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Research for the Development of Sago Palm (*Metroxylon sagu* Rottb.) Cultivation in Sarawak, Malaysia

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Propositions

1. The sago palm will be recognised as an important crop for starch-based industries in the 21st century.

2. Improved nursery practices will significantly increase the survival rate of sago palm suckers in plantation nurseries, thereby increasing the economic viability of this newly established plantation crop (this thesis).

3. Use of sago palm suckers of 7-10 cm base diameters weighing 2-5 kg will be adopted for plantations rather than larger suckers which are more difficult to obtain, bulky, and expensive to transport (this thesis).

4. A planting density of about 100 points per hectare should be adopted for plantations on deep peat for optimum yield per unit area (this thesis).

5. For maximum starch yield per unit time, sago palms should be harvested at the 'full trunk' growth stage, just before the appearance of the inflorescence structure (this thesis).

6. By improving agronomic practices, breeding and selection, the immaturity period of the sago palm can be reduced from 10 to 6 years on mineral soils and from 15 to 8 years on peat (this thesis).

7. Removal of young flowering axes can retain majority of the starch in the sago palm trunk which will otherwise be mobilised for flower and fruit development (this thesis).

8. Improved germination rate of sago palm seeds may encourage the use of sago palm seeds as a supplementary source of planting material if suckers are difficult or expensive to obtain (this thesis).

9. To sustain the development of sago palm plantations on deep peat in Sarawak, a critical mass of competent researchers is greatly craved.

10. Boss is like a durian [a large tropical fruit with strong smell and spiky husk] and subordinate is like a timun [cucumber] (a Malay proverb).

Foh Shoon JONG
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Wageningen, June 28, 1995

Contents

ACCOUNT

The following chapters of this thesis have been or will soon be published as separate articles in the ensuing publications. Minor improvements in text and presentation of the articles have been made for inclusion in this thesis.

Chapter 2

Jong, F.S. and H.S. Kueh (Accepted). "Sago palm cultivation: Factors affecting the subsequent survival of sago palm (*Metroxylon sagu*) suckers in the nursery". Japanese Journal of Tropical Agriculture. (Paper submitted to the Japan Society for the Promotion of Science (JSPS) and awarded the Second Prize in the "Inauguration of Sago Research Award" granted every four years).

Chapter 4

Jong, F.S., H.S. Kueh and J. Osman (1994). "The effects of spacing on the growth and development of sago palm (*Metroxylon sagu*) on undrained deep peat". Paper presented at the Fifth International Sago Symposium, 27-29 January 1994. Hat Yai, Thailand.

Chapter 7

Jong, F.S. (1991). "Studies on the seed germination of sago palm (*Metroxylon sagu*)". In: Ng. T.T., Y.L. Tie and H.S. Kueh (eds.). Towards greater advancement of the sago industry in The '90s. Proceedings of the Fourth International Sago Symposium, 6-9 August 1990. Kuching, Sarawak, Malaysia: 88-93.

Samenvatting

Het inleidend hoofdstuk bevat een overzicht van wat er bekend is over de teelt van de echte sagopalm (*Metroxylon sagu* Rottb.). De plant bloeit eenmalig en stoelt uit. Het zaad vormt eerst een bladrozet en pas na 4 - 6 jaar begint de stamvorming. De stam kan een lengte van 6 - 14 m bereiken en bezit een kroon van 7 - 24 geveerde bladeren. Onder optimale groeiomstandigheden vormt de palm in het rozetstadium gemiddeld twee en na het begin van de stamvorming een nieuw blad per maand en sterft tevens een blad per maand af. Aan het einde van de levenscyclus vormt de stam een enorme bloeiwijze, waarvoor het in de stam opgeslagen zetmeel wordt gebruikt. De vorming van de bloeiwijze begint 4 - 14 jaar na het begin van de stamvorming. De door voortdurende uitstoeling van de stam gevormde uitlopers vermenigvuldigen de plant vegetatief; tevens kunnen zij voor vermeerdering worden gerbruikt.

De sagostam is sinds's mensen heugenis gebruikt als zetmeelbron in zelfvoorzieningslandbouw in zuidoost Azie en reeds lang een commercieel gewas van klein-landbouwers op veengronden langs de kust van Sarawak. Momenteel exporteert Sarawak bijna 50 000 tone luchtdroog zetmeel. Sinds 1982 doet de regering van Sarawak pogingen deze teelt te verbeteren en uit te breiden, daar de sagopalm een van de weinige gewassen is die met redelijk succes op de zeer natte diepe veengronden kunnen worden verbouwd. Daarvoor is een onderzoeksstation gesticht in Sungai Talau en een laboratorium in Mukah. Tevens is in Sarawak een semi-gouvernementsorganisatie voor landontwikkeling (LCDA: Land Custody and Development Authority) belast met het aanplanten op enige tienduizenden hectares, ter ontwikkeling van de 1, 5 miljoen ha slecht gedraineerde veengronden.

Het hoofstuk wordt afgesloten met een overzicht van be belangrijkste beperkende factoren; deze leidden tot het onderzoek dat in dit proefschrift wordt behandeld.

In hoofdstuk 2 wordt het overleven van vegetatief vermeerderd plantmateriaal onderzocht. De uitlopers, rhizomen, kunnen worden afgenomen en voor aanplant worden gebruikt. Na het afnemen, worden de uitlopers in een kwekerij verder verzorgd. In de droge tijd sterft soms meer dan 20-40%. De uitlopers overleven het beste als zij worden geplant binnen drie dagen na het afnemen. Later planten leidt tot een hogere sterfte. Het snijvlak en vrijwel het gehele rhizoom moeten onder de grond worden geplaatst. Het inkorten van wortels aan het rhizoom tot slechts 1 cm heeft geen negatief effect. Inkorten van de rhizomen heeft wel een duidelijk negatief effect. Beschaduwing van de planten in de kwekerij werkt, vooral in de droge tijd, positief. Wanneer de uitolopers niet direct kunnen worden uitgeplant in de kwekerij, dienen zij te worden behandeld met een breed-spectrum fungicide.

In hoofdstuk 3 worden de resultaten gegeven van een onderzoek naar de invloed van de grootte van de uitlopers op hun groei in de kwekerij. Rhizomen met een diameter van 5 tot 15 cm groeiden goed zonder sterfte. Maar de grotere uitlopers met een diameter tussen 15 en 25 cm groeiden beter. Dergelijk uitlopers echter, zijn zwaar, volumineus en moeilijker te verkrijgen en daardoor nogal wat duurder in gerbruikt. In de kleinschalige teelt kan men vermoedelijk beter de grotere uitlopers gerbruiken, maar in de grootschalige teelt worden uitlopers van 7 - 10 cm diameter aanbevolen.

In hoofdstuk 4 worden de resultaten gegeven van een onderzoek naar het effect van de plantafstand op ongedraineerd diep veen. Daartoe werd de groei vergeleken na aanplant op respectievelijk 4, 5 m, 7, 5 m, 10, 5 M en 13, 5 M in het vierkant.

Planten op 4,5 m graf de laagste snelheid van bladontwikkeling, de geringste stamomtrek, beide, net boven de grond en op 1 m boven de grond, de kortste kruipende stam, de langste bladeren met de dunste rachis en de kleinste afmeting van de totale kroon. Deze wijze van aanplant vertoonde het geringste aantal stammen met tevens het kleinste aantal uitlopers. Het bladoppervlak van de aanplant sloot voordat de vorming van stammen begon in het derde tot vierde jaar na de aanplant in het veld.

De vegetatieve groei bleek intermediair te zijn bij een onderlinge afstand van 7, 5 m. Vergelijking met de behandeling met 4,5 m resulteerde in een significant betere snelheid van bladvorming, een grotere afmeting van bladkroon en stamomtrek, meer stamvorming en vorming van uitlopers en ook kortere bladeren met een dikkere rachis. Het bladerdek bleek gesloten op vijf tot zes jaar na het planten in het veld. Maar, vergeleken met de aanplanten op 10,5 en 13,5 m heeft de behandeling op 7,5 m een significant kleinere kroonafmeting, een lagere snelheid van bladvorming, langere bladeren met een dikkere rachis, dunnere stammen op 1 m hoogte en een tragere stamvorming.

Significant onderscheid tussen de behandelingen op resp. 10,5 en 13,5 m ontstond alleen in bladlengte, aantal uitlopers en snelheid van vorming van bladeren. Het bladerdek sloot in het achtste jaar na het planten, terwijl dat helemaal niet gebeurde op 13,5 m. De beide behandelingen onderscheidden zich niet in de gemiddelde stamlengten.

De conclusie is dat de groei van stammen suboptimaal is bij een plantwijdte van 4,5 en 7,5 m en dat het land niet ten volle wordt benut bij een plantwijdte van 13,5 m. De maximale vorming van stammen werd bereikt bij 10,5 m. Sagopalm lijkt dus op diepe veengronden op ongeveer 10 m afstand te moeten worden geplant.

Onderzoek naar de verdeling van het opgeslagen zetmeel over de lengte van de stam en de variatie daarin en tevens die van het watergehalte is weergegeven in hoofdstuk 5.

Sagostammen van vergelujkbare groeistadia op ondiep veen met daaronder klei varieren in lengte, omtrek en gewicht. Vanaf de tijd van planten blijft een dergelijke sagopalm ongeveer 5,5 jaar in het rozetstadium waarna de stamvorming begint. Bloei-initiatie vindt plaats op een leeftijd van 12,5 jaar en alle vruchten zijn gevallen na 14,5 jaar.

Het gemiddelde gehalte en ook de dichtheid van droog zetmeel neemt toe met de leeftijd van de stam tot de bloei begint. Het maximale zetmeelgehalte van 18-20% wordt gevonden tussen het tijdstip dat de bloeiwijze begint te verschijnen en de bloei. Daarna vermindert het zetmeelgehalte sterk om uiteindelijk op 4-6% te blijven staan.

Het watergehalte is hoog en blijft vrijwel constant in de lengyerichting van jonge stammen. Als de stam volwassen wordt neemt het vochtgehalte af, speciaal in het lagere deel van de stam.

Het laagste gemiddelde watergehalte wordt gevonden in stammen die hun grootste lengte hebben bereikt totdat de bloei begint. Dit correspondeert met het hoogste zetmeelgehalte. In jonge stammen, en ook in stammen na de bloei is het watergehalte hoger. Een hoge negatieve correlatie (r^2 = - 0,85) wordt gevonden tussen water- en zetmeelgehalte. Dit toont aan dat water en zetmeel elkaar onderling vervangen.

In ieder groeistadium is de dichtheid van de verse stam constant over de gehele stamlengte. Maar met de leeftijd neemt ook de dichtheid toe. Deze bereikt een maximum tussen het tijdstip dat de stam is volgroeid en het begin van de bloei. Daarna neemt de dichtheid weer af.

Het onderzoek leidt tot bergrip van het patroon van de zetmeelopslag en van de relatie tussen de dichtheid van de verse stam en de hoeveelheid zetmeel. Dit helpt om te bepalen wanneer de stam het beste kan worden geoogst voor een hoge zetmeelopbrengst per tijdseenheid en het maakt bovendien mogelijk om de zetmeelinhoud van stamdelen te schatten op basis van de diepte van het wegzakken van die stamdelen in water.

In hoofdstuk 6 wordt de bloeibiologie behandeld. Direct onder de reusachtige bloeiwijzen van een aantal sagopalmstammen werden eenvoudige platvormen geconstrueerd om de bloei te bestuderen.

In het vroegste stadium van ontwikkeling van de bloeiwijze komen de bloemknoppen in paren voor. Een van die knoppen is mannelijk, de andere volledig. De sagopalm is dus andromonoecious. Gedurende de ontwikkeling aborteert vaak een van beide bloemknoppen. Bij het verschijnen van de meeldraden zijn er overwegend slechts alleenstaande bloemknoppen aanwezig. Bij drie van de zeven onderzochte palmen werden volledige bloemen gevonden die prematuur open gingen.

Mannelijke bloemen blijven ongeveer dertig dagen geopend en volledige wel vijftig. Prematuur opengaande volledige bloemen kunnen wel drie maanden open blijven en nog niet rijpe meeldraden verdrogendan. Tussen 11.00 en 14.00 vindt men de top in het openen van de bloemen. Voor het merendeel is de sagopalm protandrisch maar overlapping van het open zijn van mannelijke en complete bloemen komt toch regelmatig voor.

Insecten, vooral *Trigona itama, Trigona apicalis* en *Apis dorsata*, werden in grote aantallen gevonden. Desondanks ontwikkelden zich alleen maar zaadloze vruchten in de meeste palmen. Dit maakt het waarschijnlijk dat de sagopalm zelf-incomptibel is. Experimenten met inhullen suggereren dat de sagopalm een obligate kruisbevruchter is.

In dit onderzoek produceerden de sagopalm ieder tussen de 276000 en 864000 volwassen bloemknoppen en 2173 tot 6675 rijpe vruchten. De groei van de vruchten duurde vanaf opening van de meeldraden tot de val van de laatste vruchten 19 -23 maanden.

In hoofdstuk 7 wordt gerapporteerd over een onderzoek naar practische methoden voor de kieming van zaden. Zaadkieming verbeterde met de rijping. Kiemingsonderzoek met volledig rijpe zaden in nat zand toonde aan dat naakte zaden beter kiemen. Wegnemen van het operculum uit de kiemporie en behandeling met 10^{-3} ^{M} giberreline verhoogde het kiemgetal en de kiemsnelheid. Een korte behandeling met geconcentreerd zwavelzuur bleek fataal. Kieming van de complete vrucht van de sagopalm bleek mogelijk in een omgeving met hoge vochtigheid. Een eenvoudige en effectieve manier is de kieming van geheel volgroeide vruchten in jute zakken in een vochtige atmosfeer.

In hoofdstuk 8 wordt een practisch gerichte evaluatie gegeven van de resultaten van het hier gerapporteerde onderzoek.

Adoptie van de resultaten van het overlevingsonderzoek van uitlopers kan leiden tot een toename van de overleving met 10 en 40 %. Daar een uitloper momenteel RM[1] 3,50 kost levert dit bij het momenteel gebruikte plantverband een vermindering van de kosten van aanplant op tussen de RM 27,- en RM 290,- per ha.

Het gebruikt van uitlopers met een diameter tussen 7 en 10 cm, met een gewicht tussen 2 en 5 kg per stuk zal vermoedelijk resulteren in een reductie van de prijsstijging van uitlopers, veroorzaakt door tijdelijke tekorten aan plantmateriaal.

Een plantverband van 10 bij 10 m, met eventueel een wijker midden in het vierkant, lijkt optimaal voor de uiteindelijke produktie. Dit is van belang voor de grootschalige aanplant op 7,5 x 7.5 m plant in driehoeksverband. Het is ook van belang voor de kleinschalige teelt die vaak een veel ruimer plantverband gebruikt.

Het onderzoek naar de verdeling van zetmeel in stammen van verschillende groeistadia leidt tot oogsten vlak voor de bloei. Te vroeg oogsten leidt tot opbrengstverlies. Te laat oogsten geeft een iets hogere opbrengst per stam, met een lagere produktie per tijdseenheid. Daar komt bij dat dan de volgende stammen vertraagd uitgroeien. Bij het juiste tijdstip van oogsten moeten de palmen zo laag mogelijk boven de grond worden gekapt. Het gevonden verband tussen zetmeelgehalte, vochtgehalte en dichtheid in de stammen kan leiden tot een practische methode van schatting van het zetmeelgehalte van stamdelen die drijven in het water, gebaseerd op het deel van de stam dat onder water verdwijnt.

[1]RM: Ringgit Malaysia, de Maleisische Dollar. Deze is thans, april 1959, ca Hfl 0,60 waard.

De resultaten van het onderzoek naar de bloei zijn van belang voor het zo noodzakelijke werk van veredeling in de toekomst. Dat geldt tevens voor het onderzoek van de zaadkieming; dit kan er tevens toe leiden dat zaad wordt gebruikt voor nieuwe aanplant, als uitlopers of te duur of onvoldoende beschikbaar zijn.

Het meest urgente probleem dat moet worden onderzocht is de bemesting op de chemisch zeer arme ongedraineerde diepe veengronden. Daarnaast is eveneens belangrijk onderzoek naar de mogelijkheid van bekorting van de zeer langdurige improductieve juveniele periode.

ABSTRACTS

General introduction (Chapter 1)

This chapter contains an overview of knowledge with respect to the cultivation of the true sago palm (*Metroxylon sagu*). The palm flowers once and forms suckers or tillers. Seedlings grow into a rosette stage of leaves and trunks are only formed after 4-6 years. The trunk may reach a length of 6-14 m and possess a trunk of 7-24 feathered leaves. An enormous inflorescence heralds the end of the life cycle. Formation of the inflorescence, for which the starch in the trunk is being used, begins 4-14 years after the start of trunk formation.

Continuous suckering multiplies the palm vegetatively, forming a cluster around the leader palm. Suckers are commonly used for vegetative propagation by man. Since time immemorial, man uses the sago palm trunk as a source of food starch in South East Asia. It has been a commercial crop of smallholder farmers on peat soils in Sarawak for a long time. At present, Sarawak exports nearly 50,000 tonnes air-dried sago palm starch.

Since 1982, the Sarawak Government tries to improve and increase its cultivation, as it is one of the few crops that can be grown with reasonable success on the rather wet deep peat soils. For this purpose, a research station has been established at Sungai Talau Station and a laboratory in Mukah. The semi-governmental agency for land development, Land Custody and Development Authority, is planting sago on some ten thousands of hectares, in order to develop part of the 1.5 million ha of poorly drained peat soils.

The chapter ends with an overview of the main limiting factors for sago palm cultivation. This lead to the research presented in this thesis.

