL: leaflet length; LW: leaflet width

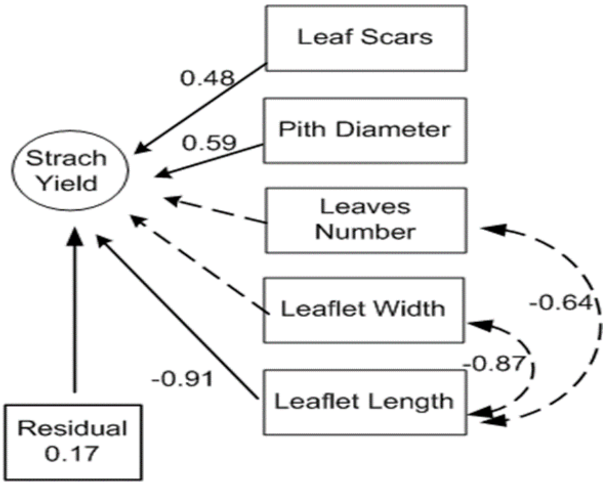

Figure 2. Path analysis diagram illustrating the interrelationships among agronomic characteristics contributing to sago starch yield. The full line shows the direct effect and the dashed line shows the indirect effect

In the field, the consideration of the harvest period was based on the age of harvest, and the minimum number of trees once harvested was 5-15 stems. Harvesting sago trees in smallholder sago plantations was not easy to do. There were several obstacles, including using simple cutting tools and transporting harvested produce from inside the plantation to outside the plantation required quite complicated land and water transportation routes. The further the plant was from the plantations, the longer the transportation route. That was why the harvesting period per hectare of a plantation with a density of approximately 200 clumps/ha took a relatively long time (about five months).

Based on the growth cycle of sago palms, the harvest age ranging from maturity to flowers took one year (Flach, 1997). With good harvest timing, farmers could harvest sago in large quantities during the *Jantung* or *Rusa* phases, thereby reducing the number of plants in the *Bunga* phase.

CONCLUSION

As a conclusion, the results of this study indicate that the best harvest time for sago palms was during the Jantung or Rusa phases. The agronomic characteristics that determine the production of sago starch were pith diameter and the number of leaf scars. Based on the coefficient of determination, the model that could explain starch yield with a pith diameter was Y= -63.26 + 2.44x with a coefficient of determination of 37%. Efforts to increase production in smallholder sago plantations must be made by improving the spacing. Plant spacing that was too close with a population density of more than 200 clumps/ ha caused overlapping leaves, which had a negative impact on the formation of sago starch. The negative effect increased with an increase in the number of leaves and the length and width of the leaflets.

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