Factors affecting the subsequent survival rate of sago palm suckers in the nursery (Chapter 2).

Suckers are the most popularly used planting material for establishing sago palms in smallholder gardens and plantations in Sarawak. In nurseries, the mortality rate of suckers is around 20-40%. In the dry season, higher mortality rates are common.

Factors suspected to affect the subsequent survival rate of sago palm suckers in nurseries were investigated. The survival of suckers was significantly enhanced if they were planted promptly, best if it was within three days after removal from the parent palm. Suckers stored for more than two weeks before planting generally showed a marked decrease in their subsequent survival in the nursery. When the cut-ends and the whole or part of the rhizome were completely buried in the soil, an increased rate of survival was also obtained. Rhizomes planted 8 cm below the soil surface or just placed on top of the soil surface had lower survival rates. Trimming of roots to as short as 1 cm did not affect the subsequent survival of the suckers. Trimming of the rhizomes to a length close to the growing point of the sucker was deleterious. Shading of suckers during the dry season appeared to contribute positively to their successful establishment.

When planting of suckers was delayed, treatment with a wide-spectrum fungicide while storing the suckers in cool and moist places was shown to reduce their mortality rate.

Effects of sucker size on the establishment of sago palms (Chapter 3).

The effects of sucker size on their subsequent establishment were investigated. Suckers of all sizes from 5 to 25 cm in base diameter were established successfully without mortality. In general, larger suckers of 15-25 cm in base diameter are faster in their establishment. However, these suckers are heavy, bulky, less abundant, and expensive to handle. In large-scale cultivation of sago palms, the use of large suckers has to be weighed in financial terms and availability of the material. It appears that larger suckers may be suitable for smallholder cultivation. In plantations, smaller suckers of 7-10 cm in base diameter are recommended.

Effects of plant spacing on the growth and development of sago palms on undrained deep peat (Chapter 4).

The growth of sago palms was compared at 4.5 m, 7.5 m, 10.5 m and 13.5 m square planting. Palms spaced at 4.5 m had the lowest frond emergence rate, smallest trunk circumference at the base and at 1 m above ground level (a.g.l.), shortest prostrate (ground) trunk, longest fronds with thinnest rachides and the smallest crown size. They produced the least numbers of trunks and suckers, and their canopy was closed before trunk formation commenced in the third to fourth year after field planting.

The vegetative growth was intermediate in the 7.5 m spacing treatment. Compared to 4.5 m spacing, these palms had significantly higher frond emergence rate, larger crown size and trunk circumference, better stem formation and suckering ability as well as shorter fronds with thicker rachides. Their canopy was closed by the fifth to sixth year after planting. However, when compared to the 10.5 m and 13.5 m spacing treatments, the 7.5 m treatment palms had significantly smaller crown size, lower frond production rate, longer fronds and thicker rachides, smaller trunks at 1 m a.g.l. and slower trunk formation. There were no differences among these treatments in the suckering ability and the size of the basal circumference of the trunk.

Significant differences between spacing treatments of 10.5 m and 13.5 m were only found in the frond length, sucker number and frond production rate. However, the canopy of palms spaced at 10.5 m was about to close in the eighth year whereas those spaced at 13.5 m remained open. No difference was found in the average trunk height between any two spacing treatments.

The formation and growth of sago palm trunks were suppressed at 4.5 and 7.5 m spacing whereas at a spacing of 13.5 m, the field was under-utilized. Among the spacing treatments, the maximum trunk production per unit area was from palms spaced at 10.5 m. This suggests that sago palm on peat should be cultivated at a spacing of about 10 m.

Distribution and variation in the starch and moisture contents of sago palms at different growth stages (Chapter 5).

Sago palms of similar growth stages established on shallow peat vary in length, circumference and weight of their trunks. From the time of planting, a sago palm remains in the rosette growth stage for about 5.5 years before trunks are formed. Flower initiation occurs at 12.5 years and the fruit drop is completed in 14.5 years.

The average content and density of dry starch increases with increasing maturity of the sago palm until flowering. Maximum starch content of18-20% is found between the full trunk growth stage (just before the emergence of inflorescence structure) and flowering stage. Thereafter, the starch content decreases sharply and remains finally at about 4 - 6%.

The moisture content is high and remains rather constant along the trunk of young sago palms. As the palm matures, moisture content decreases, especially in the lower portion of the trunk.

The lowest mean moisture content is found in palms from the full trunk growth stage to flowering stage, corresponding to the highest starch content in the trunk. In young and over-mature palms, the mean moisture content is higher. A high negative correlation (r^2 = -0.85) is found between moisture and starch contents, showing the mutual replacement of starch and moisture in the trunk.

Within each growth stage, the density of the fresh trunk is constant along the entire trunk length. However, among different growth stages, the mean density of the sago palm trunk increases gradually from the early trunk formation stage. It reaches a maximum between the full trunk growth and flowering stage before decreasing in the subsequent over-mature stages.

This study provides an understanding of the pattern of starch accumulation and the relationship between the fresh density of the trunk and the starch content in it. This enables the harvesting of palms at the correct growth stage for maximum starch yield per unit time, and facilitates the grading of sago logs for starch yield based on their buoyancy.

Flowering biology of the sago palm (Chapter 6).

Scaffolds were constructed below the gigantic inflorescence of sago palms to investigate the flowering biology. In the early stage of development, flower buds occur in pairs in a bracteole. One is a staminate (male) and the other a hermaphrodite (perfect) flower. During development, abortion of either the staminate or the hermaphrodite flower buds occurs. By anthesis, mainly single flower buds are left in each bracteole. The sago palm is andromonoecious as indicated by the presence of staminate and hermaphrodite flowers in the same inflorescence. In three of the seven palms investigated, abnormal hermaphrodite flowers which opened prematurely were encountered.

The duration of flower opening in the entire inflorescence is about 30 days for the staminate flowers and 50 days for the hermaphrodite flowers. For the abnormal hermaphrodite flowers, opening may stretch over a period of three months and the premature stamens die during the opening. The peak of daily flower opening is between 1100-1400 hours. To a large extent, the sago palm is protandrous but overlaps in the opening of staminate and hermaphrodite flowers do occur. Seedless fruits are formed in all these palms. Visiting insects (predominantly *Trigona itama, Trigona apicalis* and *Apis dorsata*) are found in great numbers during anthesis. However, only seedless fruits develop in most palms. This suggests that the pollen and pistil of sago palms may be self-incompatible. Bagging experiments to exclude visiting insects suggest that cross-pollination is obligatory in sago palms.

In the current investigation, each sago palm produced between 276,000-864,000 mature flower buds and 2174-6675 mature fruits. The duration of fruit growth from anthesis to last fruit drop is between 19-23 months.

Germination of sago palm seeds (Chapter 7).

Some practical methods to increase the germination rate of sago palm seeds were investigated. The capability of seeds to germinate was found to increase as seed maturity advanced. Germination tests conducted on mature sago palm seeds using wet sand tray showed that removal of the husk and husk plus fleshy tissue (sarcotesta) enhanced germination. Loosening of the operculum and treatment with 10^{-3} M gibberellin also increased the number and speed of germination. Brief treatment with concentrated sulphuric acid was found fatal to the seeds. Germination of the entire sago palm fruit required an environment with high humidity. An easy and effective way of achieving this is to put mature sago palm fruits in partially permeable Hessian sacks placed in a damp atmosphere.

General conclusions (Chapter 8)

In this chapter, an assessment of the research results for practical application in sago cultivation is given.

Application of the findings from experiments on the survival of suckers may lead to an increase of survival between 10 and 40%. At the current cost of about RM 3.50 per sucker, this will decrease cost of planting, at the present planting distance, between RM 72 and RM 290 per hectare. Selecting suckers with a base diameter between 7 and 10 cm and a weight between 2 and 5 kg can reduce transportation and handling costs. This may also prevent price increase due to temporary sucker shortage when larger planting materials are preferred . Planting sago palms in a 10 m square pattern, with possibly a temporary plant in the middle of the square for one-harvest trunk , appears optimal for ultimate production. Findings in the distribution of starch in the trunk at different growth stages leads to harvesting just before flowering. Based on the ralation found between starch content, moisture content and trunk density, it may lead to the development of a practical method to estimate the starch content of a trunk based on its buoyancy. The results obtained in flowering and seed germination appear to be important and may be used for future breeding and research programmes. Sago palm seeds may also be used for new planting if suckers are either too expensive or in short supply.

The most pressing problems that needs attension in sago research is fertilizer application on the notoriously poor and badly drained peat soils. It is also important to start research on shortening the unproductive phase of the cultivation.

CHAPTER 1

GENERAL INTRODUCTION

1.1 Importance of sago palm to Sarawak

Sago palm (*Metroxylon* spp.) is one of the few tropical crops which can tolerate wet growing conditions including peat swamps. It has been a starch crop of economic importance to the rural community living in certain coastal regions of Sarawak for over a century.The first export of sago flour from Sarawak dates from the early 19th century when Singapore was founded (Morris 1977). Currently, it ranks fourth among the agricultural export commodities of Sarawak producing 49,500 tonnes of air-dried starch and earning a revenue of about RM 31 million annually for the State economy (Anon. 1992).

In terms of energy value per hectare, sago is one of the highest yielding crops in the world (Foster 1978). Top yield obtained in Batu Pahat, Johore, is already higher than the actual yield of rice (Flach 1977). It has a potential yield of thirty-seven tonnes per hectare making sago highly competitive with other starch crops in terms of productivity. In view of the tremendous prospect of sago in becoming a leading starch crop of the world, the Sarawak Government is committed to develop it as a plantation crop to utilize vast areas of peat swamps (about 1.5 million hectares) which are too marginal for other economic crops.

The Government's effort to further develop the sago industry has been set in motion since 1982 when research and development on sago was intensified by the Department of Agriculture, Sarawak. In response to this, a sago research station and a laboratory were established in Sungai Talau and Mukah respectively to provide facilities for agronomic and improved processing research. The world's first commercial sago plantation is currently being developed in Mukah by a Sarawak land development agency (Land Custody and Development Authority) and more large-scale planting is planned over the next ten years. A Crop Research and Development Unit has recently been established by this agency, solely to undertake more intensive research and development on sago to support and accelerate its development.

1.2 Taxonomy

The sago palm belongs to the order *Arecales* Nakai (Heywood 1993), family *Palmae* Jussieu, subfamily *Calamoideae* Griffith, tribe *Calameae* Drude, subtribe *Metroxylinae* Blume and genus *Metroxylon* Rottboell (Uhl and Dransfield 1987). *Metroxylon* has previously been classified in the subfamily *Lepidocaroideae* (Moore 1973) but this name has been changed back into *Calamoideae* by Uhl and Dransfield (1987), in agreement with the original classification of Griffith (1844).

Beccari (1918) distinguished nine species of *Metroxylon* which he divided into *Eumetroxylon* with three species and *Coelococcus* with six species. Classification was mainly based on the size and morphology of scanty fruit specimens in herbariums. A description of each species was also given, based primarily on description by local inhabitants, literature, and limited numbers of herbarium specimens with fruits, inflorescences and leaves.

The *Eumetroxylon* species have fruits covered with 18 vertical rows of scales. The species in *Eumetroxylon* are (1): *M. sagus* Rottb. (forma typica); *M.sagus* var. *molat* Becc.; *M. sagus* var *peekelianum* Becc. and *M. sagus* var. *gogolense* Becc., (2): *M. rumphii* Mart. (forma typica); *M. rumphii* var. *rotang* Becc.; *M. rumphii* var. *longispinum* Becc.; *M. rumphii* var. *sylvestre* Becc.; *M. rumphii* var. *ceramense* Becc.; *M. rumphii* var. *ceramense* subvar. *platyphyllum* Becc.; *M. rumphii* var. *ceramense* subvar. *rubrum* Becc.; *M. rumphii* var. *ceramense* subvar. *album* Becc.; *M. rumphii* var. *ceramense* subvar. *nigrum* Becc.; *M. rumphii* var. *micracanthum* Becc.; *M. rumphii* var. *micracanthum* subvar. *tuni*; *M. rumphii* var. *micracanthum* subvar. *makanaro*; *M. rumphii* var. *buruens* Becc.; *M. rumphii* var. *flyriverense* Becc. and (3): *M. squarrosum* Becc., with seven varieties recognised by natives, although Beccari could barely distinguish these from one another because he had such a limited number of specimens available.

All *Coelococcus* species bear fruits covered with 24-29 vertical rows of scales as compared to 18 in *Eumetroxylon*. The species in *Coelococccus* are (1): *M. warburgii* Heim.; (2): *M. upoluense* Becc.; (3): *M. vitiense* Benth. et Hook; (4): *M. amicarum* var. *commune* Becc.; *M. amicarum* var. *majus* Becc.; (5): *M. salomonense* Becc. and (6): *M. bougainvillense* Becc..

Considering Beccari's classification (based on fruit shape and size) inappropriate, Rauwerdink (1986) attempted to reclassify the genus *Metroxylon* into five species. Clustering palms, unarmed (spineless) or armed with spines of any degree, producing fruits covered with 18 longitudinal series of scales, are classified as *Metroxylon sagu*. The other species of *Metroxylon, M. amicarum, M. vitiense, M. salomonense and M. warburgii,* are solitary palms, covered with 24-28 longitudinal series of scales and spinescent. Rauwerdink put *M. bougainvillense* as synonymous with *M. salomonnense* while *M. upoluense* has not been mentioned.

Rauwerdink (1986) further divided *M. sagu* into four formae, based on the characteristics of their spines as follows: (1) *M. sagu* forma *sagu*: leaf sheaths and petioles unarmed at all ages of the palm, totally smooth. (2) *M. sagu* forma *tuberatum*: the base of leaf sheaths covered with knob-like structures, irregular to the touch at all ages of the palm. Petiole, rachis and all bracts of the inflorescence perfectly smooth. The pinnae can be spiny at the apex and costa. (3) *M. sagu* forma *micracantum*: the leaf sheath, petiole and rachis of the palm not longer than 4 cm from an early age of the palm onward. Bracts of the inflorescence smooth or with scattered spinules. (4) *M. sagu* forma *longispinum*: the leaf sheath, petiole and rachis with spines that are 4-20 cm long. Bracts of inflorescence with spinules, scattered or in transverse series. Keys to species and formae are provided by Rauwerdink.

Rauwerdink (1986) has correctly pointed out that it is inappropriate to classify *Metroxylon* based on fruit morphology and size, as made by Beccari (1918). However, typifying the formae on the basis of the presence and length of the spines by Rauwerdink is also inadequate. It does not reflect the actual differences among the palms in the formae. Firstly, the length of spines changes with age as recognised by Rauwerdink. Young palms usually have longer spines on the leaf sheaths and petioles than the older palms which have formed trunks. This implies that specimens collected from palms of different ages may be rather easily misclassified. Secondly, seedlings produced from a single parent are heterogeneous in spine characters (Rauwerdink 1986). From observations at Sungai Talau Sago Research Station, seedlings with a range of spine characteristics, possibly covering the four formae, are produced from a single parent. Thus, they may have to be classified into different formae and classifying the progenies of a single parent into different formae appears improper. Thirdly, although it has been shown that some spiny or spineless palms can produce both types of seedlings, it has not been proven that all the sago palms in Beccari's *Eumetroxylon* can hybridise freely to show whether they deserve species status.

In my encounters with the sago palms in Sarawak, Indonesia and Papua New Guinea, I feel that characteristics used by the local inhabitants to differentiate the cultivars are also important considerations for species or forma classification. Some examples are the pattern and shape of spines ("sagu samakika" in Saparua Island has broad sharp spines), fruit anatomy ("sagu makanatol" in Saparua Island has three seeds in a fruit instead of one), frond shape (e.g., drooping leaflets in "sagu ihur" and "sagu makanatol") and colour of starch ("sagu ihur" has pinkish starch).

Other considerations in species and subspecific classifications should possibly include pollen morphology (Sowumni 1972), total number of leaf scars on a full-grown trunk, from the base to the initiation of flowering axis (Flach, pers. comm.), adaxial/abaxial leaf stomata ratio (Uchida 1990), or other distinctive features that are unique and unlikely to vary with age or growth conditions. Classification combining morphological traits with biochemical and molecular traits such as isozyme techniques (Hisajima 1994) may prove very useful. A taxonomist with appropriate experience in live sago palms is imperative to address the still doubtful species question in *Metroxylon*.

1.3 Ecology

The sago palm occurs between 10° south and 10° north latitudes and up to an elevation of 700 m (Flach 1977) or 1000 m (Paijmans 1980) above sea level. The best yields come from palms grown below 400 m above sea level (Deinum 1958). The minimum temperature requirement is 15° C and the optimum is 25-30° C (Deinum 1958, Flach 1977). An evenly distributed annual rainfall of 2000-4000 mm throughout the year is desirable, with precipitation permanently in excess of evaporation (Deinum 1958). Full sunshine, a soil pH of 4 or higher and regular but not continuous flooded conditions provide an ideal ecological niche for optimal growth of the sago palm (Deinum 1958, Flach 1977,'79,'80).

The sago palm is tolerant to low pH, high Al, Fe and Mn in the soil as well as heavy impervious clays (Tan 1982). It can grow on peat and mineral soils but growth is better on the latter. On mineral soils, the sago palm matures in 8-10 years (Flach 1977, '84) whereas on peat, 15-17 years are required (Johnson and Raymond 1956). It is the only crop that is capable of giving sustainable economic return on peat swamps in Sarawak (Tie and Lim 1977).

1.4 Botany and growth habit

The sago palm is a huge tropical palm storing starch in its trunk. It is hapaxantic (once-flowering) and soboliferous (tillering). It can either be propagated from seeds or suckers. Once planted, new suckers are gradually produced from the planted leader palm, forming a cluster of palms in different stages of development (Fig.1). Normally, trunks will develop from the clusters of suckers if they are not suppressed by over-shading or suffering from severe nutritional stress.

In plantings at Batu Pahat, Johore, the number of suckers is regulated to only one for development in every 18-24 months (Flach 1977,'84). This enables a regular and scheduled supply of palms for harvesting after the mature palm has been harvested. In this manner, a sago palm cluster can remain productive for a very much longer period than oil palm or rubber (Stanton 1991). Indeed, many sago gardens in Mukah and Dalat areas in Sarawak are still productive although they were planted several decades ago.

The growth of sago palms is highly variable, very much dependant on the cultivar and growth condition. A sago palm may remain in the trunkless or rosette growth stage for 3-6 years. In this stage, 24 fronds are produced per year under optimal growth conditions (Flach 1984). The trunk growth takes about 4-14 years (Flach and Schuiling 1991) and, on average, one frond is produced per month. The trunk diameter ranges from 35-60 cm (Flach 1977, Lim 1991, Mohd. Noh 1991). The crown size may vary from 6 (Anon. 1988-'92) to 24 fronds (Mohd. Noh 1991). Each frond is 5-8 m long carrying between 100-190 leaflets (Flach and Schuiling 1991, Mohd. Noh 1991).

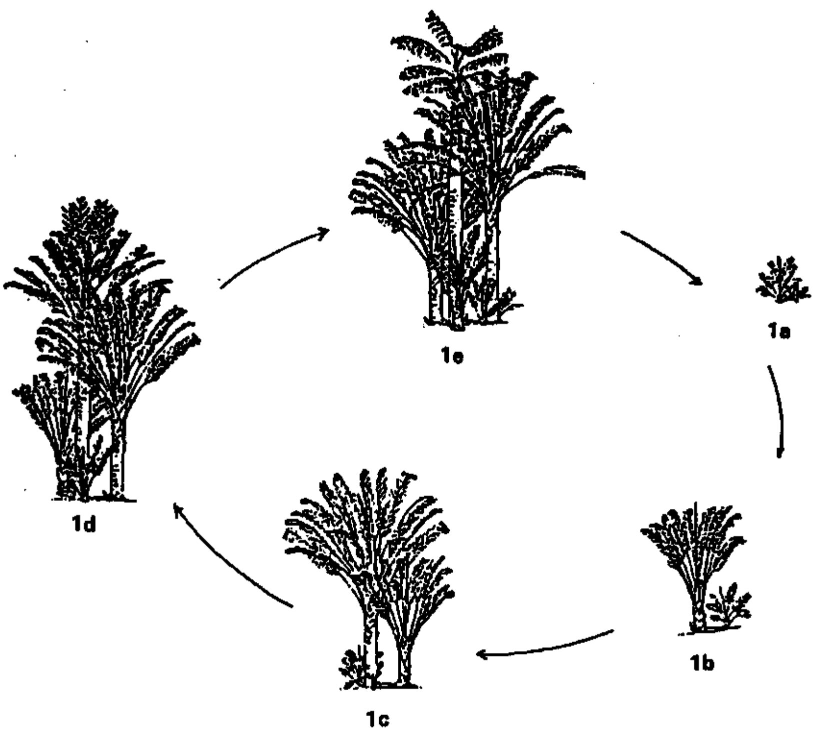

Fig 1. The growth cycle of a sago palm (adapted from Schuiling and Flach,1985). 1a. A young palm in the rosette stage. It can be established from seed or sucker. 1b. A trunk is formed as the palm grows. Note the production of a sucker at its base. 1c-1e. New suckers are regularly generated, forming a cluster of palms with different growth stages.

In a mature palm just before flowering, the trunk measures from 7 to 15 m in length (Johnson and Raymond 1956, Flach 1977, Mohd. Noh 1991) and weighs about one tonne in fresh weight. About 180-413 kg of dry starch can be extracted from a single trunk in Malaysia (Sim and Ahmed 1978, Mohd. Noh 1991). The correct time for harvesting has been reported by several workers (Johnson and Raymond 1956, Sim and Ahmed 1978, Lim 1991) to fall between the flower initiation and flowering stage but before fruits are formed. Flach (1984) advocates harvesting at or just before visible flower initiation in order to obtain the highest starch yield per unit time and surface area.

Trunk growth ends with the development of the generative phase when a huge inflorescence is produced at the terminal growing point of the trunk. In the transition between the vegetative and generative phase, the fronds gradually decrease in size until they become reduced to bracts. White colouration appears on the petiole and leaf sheath. The trunk elongates by the extension of the internodes. The flowering structure consists of 15-25 primary flower axes (Schuiling 1991, Tuwan 1991). Each ax1 is about 2-3 m long, carrying 15-20 secondary-order flower axes or ax2. Seven to ten rachillae (spikes or ax3) are borne on each ax2 (Schuiling 1991, Tuwan 1991).

It has been estimated that about 700,000-1,000,000 flower buds are borne on the ax3 of the palm (Beccari 1918, Kiew 1977, Tuwan 1991). The sago palm is monoecious and protandrous (Beccari 1918, Utami 1986) and insects have been reported to play an important role in fruit set although flowers are self-pollinated (Utami 1986). Flach (1977) suggested that cross-pollination is obligatory in the sago palm.

1.5 Cultivation

1.5.1 Traditional cultivation in Sarawak

The area of sago palms in Sarawak is about 20,000 hectares (Tie *et al* 1991). A total of 62% of this is located on organic soils, of which more than 7,500 ha are deep peat with more than 150 cm of organic material (Tie *et al* 1991). Sago palms are commonly cultivated on deep peat mainly because better mineral soils are required for other crops. Because of its ability to withstand inundation, sago palms are generally found in low-lying mineral or peat soils which are unsuitable for other crops.

In the main sago producing areas of Mukah and Dalat Districts, sago palms are almost exclusively cultivated by smallholders. Once the suckers are planted, maintenance is kept at a minimum, probably confined to a few rounds of weeding. Fertilizers are rarely used or not used at all. The palms are left to grow by themselves until harvest. Occasional weeding and removal of old fronds may be carried out. Sucker growth is normally not regulated; they are left to grow freely and are usually suppressed by heavy natural shade. The main insect pest is the sago worm, the larva of the red-stripe palm weevil (*Rynchophorus schach*). However, these grubs, considered as a delicacy by many local inhabitants, are frequently collected before they have a chance to spread and damage other palms. Diseases are hardly encountered and no proper control or preventive measures of pests and diseases are done. This creates the impression that sago palms are cultivated without the application of fertilizer and control of pests and diseases.

Many sago palm gardens are very old, some being passed down for several generations. Very often, sago gardens are associated with other vegetation. Missing points are seldom filled in, resulting in low plant density. Under such a traditional production system, sago palm has been considered the only crop capable of giving sustained economic return on peat swamps of Sarawak (Tie and Lim 1977). The annual trunk production on deep peat is estimated at 15-20 trunks per hectare whereas those on mineral soils are estimated at 25-40. However, there is no significant difference in the starch content in the palms grown on the two soil types (Tie *et al* 1991, Lim 1991). Sago palms on peat take about 12-15 years to reach maturity (Tie *et al* 1987, '89) whereas the maturity period is shortened to 8-10 years for palms grown on mineral soils (Johnson and Raymond 1956, Flach 1984). The total starch yield per unit time and area on peat is thus significantly lower. The productivity of smallholder gardens, in general, is far lower than properly tended palms in sago plantations at Batu Pahat, Johore where over a hundred trunks may be harvested per hectare annually (Flach 1984).

1.5.2 Plantation

Flach (1977, '84) reported that in Batu Pahat, Johore, sago palms are cultivated at 6 m by 6 m with suckers regulated to one every two years, or at 7 m by 7 m with suckers controlled at one in every 18 months. Suckers are used in the planting and palms are harvested about eight years later just before flower initiation. Under such a system, a yield of 24 tonnes of dry starch can be harvested in the first 5-10 years of harvest. It then declines and stabilizes at about 15 tonnes per hectare per year. The sago palms are mainly cultivated on mineral soils subject to regular flooding which brings in the nutrients. The overall scale of planting is small, usually not more than two hectares per holding.

In Sarawak, the development of the first 7700-hectare sago palm plantation is being undertaken by the Land Custody and Development Authority (LCDA). Planting commenced in 1987; suckers are used as the planting material. Palms are spaced at 7.5 m by 7.5 m in a triangular pattern on deep peat without fertilizer application (Kueh *et al* 1991). Implementation of a second 1600-hectare plantation, also on deep peat near Oya, started in 1993.

1.6 Constraints and problems of cultivation

The main constraint of sago palm cultivation in Sarawak is the low yield and the long immaturity period of ten years or more. Traditional practices are still prevailing although in recent planting assisted by the Sago Subsidy and Rehabilitation Schemes of the Department of Agriculture, Sarawak, more systematic planting is being adopted. Proper spacing and sucker regulation to one in 18-24 months are recommended. However, fertilizer use has yet to be recommended. There is still a great dearth of knowledge and experience on intensive cultivation of sago palm on deep peat, which can only be supported by research capable of addressing the most critical areas.

The main problems associated with sago palm cultivation in Sarawak may be highlighted as follows:

(a) The use of fertilizer and the methods of fertilizer application to sago palms grown on peat swamps with high water table. This is the most pressing problem associated with intensive sago palm cultivation on deep peat, a growth medium with inherently poor nutrient status. The palms are slow in growth with premature frond desiccation, small crowns, small trunks and very low starch yield.

(b) The long immaturity period needs to be shortened. This may be facilitated by means of agronomic measures or through breeding and selection work. Selection for fast maturing varieties started in 1988. More than twenty types collected from Indonesia and Papua New Guinea (Anon.1989-'93) are currently being assessed. However, it will be many years before any results are known.

(c) High mortality of sago palm suckers in the nursery, due to various factors associated with delayed planting, improper handling and incorrect nursery techniques. The preference for large suckers for planting in the plantation has resulted in a temporary shortage of supply, and higher costs incurred in handling and transportation.

(d) Uncertainty about the optimal palm spacing under plantation conditions which may lead to the use of excessive planting material, hence incurring higher establishment costs but getting lower yields.

(e) Scheduled sucker regulation system is, to a large extent, not yet adopted. This results in palm clusters overcrowded with suckers and failure to provide regular growth of successor palms for scheduled harvesting. It also delays the formation of trunks due to competition.

(f) In most traditional gardens, the stand of sago palms is sparse and often mixed with fruit and other jungle trees. This results in over-shading and suppression of palm and sucker growth, ending in low yield per unit area.

(g) Pest control is not practised. It is anticipated that if they remain unchecked, pests and disease may build up in intensive sago planting. There are signs that some minor pests such as termites and hispid beetles are becoming economically important (Megir and Jong 1991).

(h) Harvesting at the correct stage to maximise crop yield per unit time and area is not generally practised. Harvesting of palms which are too young or too old results in significant loss of starch.

(i) Processing and quality improvement. Quality control in the processing of starch has been thoroughly studied. Poor quality is largely due to delayed processing and undesirable conditions under which the sago palm logs are stored (Cecil 1982). However, problems still remain due to the unavoidable delay in harvesting, log transportation or overstocking of logs in log ponds, contributing to the inconsistent quality of processed starch.

(j) Other unknown factors. Some problems that are nonexistent now may appear in the future. These need to be tackled by a group of researchers of different specializations.

1.7 Outlines of Research in this thesis

This thesis documents field research undertaken to address some of the problems mentioned and to contribute knowledge on some aspects of growth and development of the sago palm. It is focused on practical-oriented research based on the following topics:

1.7.1 Factors affecting the survival rate of sago palm suckers in the nursery.

One of the main problems faced in the sago palm plantation in Sarawak is the high mortality rate of the sago palm suckers in the nursery. Sometimes, the mortality is as high as 50%. In this study, several factors suspected to contribute to the high mortality are investigated.

1.7.2 Effects of sucker size on the establishment of sago palms

To find out if the traditional preference using larger suckers over smaller ones has any rational basis, the growth and development of sago palms established from suckers of five different sizes are monitored over a period of six years.

1.7.3 Effects of plant spacing on the growth and development of sago palms on undrained deep peat.

To determine the optimal planting density of sago palms for intensive cultivation on deep peat, the growth and development of sago palms spaced at 4.5, 7.5, 10.5 and 13.5 m in square planting are monitored from 1984 to 1993.

1.7.4 The distribution and variation in starch and moisture contents in sago palms at different growth stages.

The pattern of starch accumulation and distribution along the sago palm trunks at different growth stages is investigated. The contents and density of starch are analysed along five evenly distributed positions in sago palms at ten growth stages. The moisture content and the trunk density in relation to its starch content in these growth stages are also studied.

1.7.5 Flowering biology of the sago palm

Basic studies essential to facilitate future breeding and selection work is undertaken. The flower bud development, types of flower present, sequence and duration of flower opening, pollen size and pollen germination, mode of pollination, assisted self- and cross-pollination as well as fruit and seed set are investigated.

1.7.6 Germination of sago palm seeds

To increase the germination rate of the sago palm seeds, the effects of seed maturity, husk and flesh (sarcotesta) removal, chemical and physical treatments as well as humidity conditions are investigated.

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CHAPTER 2

FACTORS AFFECTING THE SURVIVAL RATE OF SAGO PALM SUCKERS IN THE NURSERY

2.1 INTRODUCTION

In Sarawak, suckers are conventionally used for planting in gardens owned by smallholder farmers and in plantations. This is mainly because they are true-to-type and faster in their subsequent establishment. Compared to suckers, seedlings derived from the same parent are variable in growth vigour, degree of thorniness and sucker producing capability (Jong 1991). Sago fruits are scarce in Sarawak as mature palms are normally harvested before fruiting. Also, the majority of sago palms in Sarawak produce seedless fruits.

Suckers are usually nursed for three to five months before field planting. However, during the wet season when rainfall is about 300 mm per month, direct planting is also practised. In 1987, the world's first sago plantation was established in Mukah by the Land Custody and Development Authority (LCDA). High mortality rate of the suckers in the nurseries was encountered (Plate 1).

Because of the great demand for planting material by the plantation, suckers have to be purchased from distant areas, some of them even a few hundred kilometers away. Apart from this, contractors supplying sago palm suckers purchase them from different farmers and gather them in sufficient quantity before they are sent to the plantation. By the time the suckers arrive at the nursery site of the plantation, some of them may have been collected (i.e., separated from the parent palm) a few weeks earlier. Such a delay in planting is believed to contribute to the high mortality rate.

In view of this, factors affecting the survival of sago palm suckers are investigated to find ways of reducing sucker mortality during the nursery stage.

2.2 LITERATURE REVIEW

Schuiling and Flach (1985) illustrated how a sago palm sucker should be extracted and pruned. They reported that the sucker should be about one year old, with base diameter of about 10-15 cm (about 2 kg) and leaves of about 3 m long. It should also be easily removable, preferably taken from the parent palm that is about to be harvested. The sucker should be removed from the parent palm with a clean vertical cut (Flach 1977, Schuiling and Flach 1985) and a large part of the runner (the rhizomatous prostrate stem part) must remain attached to serve as food reserve (Kueh

1977, Schuiling and Flach 1985). Sufficiently well-developed and undamaged roots should remain on the sucker (Flach 1984). It is also desirable to rub the cut-end with wood ash (Schuiling and Flach 1985). The extracted sucker is left to dry a little (Johnson and Raymond 1956), but the roots must be prevented from drying out (Flach 1984) before planting. All the fronds are trimmed except the spear and the youngest frond (Morris 1953, Kuèh 1977, Flach 1977).

The sucker is planted in a 30 cm x 30 cm x 30 cm hole (Flach 1984) with the cut-end placed at right angle to the soil (Flach 1984). It should be well shaded (Nicholson 1921, Flach 1984) and can either be nursed or directly planted as practised in Batu Pahat, Johore (Flach 1984).

2.3 MATERIALS AND METHODS

2.3.1 Sucker preparation

Unless stated otherwise, the following procedure was used in the preparation of sago palm suckers. Suckers of about 2 kg in weight (8-10 cm in base diameter) were chosen. Each sucker was separated from the parent palm at the narrow and woody section (neck) of the rhizome with a wedge shaped tool. The soil around the sucker was removed and roots were severed to facilitate extraction. After extraction, the roots were trimmed to about 5 to 10 cm. Fronds, including the spear, were trimmed to about 30 cm from the base (Fig.1).

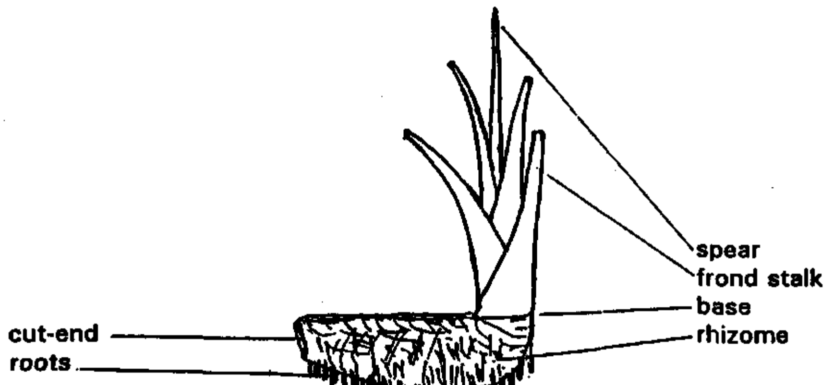

Fig 1. A sago palm sucker prepared for the nursery

2.3.2 Nursery techniques

Unless stated otherwise, the following procedure was practised. Suckers, collected in the manner described above, were planted in the nursery within two days of preparation. Nurseries were sited on peat where the water table was close to the surface. Planting was done in the rainy season at the end of 1991.

Stumps and logs were removed before the soil was leveled. Small trenches about 30 cm wide and 10 cm deep were dug and suckers were arranged to sit on the bottom of the trench. The cut-end of the rhizome was loosely covered and spaces between the rhizomes were filled with soil to anchor the suckers firmly.

2.3.3 Number of replications and size of experimental units

Unless stated otherwise, each treatment was replicated three times and 10 suckers were used in each replicate.

2.3.4 Assessment of survival rate

After four months in the nursery, the number of suckers that survived in each treatment was recorded. The results were subjected to one-way analysis of variance. Observations related to the survival of suckers were also made during and at the end of the experiment.

2.3.5 Factors investigated

The effects of the following factors on the subsequent survival rate of sago palm suckers were investigated.

2.3.5.1 Duration and shading condition of sucker keeping

Suckers were stored at six different durations as follows, under shaded and unshaded conditions.

(i) Suckers kept for zero day (planted immediately).
(ii) Suckers kept for three days
(iii) Suckers kept for seven days
(iv) Suckers kept for 14 days
(v) Suckers kept for 21 days
(vi) Suckers kept for 28 days

Shading was provided by covering them with a dense single layer of sago palm leaves so that direct sunlight on the suckers was almost completely cut off. Unshaded suckers were kept in the open field in heaps exposed to the sun.

2.3.5.2 Rhizome trimming and subsequent duration of sucker storage

The rhizome of sago palm suckers was trimmed to five levels , i.e.,10, 15, 20, 25 and 30 cm. They were kept for one day and two weeks respectively before they were planted in the nursery as described under (2.3.2).

2.3.5.3 Root trimming

Suckers were prepared as described in (2.3.1) except that the roots were trimmed to different lengths of 1, 5 and 10 cm. They were nursed in the same manner as described under (2.3.2).

2.3.5.4 Depth of planting

Suckers as prepared in (2.3.1) were planted as follows:

(i) Sitting on the soil surface
(ii) The lower half of the rhizome buried
(iii) Whole rhizome just completely buried
(iv) Rhizome buried about 8 cm below the soil surface

2.3.5.5 Shading of suckers in the nursery in the wet and dry season

Suckers were established in the nursery with and without shade during August and December, representing the dry and wet seasons respectively. The rainfall for August and December was 87 and 391 mm respectively. Overhead shade was provided by a layer of sago palm fronds and were in the East and West directions. The amount of shade was not measured but was estimated to be about 50%. Twenty suckers were used in each replicate.

2.3.5.6 Treatments of cut-ends of the rhizome

The cut-ends of sago palm suckers as prepared in (2.3.1) were treated as follows:

(i) dipped in wood ash
(ii) dipped in 1% benomyl powder (fungicide) diluted with talcum powder
(iii) dipped in 1% carbofuran granule (systemic insecticide)
(iv) dipped in a mixture of 1% benomyl and 1% carbofuran
(v) control (no treatment)

Suckers treated as described above were divided into two lots. One lot was planted on the same day and the other left for two weeks in an open field before planting in the nursery in the manner as described.

2.3.5.7 Methods of sucker handling

Sago palm suckers were extracted in the manner as described in (2.3.1) except that the fronds were trimmed in the following manner. Twenty suckers were used in each replicate.

(i) all fronds were trimmed to about 30 cm in length except for the spear which was left for handling. Trimming was done during extraction and these suckers were carried by the spear during transportation to the experimental site.

(ii) fronds including the spears were trimmed to 30 cm except for an older frond which was trimmed to a longer length for handling. Suckers trimmed and handled by the above methods were planted in the nursery as described in (2.3.2).

2.4 RESULTS

2.4.1 Duration and shading condition of sucker storage

Both the duration and the condition of keeping suckers affected their subsequent survival rate (Table 1).

Table 1. The survival rate of sago palm suckers stored for different periods under shaded and unshaded conditions

Duration of storage (days)	Survival rate (%)	
	Shaded	Unshaded
0	86.0 b	93.0 d
3	93.3 b	90.0 d
7	93.3 b	56.3 bc
14	80.0 b	60.3 cd
21	56.7 a	26.7 ab
28	60.0 a	13.3 a
S.E. (dif.)	6.9	14.1
C.V. (%)	10.8	30.0

Note: In all the tables presented in this chapter, figures followed by different letters differ significantly at p = 0.05 by DMRT.

2.4.2 Rhizome trimming and subsequent duration of storing suckers

The length of rhizomes remaining on the suckers affected their survival in the nursery significantly (Table 2). Increased rhizome trimming appeared to reduce the viability of suckers stored for two weeks before planting.

Table 2. The survival rate of suckers with rhizomes trimmed to different lengths and stored for different periods before planting

Length of rhizome left attached to the sucker (cm)	Survival rate of suckers (%) stored for	
	1 day	14 days
10	80.0 ab	13.3 a
15	63.3 a	36.7 ab
20	76.6 ab	56.7 bc
25	93.3 b	83.3 d
30	93.3 b	76.7 cd
S.E. (dif.)	7.6	0.7
C.V. (%)	11.4	24.7

2.4.3 Root trimming

No significant difference was observed in the survival of suckers when roots were trimmed to different lengths and promptly planted (Table 3).

Table 3. The survival rate of suckers with roots trimmed to different lengths

Root length after trimming (cm)	Survival rate (%)
1	90.0 a
5	93.3 a
10	90.0 a
S.E. (dif.)	3.8
C.V. (%)	5.1

2.4.4 Depth of planting

The depth of planting significantly affected the subsequent survival rate of sago palm suckers. When the rhizomes were half or just completely buried in the soil, 90% of them survived. However, when they were sitting on the soil or buried to a depth 8 cm below the soil surface, their survival rates were markedly reduced (Table 4).

Table 4. The survival rate of sago palm suckers planted at different depths

Depth of planting	Survival rate (%)
Rhizome sitting on soil surface	76.7 ab
Rhizome half buried on lower side	90.0 a
Rhizome just completely buried	90.0 a
Rhizome buried 8 cm below soil surface	70.0 b
S.E. (dif.)	7.4
C.V. (%)	11.4

2.4.5 Shading of suckers in the nursery during wet and dry seasons

During the dry season, shading of suckers in the nursery appeared to enhance their survival rate although the results were not conclusive. However, their rate of survival was reduced during the wet season when suckers were shaded. The highest survival rate was obtained when suckers were planted without shade during the wet season (Table 5).

Table 5. Effects of shading on the survival of suckers during wet and dry seasons

Shading condition	Survival rate (%)	
	Dry season	Wet season
Shaded	83.3 a	66.7 b
Unshaded	66.7 a	90.0 a
S.E. (dif.)	29	6.7
C.V. (%)	23.6	5.2

2.4.6 Treatments of cut-ends of rhizome

When newly collected suckers were used in the nursery, ash and chemical treatments did not enhance or depress their survival rate to any significant extent. However, benomyl and a mixture of benomyl and carbofuran enhanced the survival of suckers kept for two weeks before planting (Table 6). Carbofuran or ash alone did not increase the survival of stored suckers.

Table 6. Effects of chemical treatments on the survival of sago palm suckers

Cut-end treatment	Survival rate of suckers (%)	
	Newly prepared	Kept for 14 days
Ash	76.7 a	63.3 b
Carbofuran (1%)	93.3 a	66.7 ab
Benomyl (1%)	83.3 a	83.3 a
Carbofuran (1%) + benomyl (1%)	86.6 a	80.0 a
Control	70.0 a	66.7 ab
S.E.(dif.)	14.8	8.9
C.V.(%)	22.0	15.4

2.4.7 Methods of sucker handling

The survival rate of the suckers was not significantly affected by different ways of handling (Table 7).

Table 7. The survival rate of sago palm suckers handled by different methods

Method of sucker handling	Survival rate (%)
By the spear	78.3 a
By the frond stalk	93.3 a
S.E.(dif.)	13.7
C.V.(%)	9.8

2.5 DISCUSSION

2.5.1 Duration of storing suckers under shaded and open conditions

The results in Table 1 confirmed the speculation that the survival rate of sago palm suckers in the nursery could be enhanced by using freshly prepared suckers. This agrees with the recommendation of Flach (1984). To achieve higher sucker survival, they should be planted in the nursery within three days of extraction. If suckers have to be obtained from a distant place, shading while awaiting and during transportation would reduce the mortality rate considerably. It was observed that when extracted suckers were exposed to the sun in an open field, dehydration of rhizomes and frond stalks occurred gradually. Once a sucker was dehydrated, its viability was correspondingly reduced.

It was further noticed that a jelly-like exudate appeared on the cut-ends of the rhizomes. Such exudate is believed to be a wounding response and has some protective functions against microbial infection. If suckers were kept moist continuously such as by shading, watering or prompt planting in the soil, the jelly-like exudate remained on the cut-end for several days. However, the exudate dried up rapidly when the suckers were exposed to the sun in an open field.

When dying suckers were split open along the rhizome, it was frequently observed that browning of the tissue in the rhizome occurred and this initiated from the cut-end. Such browning (decaying) was more pronounced in dehydrated suckers exposed to the sun in an open field.

When suckers were shaded, the loss of viability was reduced. This is probably due to the reduction in dehydration and lowering of the surrounding temperature, making it less susceptible to microbial activities.

2.5.2 Rhizome trimming and subsequent duration of sucker storage

In normal cultivation of sago palms in Sarawak, suckers are extracted with a fair portion of the rhizome attached. The sucker is usually separated at the woody and somewhat constricted 'neck' region. Local sago farmers believe that such a method of sucker extraction will enhance its subsequent survival. The findings in this study confirm the farmers' belief and agree with the reports of Kueh (1977), Flach (1984), Schuiling and Flach (1985). Suckers with longer rhizomes survived better, especially when delay in planting was encountered. The enhanced viability could be due to the presence of greater food reserve. It could also be due to the protection of the growing point from dehydration and disease attack which frequently started from the cut-end.

Although it was shown that suckers with longer rhizomes survived better, it is not always practical to obtain suckers with long rhizomes. Besides, suckers with excessively long rhizomes are more bulky and heavy to transport. This is especially so when they have to be hand-carried to the field as practised during transplanting in the Mukah Sago Plantation. As a general guide, suckers should be separated from the parent at the constricted 'neck' of the rhizome. Sometimes where the 'neck' is absent, suckers should be extracted with a rhizome length which is about twice its diameter.

2.5.3 Root trimming

In conventional practice, roots on the lower side of the rhizome are trimmed to about 5 - 10 cm. This experiment has demonstrated that root trimming to 1 cm did not affect the subsequent survival rate of suckers planted promptly after extraction. Examination of the surviving suckers showed that new roots generated equally well and in similar numbers in all the three trimming treatments. This is different from the reports of Flach (1984) and Schuiling and Flach (1985) that well-developed and undamaged roots should remain with the sucker. The implication from this study is that the bulk of suckers for nursery can be reduced by root trimming to ease transportation and handling.

2.5.4 Depth of planting

In Sarawak, making proper planting holes for the cultivation of sago palms as described by Flach (1984) is not commonly practised. On undrained peat subject to occasional deluge, such a planting system leads to the drowning of some newly planted suckers. On muddy soil or peat, planting is simplified by pressing the rhizome partially into the soil. This anchors the sucker and keeps the cut-end and part of the rhizome in the soil. Sometimes, suckers are just seated on shallow impressions made on the soil by trampling and supported by two sticks stacked obliquely in opposite direction over the rhizome.

The results (Table 4) showed that the highest survival rate was obtained from suckers with rhizomes half or just fully buried in the soil. This finding agrees with those methods practised by local farmers. If suckers were just seated on the soil surface, some of them were dehydrated under dry condition. The cut-ends of some rhizomes were mouldy and attacked by sago worms (*Rhynchophorus shach*). When rhizomes were buried 8 cm below the soil surface, rotting of the meristem and young shoots was occasionally found. This could probably be due to suffocation when they were submerged in water during continuous heavy rainfall.

2.5.5 Shading of suckers in the nursery during wet and dry season

In sago palm cultivation by smallholders in Sarawak, suckers are nursed in drains or floating rafts in small numbers. Artificial shade is not provided but some natural shading by vegetation in the surrounding areas is very common. In contrast, nurseries in the LCDA plantation are sited in the open where shading is not available.

As indicated in Table 5, shading appeared to promote the survival of sago palm suckers in the drier months. However, the results were not conclusive and should be repeated with more replications.

From field observations, most of the sucker mortality was encountered in the first month of planting, mainly due to dehydration of suckers in the open field. This is the critical establishment period when the suckers need protection from dehydration and disease attacks before new roots are formed.

Shade was not necessary in the months with heavy rainfall as 90% of the suckers survived without it. Shading of suckers in the wet season caused decay of fronds and growing points in some suckers.

2.5.6 Treatments of cut-ends of rhizome

At the nursery site, fungal growth was common on the cut-ends of some sago palm rhizomes. *Penicillium*, *Mucor* and *Aspergillus* were the predominant species (T. K. Kueh, pers. comm.).

In this experiment, ash treatment showed no beneficial effects on the survival of sago palm suckers. Treatment with a broad spectrum fungicide such as Benomyl greatly reduced their mortality rates. The effect was more pronounced in suckers stored for a period before planting. The occurrence of mouldiness was greatly reduced in treated suckers. Treatment with 1% carbofuran or ash alone did not increase the survival rate, probably because pests were not present during the experimental period. When fresh suckers were used in the nursery, the effects of various treatments were inconclusive. Somehow, the survival rate in the control was lower than usual, for reasons undetermined.

In general, no treatment is given to the extracted suckers by most sago farmers in Sarawak. Brief sun drying (Johnson and Raymond 1956, Flach 1984, Schuiling and Flach 1985) is not practised either. Extracted suckers are usually put in a drain or on a floating raft within a few days and the mortality rate is very low. This, coupled with the finding in this experiment, suggests that chemical treatments of suckers may not be necessary if they are planted promptly. In areas where incidence of pests and diseases is high, appropriate chemical treatments will be necessary.

When suckers have to be kept while awaiting transportation, treatment with a wide spectrum fungicide would be essential to reduce death caused by fungal attacks. Treatment with insecticide would be beneficial as a preventive measure against sago worm infection.

2.5.7 Methods of sucker handling

In Sarawak, most farmers carry the sago palm suckers by the frond stalks rather than by the spears. It is believed that handling by the spear would cause damage to the growing point at the base of the spear. From the current study, an insignificantly lower rate of sucker survival was recorded when they are handled by the spear. This suggests that suckers of the size used in the experiment could be safely handled by the spear. In palms where sharp spines are present on the frond, handling by the spear which is spineless would be more convenient. However, to handle heavy suckers by the spear may cause injury to the young growing point below it as the weight supported by the spear would be greater.

It was observed that suckers with spears produced leaves faster. This may be conducive to the establishment of the palm. However, the spears are usually broken during transportation where rough handling becomes a standard practice in plantation. In current practices, pruning of all fronds except the spear and the youngest frond (Kueh 1977, Flach 1977, '84, Schuiling and Flach 1985) is uncommon in Sarawak. All fronds including the spear are pruned, except one older frond which is pruned to a longer length for handling.

2.6 CONCLUSIONS

To increase the subsequent survival rate of suckers either in the nursery or in the field, the following measures are recommended as indicated from the above findings:

(a) Suckers should be separated from the parent palm at the 'neck' region. If this is absent, sucker should be extracted with a length of rhizome attached to it, of approximately twice its diameter.

(b) For a sucker of about 2 kg, roots should be trimmed to 1 - 2 cm.

(c) Suckers should be planted promptly, preferably within three days, after extraction.

(d) If delay in planting is unavoidable, the suckers should be kept in a cool and moist place such as under heavy shade. A wide spectrum fungicide should be used to treat the suckers, especially the cut-ends of the rhizomes. Storage of suckers for more than two weeks should be avoided.

(e) Suckers should be planted by partially or just completely burying the rhizome in the soil. The cut-end of the rhizome should be covered to avoid dehydration and pest attack.

(f) In the dry season, a nursery should be sited in a place where there is ample soil moisture. It is important to keep the rhizome moist all the time. A nursery surrounded by natural shade would be beneficial in the dry season. Shading of suckers in the wet season is undesirable.

(g) Direct planting in the field can be practised in the rainy season when the water table is high. However, freshly extracted suckers should be used.

With the practices mentioned, the survival rates of suckers in the field can be increased to as high as 90%. This will substantially reduce the cost in nursery establishment due to high mortality rate of suckers.

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CHAPTER 3

EFFECTS OF SUCKER SIZE ON THE ESTABLISHMENT OF SAGO PALMS

3.1 INTRODUCTION

In Sarawak, sago farmers prefer larger suckers for planting, usually with a base diameter of 10-20 cm. This is because they believe that larger suckers establish faster in the field.

When a sago plantation was established in Mukah, Sarawak, in 1987, large suckers were preferred based on the above belief and practices. As large suckers are less abundant, more difficult to extract and transport, a shortage of supply of this kind of suckers to the plantation was experienced. This resulted in a price hike of planting material and caused some social problems such as theft of planting materials in some villages.

In view of this, a field experiment was laid down in early 1987 to study the growth and development of sago palms established from suckers of different sizes. Upon completion of this study, it is hoped that a recommendation on the use of optimal sized suckers may be made. This should benefit the new sago plantations which are anticipated to emerge fast in Sarawak.

3.2 LITERATURE REVIEW

In Batu Pahat, Johore, a trimmed sago palm sucker ready for planting is about 2 kg and has a base diameter of 10-15 cm (Flach 1984, Schuiling and Flach 1985). The use of 3 kg suckers has been reported in sago palm plantations at Rangsang Island, Riau (Tampubolon and Hamzah 1988). Well-developed suckers of less than one year of age are suggested by Morris (1953). Kueh (1977) and Flach (1984) reported that large suckers would probably establish more rapidly and mature faster. However, suckers with stem diameters of 10-13 cm are most convenient to handle (Kueh 1977). For nursery in polybags, Schuiling and Flach (1985) suggested the use of smaller suckers as the greater ease of handling might outweigh the lower survival rate of smaller suckers. Besides, in a well cared for nursery, the difference in survival rate between big and small suckers would be smaller than in the field (Schuiling and Flach 1985).

In the Sungai Talau Sago Research Station of the Department of Agriculture, Sarawak, suckers of about 2 kg are used in most of the trials (Anon. 1987-'90). In most farmers' holdings in Sarawak, suckers of varying sizes are used but most farmers prefer bigger ones as they claim that bigger suckers establish faster after planting.

3.3 MATERIALS AND METHODS

Seven sets of sago palm suckers, each consisting of five suckers of diameters 5, 10, 15, 20 and 25 cm (measured at the base of the stem) were chosen. Each set was taken from a single parent palm in order to minimise genetic variation. The suckers were extracted with a good portion of the rhizome attached, as practised by farmers in Sarawak. Fronds were trimmed at about 20 cm above the growing point and roots to about 5 cm in length. The weights of these suckers were recorded before they were put in a nursery.

After about four months in the nursery, five sets of healthy growing suckers were selected out of the seven sets. They were planted on deep peat under minimal drainage condition at the Sungai Talau Research Station, at a square spacing of 7.5 m x 7.5 m in a Latin square design. Fertilizers were added annually at the rate of 0.35 kg N, 0.5 kg P_2O_5 and 0.9 kg K_2O per cluster in the forms of ammonium sulphate, Christmas Island rock phosphate and muriate of potash respectively during the drier periods of the year. Weeding was done twice yearly and sucker growth was regulated to one in every 18 months.

The annual rate of frond emergence was determined by marking any fronds formed within a year with paint of a particular colour. At the end of 1993, the following growth parameters of palm development were recorded.

(a) The base diameter of the palm measured with a measuring tape around the outer circumference of the base just above ground level.

(b) The palm height measured from ground level to the tip of the youngest fully-opened frond.

(c) The length of the oldest living frond measured from the base of the petiole to the end of the rachis.

(d) The circumference of the rachis of the oldest living frond, measured around the rachis at a position just below the lowest pair of leaflets.

(e) The visible height of the trunk measured from ground level to the base of the leaf sheath of the oldest living frond.

The collected data was analysed by Genstat 5 Programme (release 2.2) developed by the Lawes Agricultural Trust, Rothamsted Experimental Station.

3.4 RESULTS

3.4.1 The size and weight relationship of suckers

The weight of suckers increased exponentially with their base diameter (Fig.1). The range of mean weight for suckers of 5 to 25 cm in base diameter was 1 to 28.7 kg.

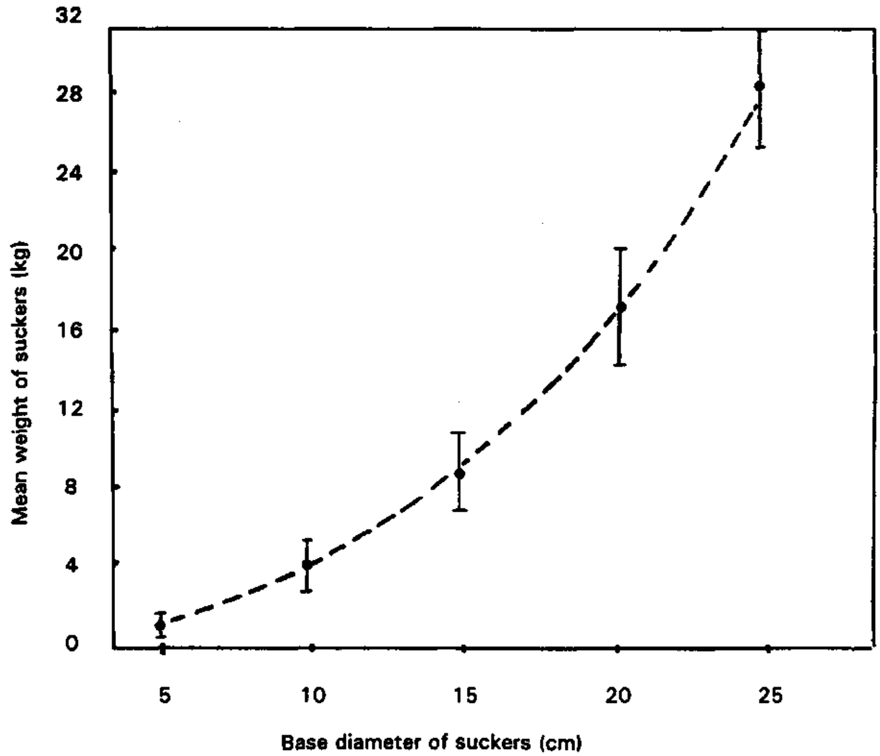

Fig. 1. The size-weight relationship of sago palm suckers used for planting

3.4.2 Effects of sucker size on the annual rate of frond production

The rate of frond production was not analysed in 1988 although it appeared that palms established from the 5-cm suckers were slower in frond formation, as shown in 1989. From 1990 to 1993, the frond production rate of all the palms established from different sizes was not significantly different (Table 1).

Table 1. Rate of frond emergence in sago palms established from suckers of different sizes.

	Rate of frond emergence (no. $palm^{-1}$ $year^{-1}$)					
Base diameter of suckers (cm)	1988	1989	1990	1991	1992	1993
5	5.0	8.6	12.1	11.6	10.6	8.8
10	7.5	10.0	11.6	10.6	9.4	8.2
15	8.0	11.4	11.8	12.4	10.2	8.8
20	8.4	11.8	12.2	12.4	9.8	8.8
25	8.6	12.2	11.8	12.2	9.0	8.6
S.E. (dif.)	-	1.1	1.5	0.8	0.8	0.6
C.V. (%)	-	16.3	12.5	10.9	13.2	10.8

3.4.3 Effects of sucker size on other growth parameters

The rachis girth, frond length, palm height, base diameter and trunk length recorded in 1993 showed significant linear response to different sizes of suckers(Table 2). In general, all these parameters increased linearly with increased size of suckers that they were established from.

Table 2. Mean growth parameters of sago palms in response to different sizes of suckers used for planting, in the 6th year after planting.

Base diameter of sucker (cm)	Rachis girth (cm)	Base diameter (cm)	Palm height (cm)	Trunk length (cm)	Frond length (cm)
5	16.6	42.0	695	36.0	536
10	16.4	41.2	743	33.4	550
15	20.0	51.0	769	72.0	582
20	18.6	49.6	774	76.0	591
25	19.4	50.4	812	79.0	597
SE (dif.)	1.4	3.7	49.8	21.9	32.6
C.V. (%)	11.9	12.4	10.4	58.4	9.0
F ratio (1,12) linear effect	6.5	9.5	5.7	6.9	5.0

3.5 DISCUSSION

The size-weight relation of planting suckers enables one to estimate their weight once their sizes are known (and vice versa). Smaller suckers show lower relative weight increase than the larger ones.

The rate of frond emergence has been taken as an important parameter to monitor palm growth. Kraalingen (1984) observed that sago palms had a reduced rate of frond production under wet conditions of growth. In this study, the rate of frond emergence increased gradually from 1988 to 1991 in all the palms regardless of the size of suckers that they were established from. The frond emergence rate declined after that, corresponding to the onset of trunk formation, in a similar trend as reported by Flach and Schuiling (1989). However, the frond production rate was lower than that of 24 in the rosette stage and 12 after the trunk formation as reported for palms grown under optimal conditions. The much lower rate of frond emergence could be due to palms being cultivated under sub-optimal conditions in deep peat or due to varietal differences of the sago palms used. Nonetheless, the rate of frond production from 1990 onwards was not significantly different among palms established from different sucker sizes. This indicates that sucker size used for planting has no significant influence on subsequent frond production rate.

The mean difference in trunk height between the tallest and the shortest palm in this trial is 45.6 cm. As the mean annual trunk increase of sago palms at Sg. Talau Station is 130cm, it suggests that the age difference between the tallest and shortest palms in this trial is about three to four months. This is supported by the observation that trunk formation in all the treatment palms started within the same year in 1993, about six years after planting.

In the current study, suckers of all five sizes established successfully in the field. Suckers of 15 to 25 cm in base diameter were in general superior in their subsequent growth to smaller ones with 5-10 cm in base diameter. This supports the reports of Kueh (1977) and Flach (1984) and confirms the farmers' claim that larger suckers (within the investigated range in this experiment) are superior in their subsequent establishment. Suckers with base diameter of 15- 25 cm are, however, both heavy and bulky to handle. The smallest of the lots, with base diameter 15 cm, is about 9 kg. This is more than four times the weight of those used for commercial planting in Batu Pahat, Johore as described by Flach (1984) and Schuiling and Flach (1985).

In smallholder sago palm cultivation, availability and transportation of large suckers are no problem as small quantities are collected each time from river banks or nearby gardens. The scenario changed when a sago plantation was established in 1987 in Mukah. The great demand for large suckers led to a temporary shortage of supply which caused a price hike. Besides, they had to be purchased from more remote areas which incurred additional costs.

In plantation operation, the advantage of using large suckers needs to be weighed against the additional expenditure incurred. Only if the former outweighs the latter, and if larger suckers are not in short supply, can they be used in the operation. As sago palms grown in organic soils in Sarawak mature in about 12 years or more (Lim 1991), a delay of 3-4 months in growth is of little importance. It may be compensated by cost saving for the purchase, handling and establishment of smaller suckers.

In Sarawak where sago plantations are expected to be fast expanding in the next decade, the demand for planting material will be tremendous. This, coupled with the high cost of transportation (poor road condition and long distances) will make the use of smaller suckers inevitable. Use of smaller suckers, weighing 2 kg for example, also offers the following advantages:

(a) it eases short-supply situation and reduces the price of planting material.

(b) it reduces costs of transportation, handling, nursery establishment and field planting.

Theoretically, if optimal-sized suckers cannot be found, use of materials close to the optimum is desirable. Again, this should be assessed in financial terms with the use of suckers even smaller than 2 kg which has been successfully adopted in sago palm cultivation in Batu Pahat (Flach 1984).

3.6 CONCLUSIONS

The findings in this study reflect that larger suckers of 15 to 25 cm in base diameters establish faster than those of 5 and 10 cm. Of the larger suckers, those with base diameter of 15 cm are more advantageous in terms of ease of handling and transportation. In practice, suckers of 15 -25 cm in base diameter are heavy, bulky and more expensive to handle. They may only be suitable for planting in smallholder gardens where a smaller quantity is needed and can be obtained from nearby places. For large scale planting, the advantages of large suckers have to be weighed in financial terms against other factors such as the availability of the material and the exponential increase in the costs of transportation, handling, nursery and field planting. Use of suckers with base diameters of 7 to 10 cm and corresponding weights of 2 to 5 kg will be more appropriate.

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CHAPTER 4

EFFECTS OF PLANT SPACING ON THE GROWTH AND DEVELOPMENT OF SAGO PALM ON UNDRAINED DEEP PEAT.

4.1 INTRODUCTION

Most of the sago palms in Sarawak are found in the Mukah and Dalat Districts, cultivated by the Melanau community in smallholdings as described in (1.5.1). Scientifically-proven appropriate planting densities have not been established, resulting in low trunk yield per unit area. Systematic monoculture of sago palms planted at 9.1 m square was only introduced by the Department of Agriculture in 1980.

This experiment was started in 1984 by Mr. Jaman Hj. Osman and handed over to me in 1986. In this study, the growth and development of sago palms at different planting densities on undrained deep peat is monitored. The main objective is to find out an optimal spacing for sago palm cultivation on deep peat to maximise crop yield per unit area.

4.2 LITERATURE REVIEW

Flach and Schuiling (1989) reported 7 m by 7 m square planting of sago palms in Batu Pahat, Johore on mineral soils. They (Flach and Schuiling, 1991) also calculated that the planting distance for the Sarawak type of sago palms should be 8 m by 8 m because of its higher number of leaflets than the Batu Pahat type. Sucker growth was regulated to two in every three years. In this manner, 25 tonnes of dry starch per hectare per year could be obtained in the first 5-10 years of harvest. It later declines to 15 tonnes per hectare per year. A similar yield was obtained when palms were spaced at 6 m by 6 m, with one sucker allowed to develop in every two years (Flach 1984). The same author (1977) also proposed planting of a filler palm in the centre of the interrows. This will be maintained at a single stem and harvested in seven years to maximise the use of sunlight and space in the early phase of establishment. Such a system will accommodate an initial density of 554 points per hectare.

Planting distance of 10 m by 10 m has been recommended (Anon. 1980, Wisastro and Asmataruna 1982, and Tan 1982). A planting distance of 6.1 m by 6.1 m was recommended by the Agricultural Extension Bureau in Batu Pahat, Johore. However, some growers changed it to 9.1 m by 9.1 m because the former was too crowded to work in and hindered the vigorous growth of palm (cited by Watanabe, 1986). Sato *et al* (1979) recommended plant spacing of 6 m by 9 m or 5-6 m by 14-15 m.

Kueh and Jong (1993) recommended a spacing of 8 m by 8 m in triangular pattern as it gives 15% more planting points per unit area than square planting. In a sago plantation feasibility study on deep peat, a triangular spacing of 7.5 m was recommended (Kueh *et al*, 1990).

In a sago palm cultivation subsidy scheme in Batu Pahat, West Johore, RISDA recommended a planting distance of 7 m by 7 m (quoted by Mohd Noh and Jamadan, 1991). Regardless of soil type, a square spacing of 9.1 m (30 feet) was recommended by the Department of Agriculture, Sarawak, in 1980. This was revised to 8.5 m square spacing in 1990.

In a survey made on peat soil at Rangsang Island, Riau, Tampobolon and Hamzah (1988) reported a plant spacing of 9 m by 9 m. There was a tendency to change this to 7 m x 15 m. In an old garden of 9 years 4 months with 175 clumps per hectare, the total number of trunks found in two varieties of sago palms, 'rumbia sago' and 'rumbia bemban', ranged from 179 to 303 per hectare. The trunk height ranged from 2.5 to 4.2 m and trunk diameter between 46 cm and 51 cm (or circumference of 144 to 160 cm).

All the recommendations or reports made on plant spacing were based on observations from existing sago planting. Properly designed spacing trials to decide the optimal planting density are lacking. In this study, early results of a sago palm spacing trial on deep peat are presented.

4.3 MATERIALS AND METHODS

4.3.1 Plant materials

A spineless cultivar of sago palm was used in this trial. Suckers of about 2 kg in weight were extracted by separation at the hard portion of the rhizome. The roots and fronds were trimmed to 5 cm and 30 cm respectively.

4.3.2 Nursery

A shallow trench of about 8-10 cm in depth was dug in peat with high water table. The prepared suckers were placed in the trench with the rhizomes arranged adjacently to each other in rows. The rhizomes of the suckers were partially or just completely covered with peat. They were nursed for about four months and healthy suckers were selected for transplanting to the experimental site on deep peat.

4.3.3 Spacing treatments and experimental design

Four spacing treatments were compared, viz., at 4.5 m, 7.5 m, 10.5 m and 13.5 m apart all in a square pattern. A randomised complete block design with three replications for each treatment was adopted. Field planting commenced in mid 1984.

The size of treatment plot was 0.35 hectare. In all the treatments, data was collected from recorded palms in the centre of each plot, about 0.07 hectare in area, surrounded by perimeter guard rows. The numbers of recorded palms were 4, 6, 12 and 36 for spacing of 4.5, 7.5, 10.5 and 13.5 m respectively.

4.3.4 Maintenance

Maintenance was confined to weeding, sucker regulation and fertilizer application. Row weeding was carried out twice a year in the first five years and once a year after that. Sucker growth was regulated to one in every eighteen months by selective pruning. Each palm cluster was given 0.35 kg N, 0.5kg P_2O_5 and 0.9 kg K_2O per year, as ammonium sulphate, Christmas Island rock phosphate and muriate of potash respectively. The fertilizers were applied during the drier months when the ground was not covered in water.

4.3.5 Data collection

The rate of frond emergence of the leader palm was recorded annually to indicate growth. This was done by marking all the fronds that emerged within a particular year with paint of a certain colour. Assessment of trunk growth began in 1990 when trunk initiated in some palms. The following growth parameters were also recorded from the leader palm in 1993:

4.3.5.1 Trunk height

This was measured from the ground to the sheath base of the oldest living frond on the trunk of the palm.

4.3.5.2 Circumference of trunk

This was measured at two places along the trunk, (i) at the base just above the ground level and (ii) at 1 metre above ground level (a.g.l.).

4.3.5.3 Crown size

The total number of living fronds in the crown was counted.

4.3.5.4 Circumference of rachis

This was measured at the point just below the first pair of leaflets of the oldest living frond.

4.3.5.5 Frond length

This was measured from the base of the frond stalk to the tip of the last leaflet. The oldest living frond in each palm was used.

4.3.5.6 Sucker number

The number of suckers produced from the leader palm was counted. Only suckers with base diameter of approximately 8 cm or more were counted.

4.3.5.7 Length of prostrate stem

This was measured from the end of the horizontal ground stem, to the point where the stem grew up to form a vertical trunk. Measurement was taken on the upper surface of the prostrate stem.

The pith volume of a palm with a bark of 1.2 cm was calculated as follows:

$$Vp = \pi(r-1.2)^2h/10000$$

where Vp = volume of pith (m^3), r = radius of palm trunk (cm) and h = palm height (m). The radius is measured at 1 m a.g.l.

Data collected was analysed with Genstat 5 (R2.2) Statistical programme.

4.4 RESULTS

4.4.1 The rate of frond production

In all treatments, the frond production rate was the highest after the first year of planting and declined gradually after that (Table 1). In the fourth and fifth years, the rate decreased significantly in the 4.5 m treatment. From the sixth year onwards, palms spaced at 7.5 m showed a significantly slower frond production rate as compared to the wider spacing treatments of 10.5 m and 13.5 m. The frond formation rate was the highest in the 13.5 m spacing treatment.

Table 1. Effects of spacing on the rate of frond production in sago palms

Spacing in square planting (m x m)	Rate of frond emergence (no. palm^{-1} year^{-1})							
	1985	1986	1987	1988	1989	1990	1991	1992
4.5	14.8	11.6	10.6	7.9	6.1	5.0	5.2	4.7
7.5	13.7	12.0	11.1	11.4	9.2	7.4	7.5	6.4
10.5	13.3	13.0	11.5	11.6	10.1	8.9	9.1	8.6
13.5	14.9	12.3	11.8	12.0	9.9	9.6	10.7	9.0
S.E. (dif.)	-	-	-	0.7	0.5	0.3	0.5	0.4
C.V.(%)	-	-	-	8.2	6.5	5.1	7.4	5.8

4.4.2 Effects of spacing on growth of crown, prostrate stem, fronds, suckers and trunk of sago palms

Response to the spacing treatments of the vegetative growth of the leader palm, as represented by the following parameters, is shown in Table 2.

4.4.2.1 Crown size

The crown size increased significantly with increased spacing treatments. The smallest crown of 5.3 fronds was found in the 4.5 m spacing and the largest crown of 10.3 fronds in the 13.5 m spacing. Intermediate crown size was found in the 7.5 and 10.5 m spacing.

4.4.2.2 Frond length and circumference of rachis

In general, palms spaced at 4.5 m and 7.5 m had significantly longer fronds than those spaced at 10.5 and 13.5 m. The longest fronds were found in palms spaced at 4.5 m. Palms spaced at 7.5 m had shorter fronds than palms at 4.5 m spacing but longer than those spaced at 10.5 m and 13.5 m. The shortest fronds were found in palms spaced at 10.5 m.

Significant differences in the circumference of the rachides were found between all except the 10.5 m and 13.5 m spacing treatments. The circumference increased in palms as spacing increased from the 4.5 m to the 10.5 m treatments.

Table 2. Parameters of vegetative growth of the leader palm at four different spacings, nine years after planting.

spacing (m xm) square	No. of fronds in crown	Frond length (cm)	Rachis circumf. (cm)	Number of suckers	Prostrate stem length (cm)	Trunk circumf'ce at base (cm)	Trunk circumf'ce at1 m a.g.l (cm)	Trunk height (cm)
4.5	5.3	730	18.7	11.3	115.8	146.6	111.2	282
7.5	7.2	703	21.3	23.4	148.7	174.4	128.6	298
10.5	9.2	641	24.0	30.0	172.1	172.7	139.7	314
13.5	10.3	668	24.4	23.0	167.5	176.8	140.3	300
S.E. (dif.)	0.8	20.2	1.2	2.0	10.1	6.0	3.1	35.2
C.V. (%)	7.6	2.9	5.3	9.1	6.7	3.6	2.4	11.8

4.4.2.3 Prostrate stem

Palms spaced at 4.5 m and 7.5 m had significantly shorter prostrate stems than those spaced at 10.5 m and 13.5 m. The prostate stems of palms spaced at 7.5 m was significantly longer than those in the 4.5 m treatment but shorter than those spaced at 10.5 m and 13.5 m. No significant difference was detected between the 10.5 m and 13.5 m spacing treatments.

4.4.2.4 Suckering ability

Significant differences in the number of suckers with a base diameter of approximately 8 cm or more were found between all except the 7.5 and the 13.5 m treatments. The number of the suckers was lowest in the 4.5 m spacing and highest in the 10.5 m spacing. Palms spaced at 7.5 m and 13.5 m had more suckers than the 4.5 m spacing but less than those spaced at 10.5 m.

4.4.2.5 Trunk height of leader palms

For leader palms that form trunks, the mean trunk height was similar in all the four spacing treatments.

4.4.2.6 Trunk circumference

Palms spaced at 4.5 m and 7.5 m showed significantly smaller trunk circumference at the base. When the trunk circumference was taken at 1 m a.g.l, the smallest trunk was found in the 4.5 m treatment. Trunk circumference at 1 m a.g.l of 7.5 m spacing treatment palms was significantly larger than that in the 4.5 m spacing treatment but smaller than those spaced at 10.5 m and 13.5 m. No difference was found in the 10.5 m and 13.5 m spacing treatments which possesed the largest trunk circumference at 1 m a.g.l..

4.4.3 Trunk formation capability

4.4.3.1 Trunk Number

Nine years after planting, only 35.2% of the leader palms spaced at 4.5 m formed trunks. Palms spaced at 7.5 m 10.5 m and 13.5 m registered a trunk formation of 80.6, 94.4 and 100% respectively. In addition, the average number of trunks formed from the follower palms were 5, 45, 137 and 110 per hectare respectively for palms spaced at 4.5 m, 7.5 m, 10.5 m and 13.5 m. The total number of trunks formed per hectare since planting were 179, 189, 223 and 165 respectively (Table 3). Trunk formation started in early 1990 and trunk yield was assessed in mid 1993. The trunk production per unit area and time over the past 3.5 years was 51, 54, 64 and 47 respectively for palms spaced at 4.5 m, 7.5 m, 10.5 m and 13.5 m.

Table 3. Effects of spacing treatments on trunk production of sago palms at nine years after planting. Trunk formation started at about six years after planting (1990) and trunk yield was assessed in mid1993.

Spacing (m x m) square	No. of points per ha.	% Trunk formation in leader palm	Leader trunks per ha.	Follower trunks per ha.	Total trunks per ha.	Trunks per ha per year
4.5	494	35.2	174	5	179	51
7.5	178	80.6	144	45	189	54
10.5	91	94.4	86	137	223	64
13.5	55	100	55	110	165	47

4.4.3.2 Total pith volume

The mean pith volume of the leader palms was smallest in the 4.5 and 7.5 m spacing treatments. The pith volume per hectare in the leader palms was highest in the 7.5 m spacing treatments. The highest total pith volume per hectare, however, was found in 10.5 spacing treatment, followed by 7.5, 13.5 and 4.5 m respectively (Table 4).

Table 4 Pith volume of sago palm trunks at different planting density treatments, nine years after planting.

spacing (m x m) square	Mean pith volume of leader palm (m^3)	Pith volume per hectare (m^3)		
		leader palm	follower palm	Total
4.5	0.21	35.7	0.98	36.7
7.5	0.30	43.5	9.94	53.5
10.5	0.38	33.0	35.9	68.9
13.5	0.37	20.8	29.2	50.0

4.5 DISCUSSION

Sago palms cultivated on deep peat were reported to possess fewer leaves showing all kinds of nutritional deficiency symptoms and were slower in growth (Flach 1977). It was said to reach maturity in 15-17 years as compared to 8-10 years on mineral soils (Johnson and Raymond 1956). In Sarawak, some palms established on peat can attain maturity in 12 years, as observed from palms cultivated at Stapok deep peat station (Kueh H.S. pers. com.) and at Sungai Talau Sago Research Station.

4.5.1 The rate of frond emergence

Under optimal conditions, sago palms in the rosette stage have a frond production rate of 24 per annum which declines to 12 per annum after the start of trunk formation (Flach *et al.* 1986, Flach and Schuiling 1989). However, in the current study, the frond production rate was much lower, i.e., 12 - 15 during the first three years of planting before trunks were formed. It slowed down to below 10 thereafter. The same holds true for most other palms grown on deep peat at Sungai Talau Station (Jong, 1987-1992). The longevity of fronds was between 8 and 13 months compared to Flach's report of 18 months (Flach, 1977, 1984). Such reduced frond longevity is probably due to the sub-optimal growth condition in deep peat. This is reflected by the small crown size and premature senescence of fronds (Jong 1988).

In this experiment, palms cultivated at higher densities had slower frond production rate, especially towards the later stage of growth when the canopy had closed. This was most obvious in palms spaced at 4.5 m when a drastic decrease in the frond production rate was noted in the fourth year before trunks were formed. This is most likely due to intense competition for light and nutrients at such close spacing.

A general decline in the rate of frond production in all treatments from 1989 was noticed. This is a common phenomenon in the transition between rosette and trunk formation stage, also found in palms in other experimental trials at Sungai Talau Station.

4.5.2 Effects of spacing on growth of crown, prostrate stem, trunk, fronds and suckers of sago palms

4.5.2.1 Crown Size

In this experiment, the number of living fronds on the palm crown was far less than 17 to 22 which Flach and Schuiling (1989) considered to be under optimal growth conditions . On riverine alluvial clay soils, the crown size of sago palm ranged from 15.3 to 23.7 (Mohd. Noh and Jamadon 1991). In Sarawak, a healthy palm grown on mineral soil usually possesses an average of 15 to 18 fronds, whereas those established on peat and under semi-wild condition have smaller crowns of about 10 to 15 fronds.

The crown sizes of palms spaced at 4.5 m and 7.5 m are very low indeed as compared to those palms in wider spacing treatments. This reflects that palm growth was very much retarded under high density planting.

4.5.2.2 Frond length and rachis circumference

The frond lengths of 641-730 cm in this study are within the range of 590-810 cm found on riverine alluvial soils (Mohd. Noh and Jamadon 1991). The long, thin and erect fronds found on palms cultivated at spacing of 4.5 m was most likely due to the early closure of the canopy, resulting in the etiolation of fronds. Intense competition for space, light and nutrients could have contributed to the smaller sizes of the rachides. Such observation was not obvious in palms spaced at 10.5 m and 13.5 m. The latter appeared to have normal rachis length and size.

4.5.2.3 Prostrate stem

Prostrate stem growth is a peculiar behaviour of sago palm probably to avoid over crowding and to produce a trunk at a favourable site. This behaviour is clearly observed in most of the sago palms at the Sungai Talau Station and has also been reported in Batu Pahat (Flach 1984). Kraalingen (1984) reported that there are differences in the rhizomes (equivalent to the prostrate stem reported here) of different varieties and those of 1 m are preferred for cultivation.

At high density planting of 4.5 m by 4.5 m, palms tend to grow upward nearer to the planting point, resulting in palms with shorter prostrate stems. The length of the prostrate stem may thus be determined by environmental factors rather than varieties

(Kraalingen 1984). This, however, did not accelerate trunk formation. Palms in a cluster with short prostrate stems at high density planting were over crowded, contributing to smaller trunk size and their inability to form trunks.

4.5.2.4 Suckering ability

The formation of suckers to enable a continuous supply of palms for harvesting is essential in sago palm cultivation. In this trial, palms spaced at 4.5 m produced very few suckers and almost all of them were thin and stunted, except for a few produced in the first few years of growth. Barely 1% of the suckers produced at this spacing treatment produced trunk after nine years.

Planted at 4.5 m by 4.5 m, a continuous supply of palms to replenish the harvested ones was not possible despite carefully regulated sucker pruning. In contrast, palms spaced at 10.5 m and 13.5 m had healthy suckers in various stages of growth, responding favourably to the scheduled staggered pruning regime. Suckers of palms spaced at 7.5 m, although plentiful, were generally smaller as compared to those in 10.5 and 13.5 m spacing treatments.

4.5.2.5 Trunk circumference

The trunk circumference at the base was smaller in palms spaced at 4.5 m. This reflects that spacing treatments were exerting their effects in the early stage of palm growth, before the trunk was formed. Palms spaced at 7.5 m were only affected at a later stage as reflected by the trunk circumference at 1 m a.g.l.. As the volume ($\pi r^2 h$) of the trunk is a measure of the starch content in a normal mature palm, a decrease in the trunk radius (r) signifies a quadratic (r^2) decrease in the starch content. The subsequent starch yield of palm trunks from 4.5 m or 7.5 m spacing will be expected to be lower than that cultivated at wider spacing unless they are substantially taller upon attaining maturity. The trunk size of palms spaced at 10.5 and 13.5 m was within the range recorded for healthy palms (Lim 1991, Jong, *loc. cit.*). However, they were generally smaller than those of 131-180 cm on riverine alluvial clay in Batu Pahat (Mohd Noh and Jamadan 1991) and 144-160 cm on peat at Riau (Tampubolon and Hamzah 1988).

4.5.2.6 Trunk height

As with other trials at the Sungai Talau Station, some palms started to form trunks at five to six years after planting. Other palms might be a bit slower, and yet some others were unable to do so even after ten years.

For palms that formed trunks, the average trunk height was similar despite different spacing treatments. At close spacing of 4.5 m, most of the trunks were formed in 1990 (5.5 - 6 years after planting) with very few trunks formed after that. For palms spaced wider apart, trunk formation was more gradual, spread over 1990 to 1993, thus contributing to the higher percentage of trunk formation as shown. In fact, trunks formed in palms spaced at 10.5 and 13.5 m were much taller than those formed concurrently in the 4.5 m spacing. The result presented here is the average height of all the trunks formed between 1990 and 1993 which does not reflect the trunk height variation in each spacing treatment. This average trunk height is within the range of 251-419 cm as reported on peat at Riau (Tampubolon and Hamzah 1988).

4.5.3 Effects of spacing on capability of trunk formation

4.5.3.1 Trunk Number

As sago palm trunks are harvested for starch extraction, it is most important for the cultivated palm to produce trunks. It is equally important that each palm can generate follower palms that can also produce trunks. This is to ensure a continuous supply of mature palms for subsequent rounds of harvesting. The above conditions are usually fulfilled in good sago palm holdings in Sarawak.

Palms cultivated at high density of 4.5 m spacing were severely restricted in their ability to form trunks (Plate 2). This happened to both the leader and the follower palms. Whatever planting density, trunk formation appeared to be regulated automatically through intense competition. In this study, trunk production in palms spaced at 13.5 m (55 palms ha^{-1}) was increased by the production of more trunks per cluster from follower palms (Plate 3). This gives a comparable yield to those palms cultivated at closer spacing of 4.5 m (494 palms ha^{-1}) where most palms were unable to form trunks.

Trunks produced from palms spaced at 7.5 m were rather small with only few follower palms capable of forming trunks. With palms spaced at 10.5 m, 94.4% of the leader palms would further their development to form trunks. Besides, an average of 1.6 trunks of normal size was formed from the follower palms per cluster, accounting for the highest trunk production per unit area among the four spacing treatments.

Watanabe (1986) reported that in existing sago gardens in Batu Pahat, Johore, 150-425 trunks of various growth stages were found per hectare. This can be calculated as 38-106 trunks per hectare per year with a mean of 74. The trunk yield in this study is lower but is expected to increase when the leader palms attain maturity because more followers will be produced. This will give a trunk yield comparable to the average figure of Watanabe (1986). The total trunk yield in the palms spaced at 10.5 m is comparable to those of 179-303 in 9 years 4 months' old palms on peat at Riau (Tampubolon and Hamzah 1988).

The most favourable spacing for sago cultivation on deep peat appeared to be 10.5 m, which yielded the highest number of trunks per unit time and area. Palms at wider spacing were unable to maximise land use whereas close spacing appeared to reduce trunk production. This finding agrees well with the reports and recommendations of Anon. (1980), Wisastro and Asmataruna (1982), Tan (1982) as well as the practices of planting at 30 ft by 30 ft by some farmers in Batu Pahat, Johore.

4.5.3.2 Total pith volume

The pith volume is an indication of the starch content in mature sago palm trunks. Smaller pith volumes of palms at 4.5 and 7.5 m spacing is mainly due to their small trunk sizes. Among the four planting densities, the total pith volume per hectare is highest in the 10.5 m spacing treatments (Fig. 1). This shows that maximum starch may be expected from palms grown at this spacing.

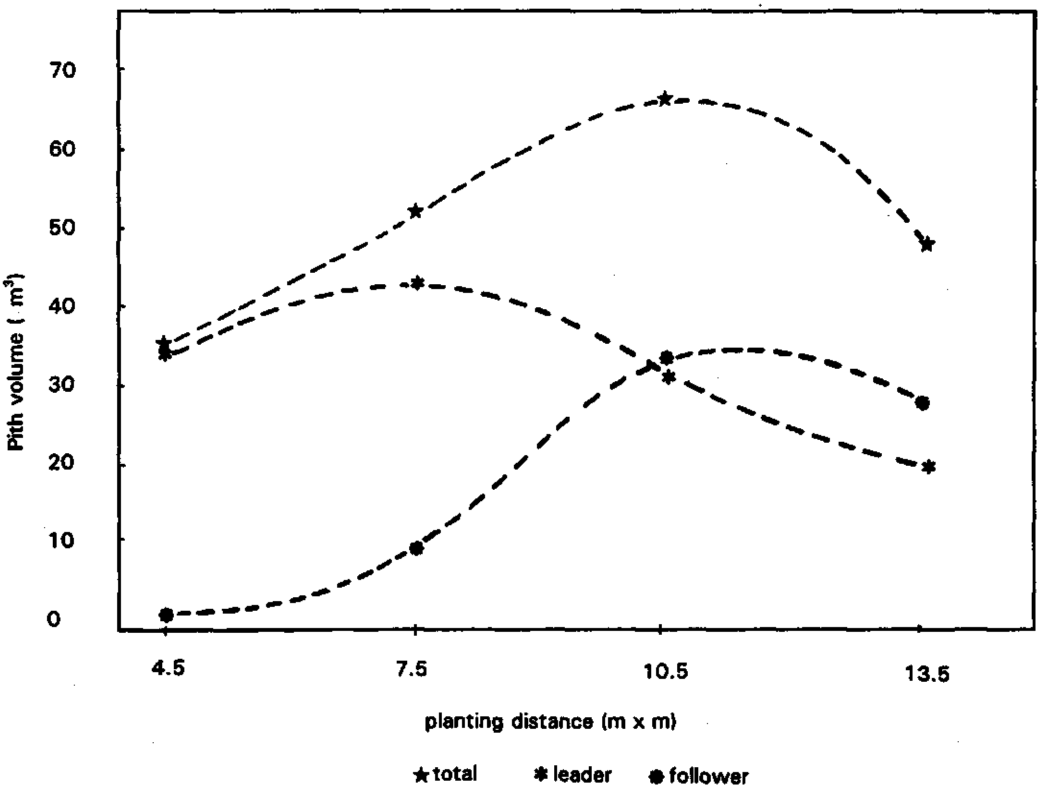

Fig. 1. Pith volume of trunk of sago palms cultivated at different square planting distance. (Although the palms are nine years old, no trunks are ready for harvesting yet.)

Although about 60 apparently healthy trunks were formed per hectare per year from palms cultivated at 10.5 m spacing on deep peat in this study, the quality of the trunk has yet to be determined. The normal yield of about 200 kg of dry starch per mature trunk (Lim 1991, Sim and Lim 1987) would not be expected as most of these palms were retarded. This is reflected by much fewer functional fronds on the crown.

4.5.3.3 <u>Application of findings to sago palm plantation</u>

Sago palms cultivated under the traditional system are doing reasonably well on mineral and shallow peat soils. This is probably because sago palms possess a very extensive root system that can extract nutrients from the soil efficiently (Kueh *et al* 1990). However, such yield is far from the estimated potential of about 34 tonnes (Flach 1977) and could be improved with improved agronomic practices such as proper spacing and fertilizer addition. The century-old traditional system of sago palm cultivation in Sarawak should be gradually revamped, by incorporating proper agronomic practices developed from research to close the yield gap.

A recent investigation by the author showed that a normal sago palm after trunk formation and grown in full sunshine had an average leaf area of 220 m^2. Under optimal conditions, a palm attains maturity in ten years. A full-grown palm cluster with sucker growth regulation at 1.5 to 2 years interval will consist of at least three full-sized crowns with two to three well-sized suckers of much smaller crown size. This will give a leaf area of about 900 m^2 per palm cluster. With an optimal leaf area index (LAI) of 7.5 (Flach 1984), the optimal number of palm clusters per hectare will be 83. This agrees quite well with the findings in this experiment.

The optimal LAI is only achieved when canopy closes. In the early phase of sago palm establishment, inter-palm space is not fully utilised. Suitable intercrops of economic value or another palm maintained at a single stem as described by Flach (1977) may be established. In new plantations in Sarawak, many stumps or felled timbers need to be cleared before planting. In this case, it is probably more economical to plant sago palms at 8 m by 12 m where clearing, management and maintenance is likely to be easier.

A 7.5 m spacing in a triangular pattern (205 palms ha^{-1}) was adopted by a sago plantation in Mukah, Sarawak. It is anticipated that the quantitative yield of trunk per unit time and area will not be advantageous over those planted at about 100 points per hectare. Cultivation of palms at higher density will incur higher investment cost but not necessarily getting the intended higher return, as the quantity and quality of the palm trunks produced will be poor. Therefore, the palm spacing needs to be readjusted following the leaf area index. For the existing palms planted at 7.5 m triangular spacing, suckers should be regulated to only one in each clump every five years. Another way is to regulate alternate palm to a single stem and harvest at maturity as proposed by Flach (1977). This would bring down the LAI close to the optimum and remove the possibility of suppression in trunk formation as reported in palms at close spacing.

4.6 CONCLUSIONS

Sago palms cultivated closely together have retarded frond formation, thin and long fronds, inhibited trunk formation and smaller trunk size. Regardless of the planting density, the number of trunks produced was between 47 and 64 per hectare per year, with the highest yield from palms cultivated at a density of 91 points per hectare.

Based on the above findings and coupled with the current practices of cultivating sago palms in peat with little agronomic input, it is suggested that the optimum planting density of sago palms on deep peat in Sarawak is around 100 points per hectare. Future research warrants a study to examine the interaction of fertilizer rate with planting density to provide a guideline for sustainable intensive sago cultivation on deep peat which has inherently low nutrient status.

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CHAPTER 5

DISTRIBUTION AND VARIATION IN STARCH AND MOISTURE CONTENTS IN SAGO PALMS AT DIFFERENT GROWTH STAGES

5.1 INTRODUCTION

Throughout the growth cycle of the sago palms, twelve growth stages are known by the local sago farmers in Sarawak. These are the rosette, trunk formation, early trunk growth (two stages), mid trunk growth, late trunk growth, full trunk growth, bolting, flowering, young fruiting, mature fruiting and dying stage. Sago palms are normally harvested for processing in between the full trunk growth stage and flowering stage. However, depending on the need for cash by farmers and permissiblity of weather conditions for sago log transportation, they may be harvested at a slightly younger or older stage. Palms harvested too much younger or older usually fetch lower prices. This is because experienced sago processing factory owners can judge quite accurately from the appearance of the trunk that these palms contain very little starch. However, there is still a dearth of scientific information in the following areas:

(a) Whether there is any starch in young palms and whether these young palms can be harvested to get an early return;

(b) The starch distribution in palms at different stages of growth, from trunk formation to dying stages;

(c) The relationship of fresh pith density and the contents of starch and moisture in it;

(d) The re-distribution of starch in the trunk as it approaches the end of its life span.

5.2 LITERATURE REVIEW

Variations in starch yield in sago palms at selected growth stages have been reported by Sim and Ahmed (1978) and Sim and Lim (1987). They believe that the best time for felling is between flowering and fruiting stage. Also, Johnson and Raymond (1956) reported that for maximum sago production, palms are best harvested after flowering and before fruit development. Lim (1991) found that the highest starch content is at the flowering stage although the starch yield is not different from the inflorescence emerging stage to the flowering stage. Flach (1973) and Flach *et al.* (1989) reported that in Batu Pahat, Johore of Peninsular Malaysia, palms are harvested before flower initiation at about eight years after planting.

Sim and Ahmed (1978) showed that starch was generally accumulated from the base upwards. The highest starch concentration is found between 1.5 - 6 m from the base and the lowest at the top of the trunk as it is probably used for flower and fruit development. Kraalingen (1984a) also reported that starch appears to accumulate from the base upwards in young palms. He found that at flower initiation, starch appears to travel upwards to settle anew at the top of the trunk. In Papua New Guinea, some Papuans remove the flower buds to retain the starch in the trunk for later harvesting (Barrau 1959). Lim (1991) found that the starch content from maximum vegetative to mature fruit stage is, in general, evenly distributed along the trunk except for the last part where the starch content decreased. The highest content is found at the base of the palm and the lowest at 1 to 2 m below the crown. Johnson and Raymond (1956) and Cecil *et al.* (1982) also reported likewise. The starch content (fresh weight) of sago palm in West Java varies between 18.8 and 38.8% and that more variation is noted longitudinally in the trunk (Wina *et al.* 1986).

The above conclusions were drawn from investigations made only on a part of the growth stages. Systematic investigation on the pattern of starch accumulation or mobilization over a complete range of the trunk development stages has not been fully reported.

5.3 MATERIALS AND METHODS

5.3.1 Plant materials

To minimise variability in growth due to differences in soil types and other factors, sago palms of the spineless cultivar were selected from a cultivated and properly maintained garden near Kampung Teh, Dalat. These palms were planted from suckers in 1978 on shallow peat (about 30 cm in depth) overlying clay subsoil. They were apparently healthy in growth. The actual ages of palms in the dying and mature fruiting stages were known from the planting date. The ages of other palms were estimated based on farmers' memory, experience and comparison with growth stages of nearby palms of known ages. Of the twelve growth stages described, only the later ten stages that possess visible trunks were chosen for this study (Table 1).

In addition, palms in stage 11 with abnormal (little or no) fruit development caused by damages to the inflorescence structures were also harvested for starch content determination. This was to find out whether removal or damaging of flower buds would delay the loss of starch in over-mature palms.

Table 1. Known stages of growth and development of sago palm in Sarawak.

Dev,t stage	Est'ed age from planting (yr)	Local name	Duration of trunk growth (yr)	Growth description
1	1 - 5.5	sulur	0	Rosette stage to the start of trunk formation- Sucker-like young palm without visible trunk.
2	5.5	angat burid	0	Starting of trunk formation - A transition between rosette and trunk growth. Short trunks are found upon removal of dead sheaths at the base of the palm at ground level.
3	7	upong muda	1.5	Young Trunk Growth - Trunks are about 1-2 m in length.
4	8	upong tua	2.5	25% Trunk Growth - Trunks are about 2-5 m in length.
5	9	bibang	3.5	50% Trunk Growth - Trunks are about 4-7 m in length.
6	10	pelawai	4.5	75% Trunk Growth - Trunks are about 6-8 m in length.
7	11.5	pelawai manit	6	Full Trunk Growth - Full growth of harvestable trunk (7-14 m). Leaves become erect and small at the palm terminal. Appearance of whitish colouration on the stalks of these fronds.
8	12	bubul	6.5	Bolting - Appearance of torpedo shaped flowering structure at the palm terminal. It is characterised by the elongation of the trunk at the top of the crown and frond reduction to bract-like structures.
9	12.5	angau muda	7	Flowering - Well-developed flowering structure with primary, secondary and tertiary flowering axes spreading out at the terminal. Flowers are in the pre- or post-anthesis stage.
10	13	angau muda (same as stage 9)	7.5	Young fruiting - Fruits are about 20-30 mm in diameter. Endosperms of the seeds (if any) are still soft and small. Most fronds are still intact and presumably functional.

11	14	angau tua	8.5	Mature fruiting - Fruits are mature, of diameter 30-40 mm. Seeds (if any) are well developed with dark-brown seed coat and bony endosperms. Most fronds are in senescent stage.
12	14.5	mugun	9	Dying stage - Most fruits have been shed and all fronds are in senescent stage.

5.3.2 Sampling

Depending on availability, three or more palms of each of the above growth stages were felled just above ground level by means of a chainsaw. The length of the trunk was measured from the point of felling to the sheath base of the oldest living frond to represent the harvestable trunk. Trunk samples for starch and moisture content determination were taken from five evenly spaced sampling points along the trunk. The sample nearest to the base was named No. 1 and that closest to the crown, No. 5. This was to reflect the longitudinal distribution of starch and moisture from the base to the top of the trunk in each growth stage of uneven trunk length. If samplings were done at fixed intervals, say, at 1 m, only two or three samples could be taken from very young palms. If sampling was done at closer intervals of 0.5 m, twenty or more samples would have to be taken and analysed from palms with long trunks. This was beyond the financial capacity of this project.

A disc of about 2 cm thick was cut out at each of the sampling points and put in a properly labelled polythene bag. The trunk was further cut into convenient lengths (if required) to determine the total weight of the harvestable trunk.

5.3.3 Starch extraction

From the sample discs collected, a segment of about 500 g was excised for analysis and its weight determined. The remaining discs were saved for moisture determination. From the segment, the bark (about 10 to 12 mm thick) was separated from the pith by a chopper. The weight and volume of the bark and pith were determined, the latter by water displacement. The bark was not used for starch extraction as it is too hard to process and contains little starch (Cecil, 1982).

The pith was chopped into about one cm^3 cubes and ground in a motorised grinder with an equal volume of water until it was well broken up. The content was then poured through a piece of bag-shaped nylon sieve (of about 200 μm mesh size) placed on top of a plastic pail. The starch was extracted by squeezing the nylon bag with the content in several washes of water until the liquid passing out of the nylon sieve became clear and no more starch could be squeezed out of the hampas[1]. The filtrate collected was left to settle in a pre-weighed aluminium tray. After the starch had settled completely at the bottom, excess water was decanted. The tray with the starch was dried in an oven at 68^0 Celsius[2] for 12 hours, following a procedure established at the Agricultural Research Centre, Sarawak. The weight of the dry starch was then determined immediately after removal from the oven to prevent the absorption of moisture from the atmosphere.

5.3.4 Moisture determination

From the remaining discs, a segment of about 200 g was excised. The bark was separated from the pith in a manner as described earlier and the fresh weight of both fractions was determined separately by weighing. Their volumes were determined by water displacement. Both the bark and the pith were chopped into small pieces of about 5 mm in thickness and dried in an oven at 100^0 Celsius until no further weight loss.

5.3.5 Determination of the size of starch granules

The lengths of starch grains were determined using a microscope with calibrated eyepiece. Starch samples were obtained from the five sampling positions in growth stages 3, 7 and 11. A tiny amount of starch was placed on a microscopic slide in a drop of potassium iodide solution and covered with a slip. At a magnification of 400 times, starch granules found along the calibration line at four random spots on each slide were measured.

5.3.6 Calculations

A sago palm trunk is cylindrical in shape consisting of a thin outer layer of bark and the internal pith. The pith contains water, starch and other dry matter. This holds true also for the bark which is discarded as it contains very little starch (Cecil *et al.* 1982). Thus, all the determinations made on pith, trunk and bark in this paper with regard to starch content, starch density, moisture and dry matter contents are interrelated.

The starch content is expressed as the percentage of dry starch that can be extracted from a given weight of fresh sample. This enables easy estimation of the total dry starch yield of a palm once its fresh weight is known. Starch density is best expressed in gram dry starch per cubic centimeter of fresh sample (Kraalingen 1984a, '84b). The following formulae are used in the calculations:

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[1]fibrous residue of rasped pith after starch is extracted

[2]sago palm starch gelatinises between 72-90°C

(i) Content of dry starch in sample = $\frac{\text{weight of dry starch extracted from sample (g)}}{\text{weight of fresh sample (g)}} \times 100\%$

(ii) Density of dry starch in sample = $\frac{\text{weight of dry starch extracted from sample (g)}}{\text{volume of fresh sample (cm}^3\text{)}}$

(iii) Density of fresh sample = $\frac{\text{weight of fresh sample (g)}}{\text{volume of fresh sample (cm}^3\text{)}}$

(iv) Moisture content of sample = $\frac{\text{fresh weight of sample - dry weight of sample (g)}}{\text{fresh weight of sample (g)}} \times 100\%$

(v) Estimated dry starch yield per palm = Total weight of trunk (kg) x Av. content of dry starch from 5 samples in the trunk (%)

(vi) Dry starch yield per unit time = $\frac{\text{Average yield of palm in a growth stage (kg)}}{\text{time to reach the growth stage from planting (yr)}}$

Analysis of variance was done by P C STAT developed by Georgia University, USA and Statpal II (version 5) programmes for microcomputers.

5.4 RESULTS

5.4.1 Growth data and estimated age of palms at different growth stages

Trunk length and weight varied considerably within each and among different growth stages but generally increased with age and reached a maximum at the full trunk growth stage (Table 2) at the age of 11.5 years after planting from suckers.

However, overlaps in the lengths and weights of trunks were common especially after the 8th year of planting, i.e., some younger palms were seen to possess longer trunks and higher weights than those of the older ones.

The trunk circumference measured at 1 metre a.g.l. also showed considerable variations especially among the different growth stages.

Table 2. Growth data of sago palms for this study

Dev't stage	Est'd age (yr) fr. planting	Duration of trunk growth(yr.)	Palm No.	Trunk ht.(cm)	Trunk wt. (kg)	Trunk circumf'ce 1m a.g.l (cm)	Trunk vol.(m^3)
3. young trunk growth	7	1.5	1	179	253	148	0.31
			2	157	187	141	0.25
			3	185	253	150	0.33
4. 25% trunk growth	8	2.5	1	295	566	167	0.87
			2	500	406	119	0.56
			3	410	394	127	0.79
			4	479	664	144	0.79
5. 50% trunk growth	9	3.5	1	550	573	137	0.82
			2	700	744	135	1.01
			3	595	580	123	0.72
6. 75% trunk growth	10	4.5	1	745	940	146	1.26
			2	677	942	147	1.16
			3	800	938	155	1.53
7. Full trunk growth	11.5	6	1	800	1062	153	1.49
			2	840	1087	160	1.71
			3	740	973	155	1.41
8. Bolting	12	6.5	1	825	1169	162	1.72
			2	733	1124	140	1.14
			3	741	1123	160	1.51
9. Young flowering	12.5	7	1	660	901	160	1.34
			2	767	1058	152	1.41
			3	741	1088	160	1.50
			4	969	1349	153	1.80
10. Young fruiting	13	7.5	1	560	730	163	1.18
			2	487	600	146	0.83
			3	802	1123	152	1.47
			4	700	603	135	1.01
11. Mature fruiting	14	8.5	1	720	791	146	1.22
			2	530	573	160	1.08
			3	535	519	145	0.89
12. Dying	14.5	9	1	770	681	157	1.51
			2	682	709	140	1.06
			3	807	935	145	1.34
			4	470	352	138	0.71

5.4.2 Longitudinal variation of starch distribution along the sago palm trunk at each growth stage

5.4.2.1 Starch distribution along the sago palm trunk

(i) Starch content

The starch content of the pith at five sampling points along the trunk varied significantly in palms of stages 5, 6, 7, 8 and 10 (Table 3, Fig. 1). For palms at the young trunk growth stages of 3 and 4, higher starch content was found at the bottommost position even though the difference was not significant. At stages 5 to 7, the lower sections of the trunk had markedly higher starch content than the upper portions. In palms of growth stage 9, high starch content of 20 to 25% was found evenly distributed along the trunk. At stage 10, a sharp drop in starch content was observed in the topmost position. Starch content in the remaining four-fifth of the trunk showed a decreasing trend from the upper to the lower portion. At stages 11 and 12, low starch content was found evenly distributed along the whole trunk.

Table 3 Starch distribution in sago palm pith at five sampling positions along the trunk

Sampling position	Starch content (%) at different growth stages									
	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12
1	5.06	13.91	19.93a	19.77a	25.01a	23.43ab	19.94	11.95bc	4.50	5.69
2	1.88	9.12	13.82ab	19.72a	23.79a	25.83a	25.73	15.40ab	5.74	7.24
3	o.78	8.32	9.20bc	17.96ab	25.19a	22.81ab	23.91	16.69ab	6.95	8.50
4	0.49	5.29	2.93cd	13.59ab	21.51a	22.33ab	23.02	18.73a	6.02	9.06
5	0.83	3.26	1.24d	10.99b	13.53b	18.68b	25.48	9.47a	2.13	4.10
Mean	**1.85**	**8.00**	**9.42**	**18.35**	**21.81**	**22.62**	**23.62**	**14.45**	**5.07**	**6.92**
S.E. (dif) C.V.(%)	3.12 211	5.03 89.2	3.07 39.96	3.79 28.35	3.35 18.8	2.22 12.04	2.93 17.60	2.69 26.4	3.93 101	3.79 77.5

*Note: Figures in the columns followed by different letters are significantly different at p=0.05 by DMRT.

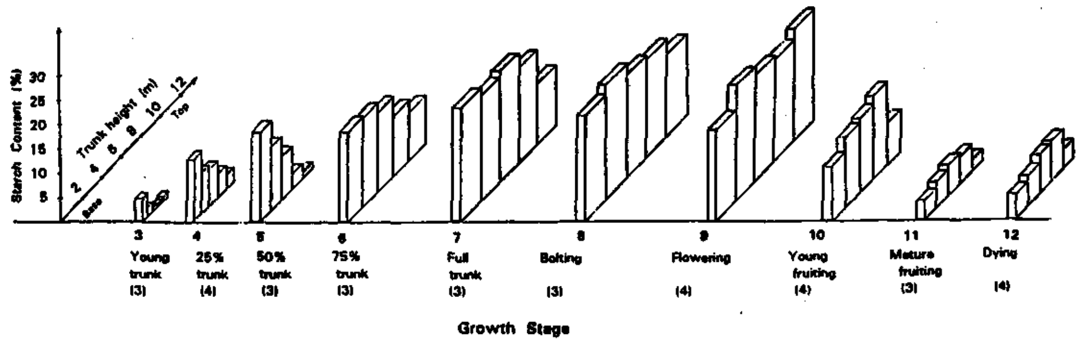

Fig. 1 The distribution of starch content along five evenly spaced positions in the trunk of sago palms. Note the increase in starch content from the base to the top as maturity of the palm advances and the movement of starch from the base to the top at flowering. The trunks of palms in the late stages of growth are shorter because they are the leader palms (explained in 5.5.1). The number in brackets indicates the averaged number of investigated palms.

(ii) <u>Starch density</u>

The density of dry starch at the five sampling positions along the trunk (Table 4) was very low in stages 3 and 4. The highest density was mostly found at the base of the trunk even though the difference along the trunk was not significant. However, in palms at stages 5 to 8, significantly higher density of dry starch was found towards the base of the trunk, with decreasing density towards the upper portion. The difference in starch density became less prominent when the palms were more mature. At stages 7 and 8, only the topmost section showed significantly lower starch density. The pith starch density, highest (0.18g cm^{-3}) in stage 9, was found to be uniformly distributed along the entire trunk. At stage 10, the lowest starch density was found at the topmost position with a gradual decrease from the upper to lower trunk in the remaining 80% of the trunk. A much lower starch density was found evenly distributed along the trunk of the palm in mature fruiting and dying stages.

5.4.2.2 <u>Variation in moisture content along the trunk</u>

The pith moisture content in the pith along the sampling positions varied significantly in growth stages 5 to 8 but was rather constant at growth stages 3, 4, 9, 10, 11 and 12 (Table 5). In growth stages 5 to 8, moisture content in the pith increased from the lower to the upper portion of the trunk.

Table 4 Starch density of pith at five sampling positions along sago palm pith.

Sampl'g position	Starch density (g cm^{-3}) at different growth stages									
	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12
1	.032	.102	.120a	.137ab	.160a	.167ab	.153	.088ab	.031	.038
2	.004	.069	.100ab	.143a	.193a	.193a	.183	.108ab	.042	.051
3	.005	.064	.060bc	.130ab	.180a	.180ab	.183	.125a	.046	.056
4	.004	.039	.025cd	.097ab	.157a	.153ab	.180	.128a	.042	.064
5	.005	.021	.009d	.080b	.103b	.143b	.180	.063b	.015	.017
Mean	.010	.059	.628	.117	.163	.167	.176	.102	.036	.045
S.E.(dif.)	.02	.04	.02	.03	.02	.06	.02	.04	.03	.10
C.V.(%)	227	92.1	35.1	28.9	12.9	14.3	14.4	53.5	97.9	419

*Note: Figures in the columns followed by different letters are significantly different at p=0.05by DMRT.

Table 5. Pith moisture content along the trunk of sago palm.

Sampl'g position	Pith moisture content (%) at different growth stages									
	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12
1	83.1	67.7	62.1c	61.6b	55.5b	57.2b	55.4	62.4	70.8	71.4
2	87.7	75.7	73.7b	66.9ab	58.9ab	56.6b	57.2	60.9	71.6	70.1
3	88.1	80.7	76.1b	71.4ab	57.3b	58.7b	58.9	58.1	70.9	68.3
4	89.4	83.8	85.2a	76.8ab	58.7ab	58.2b	55.9	56.3	76.7	67.2
5	89.4	85.2	89.5a	81.3a	64.8a	65.3a	57.0	62.7	76.1	68.1
Mean	87.5	78.6	77.3	71.7	61.2	59.2	56.9	60.1	72.2	69.0
S.E.(dif.)	3.6	8.5	3.4	8.5	2.8	2.0	2.3	5.4	7.2	7.9
C.V.(%)	5.1	15.2	5.3	14.5	5.6	4.2	5.0	12.6	12.3	16.1

*Note: Figures in the columns followed by different letters are significantly different at p=0.05 by DMRT.

5.4.2.3 Variation in the density of fresh pith

The density of fresh pith at the sampling positions along the trunk did not differ significantly within each growth stage (Table 6).

Table 6 The density of fresh pith in the trunk of sago palm

Sampl'g position	Fresh pith density (g cm^{-3}) at different growth stages									
	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7	Stage 8	Stage 9	Stage 10	Stage 11	Stage 12
1	.65	.75	62	.68	.73	.70	.76	.73	.66	.65
2	.63	.67	.72	.73	.77	.75	.72	.72	.70	.67
3	.62	.73	.69	.71	.74	.73	.76	.74	.69	.65
4	.61	.62	.74	.72	.73	.73	.80	.69	.70	.70
5	.61	.58	.73	.71	.73	.73	.72	.66	.65	.60
Mean	**.62**	**.67**	.70	.71	.75	.73	.75	.71	.68	.65
S.E. (dif.)	.02	.12	.13	.02	.06	.05	.05	.05	.04	.07
C.V. (%)	3.9	22.0	23.0	4.2	9.1	8.0	8.6	9.7	7.0	16.1

*Note: Figures in all the columns are not significantly different at $p=0.05$ by DMRT.

5.4.3 Variations in starch content, starch density, moisture content and density of fresh pith among sago palms at different growth stages

The variations in the average starch content and density, average moisture content as well as the fresh pith and trunk densities are presented in Table 7.

5.4.3.1 Average starch content and density in the pith and trunk[3] of sago palm

The mean starch content in the pith and trunk increased significantly from stages 3 to 6, and then plateaued off at a maximum content of 21.8 to 23.6% from stages 7 to 9 before decreasing sharply in stages 10 to 12. Young palms contained very little starch in the trunk and the highest starch content was found in palms in stage 9.

[3]trunk = pith + bark

A significant increase in the mean density of dry starch in the pith and trunk was noted from stages 3 to 7. The starch density then stabilized at its maximum from stages 7 to 9. Thereafter, a sharp decrease was noted at stages 10 to 12. The highest density was attained in stage 9 although the difference among stages 7, 8 and 9 was not significant.

5.4.3.2 Average moisture content of pith, bark and trunk

The moisture content in the pith among sago palms at several development stages was significantly different. Similar differences were also found in the average moisture content of the entire trunk. Moisture content of the pith and trunk decreased with increased palm maturity and reached a plateau from stages 7 to 10 before decreasing at stage 11. In the bark, moisture content was the highest in the early three growth stages and remained between 52.1 and 60.2% thereafter.

Table 7 Variation in the mean starch content, starch density, moisture content and fresh palm density in the pith and trunk of sago palms at different growth stages

		Development stage									
		3	4	5	6	7	8	9	10	11	12
Starch content (%)	Pith	1.85e	8.0ad	9.42c	18.4b	21.8a	22.6a	23.6a	14.5b	5.1de	6.9c
	Trunk	1.47e	6.5cd	7.6c	13.7b	18.6a	19a	20.1a	12.1b	4.2de	5.8cd
Starch density (g cm^{-3})	Pith	0.10d	.06bc	.06bc	.12ab	.163a	.167a	.176a	.10b	.04cd	.05c
	Trunk	0.12d	.05c	.05c	.10b	.15a	.15a	.16a	.09b	.03cd	.04c
Moisture content (%)	Pith	87.5a	78.6b	77bc	71.7cd	61.2e	59.2e	56.9e	60.1e	72.2cd	69d
	Bark	65a	63.2a	63.1a	55.8bc	60ab	58bc	52.5c	52.1c	56.1cd	52c
	Trunk	83.1a	75.8b	74bc	68.5d	60.7e	59.4e	56.2e	58.6e	69.1cd	67d
Fresh density (g cm^{-3})	Pith	.62d	.67d	.70abc	.71abc	.75a	.73ab	.75a	.71abc	.68bcd	.65cd
	Bark	.68d	.71bcd	.75abc	.75abc	.78a	.76ab	.79a	.75abc	.72bcd	.70cd

Note: Figures in the rows followed by different letters are significantly different at $p=0.05$ by DMRT.

5.4.3.3 Average density of fresh pith and trunk

The density of fresh pith and trunk varied considerably among palms at different growth stages. It increased from stages 3 to 6 and remained at peak values at stages 7 to 9 before declining from stage 10 to 11.

5.4.4 Sizes of starch granules

The largest starch granules were found in mature-fruiting palms (stage 11) and the smallest in the youngest palms (stage 3). The difference is only statistically significant in the youngest palms (Table 8). For both growth stages 3 and 7, smaller starch granules were distributed at the topmost positions of the trunks. At growth stage 11, large starch granules were evently distributed along the trunk.

Table 8. The length of starch granules in sago palms of three different growth stages

Growth stage	Average length of starch granules (µm)					
	Position 1	Position 2	Position 3	Position 4	Position 5	Grand Mean
3. Young trunk	36.4 b	39.2 a	37.3 b	34.4 b	32.8 c	**35.7**
7. Full-trunk	43.0 b	45.0 a	41.9 b	37.1 c	33.9 d	**39.8**
11. Late maturity	42.7	41.9	45.4	41.2	41.0	**42.4**

Figures followed by different letters in the sampling positions along the rows differ signicantly at $p=0.05$ by DMRT

5.4.5 Total starch yield and yield per unit time

The yield of starch in the trunk increased steadily from stages 3 to 6 and then plateaued off at stages 7, 8 and 9 before declining sharply from stage 10 onwards (Table 9).

Table 9 Starch yield of sago palms at different development stages

Development stage	3	4	5	6	7	8	9	10	11	12
Estimated age (yr)	7	8	9	10	11.5	12	12.5	13	14	14.5
Av. starch yield per palm (kg)	3.6d	36.9de	49.2cd	128.7b	203.4a	216.6a	219.4a	93.1bc	24.8de	41.8de
Yield/unit time (kg/yr)	0.52e	4.62cd	5.47cd	12.87b	17.69a	18.04a	17.55a	7.16c	1.77de	2.88de

Note: Figures in the rows followed by different letters are significantly different at $p=0.05$ by DMRT.

The highest yields were obtained from stages 7 to 9. Although stage 9 contained slightly more yield than stages 7 and 8, the difference was insignificant. The maximum yield per unit time also occurred at stages 7 to 9.

5.4.6 Comparison of starch yield in over-mature (stage 11) palms with normal and abnormal fruit development.

Palms at stage 11 with normal fruit development contained an average of 4.16% of starch evenly distributed along the trunk. In contrast, palms at the same growth stage but with little or no fruit development contained an average of 19.9% starch, with slightly lower levels at the bottommost and topmost positions of the trunk (Table 10).

Table 10. Comparison of starch content in mature palms (stage 11) with normal and abnormal fruit development

Sampling position		1	2	3	4	5	mean
Starch content (%)	Normal fruit dev't	4.50	5.74	2.45	6.02	2.12	4.16
	Abnormal fruit dev't	18.97ab	21.50a	22.59a	21.51a	14.56b	19.9

Note: Figures in the rows followed by different letters are significantly different at p=0.05 by DMRT .

5.5 DISCUSSION

5.5.1 Growth data

Under optimal growth conditions, the age of sago palm can be predicted from the following equation (Flach & Schuiling 1989):

$$\text{Age (yrs)} = 4 \text{ (or 4.5)} + \frac{[\text{no. of internodes} + \text{no. of functional leaves}]}{12}$$

This is based on the estimate that palms grown from seeds take 4 to 4.5 years to form trunks and after that it is assumed that they produce an average of 12 fronds per year. However, under sub-optimal conditions, palms may remain in the rosette stage for more than nine years as reported in palms cultivated at high density (Jong *et al.* 1994). Thus, for the description of the different growth stages, the physiological age would be more realistic than the actual age or parameters such as palm height or trunk circumference. Flach (pers.com.) stipulated that the development stages could be reflected by the number of leaf scars present on the trunk and this subject deserves further investigation.

As the sago palms used in this study were selected from a cultivated garden with known background, the estimated age of the various growth stages was close to the actual age of these palms. The rosette stage of 5.5 years reported in this study agrees closely with sago research work on deep peat by the Department of Agriculture, Sarawak (Anon. 1991-'93) but differed considerably from those stipulated by Flach & Schuiling (1989) for palms of three years nine months in age under optimal growth conditions. This is normal in Sarawak as sago palms are observed to reach the harvestable stage at widely different ages here. Depending on soil fertility and growth conditions, sago palms are estimated to attain maturity in 10.3 years on mineral soils and about 12.5 years on deep peat (Lim 1991).

Variation and overlapping in the length, weight and circumference of the sago palm trunks within each and among different growth stages are common (Table 2). These are most likely due to environmental differences. In an open field, the first batches of sago (leader) palms to reach maturity generally have shorter trunks than the follower palms. This is probably due to the absence of overhead shading of the leader palm as compared to the followers which have to elongate under the umbrella of the leader in order to compete for sunlight. Under such a situation and upon harvesting of the leader palm, the followers would get more sunshine and hence be expected to increase in the circumference of the newly formed trunk thereafter.

5.5.2 Longitudinal variations in the starch content, ~~starch moisture~~ moisture content, starch density and fresh pith density along sago palm trunks at each growth stage

5.5.2.1 Starch content and density

In this study, distribution of the starch content and density in the trunk follows an almost identical pattern and hence they are discussed together.

The progressive increase of starch content and density from the base to the upper portion of the trunk agrees with the reports of Sim and Ahmed (1978) and Kraalingen (1984a). However, this finding cannot be directly compared with that of Lim (1991) who studied the total weight of starch in a one-metre log section rather than the percentage of starch. The trunk circumference of a sago palm along its entire length is variable, usually the biggest at the base and middle portions and smallest at the top. This has a great influence on the total starch yield in each log section. In earlier reported studies, investigations were mainly carried out on palms from 'late trunk formation' to 'mature fruit' stages. A more complete spectrum of the trunk growth has to be investigated to give a clearer picture of the starch distribution.

From stage 7 to 10, higher starch contents were generally found at progressively higher sampling positions from the base with a concurrent decrease at the bottommost position. This probably indicates the initiation of an upward mobilization of starch from the base to the upper portion of the trunk. The apparent upward movement of starch was also reported by Kraalingen (1984a).

The sharp decline in starch content from stage 10 onward is interpreted as mobilization and conversion of starch into other forms of energy for flower and fruit development. The drastic decline in starch content at the topmost portion is probably due to its closeness to the developing fruits. Starch in this part of the trunk is converted into soluble forms ready to be mobilised to the sink. By stage 11 or when the fruits are mature, only little starch is left unused which probably decays together with the trunk.

Mobilisation and utilization of the majority of starch in the trunk for flower and fruit development is strongly supported by comparison of starch contents in palms at stage 11 which have normal and abnormal fruit development. The latter are found to contain an average of 19.9% dry starch in the trunk, with a lesser amount found at the topmost and bottommost sampling positions (Table 9). This supports the report of Barrau (1959) that the Papuans remove the flower buds to delay starch loss in flowering sago palms. In the absence of fruits, most of the starch remains immobilised and probably decays with the dying trunk later. This finding provides strong evidence to support the second theory of Kraalingen (1984a) and speculation of Sim and Ahmed (1978), that starch is mobilised to the top for fruit development.

Kraalingen (1984a) speculated that the lower starch content at the bottom portion of the trunk of flowering and fruiting palms might be due to the presence of more fibres and channels and demand by sucker development. Utilization of starch in this manner is rather insignificant as observed from the high starch content in over-mature palms without fruit development. Furthermore, suckers are continuously generated from the parent palm, even as early as the first year of planting, rather than sprouting in a pulse from maturing palms.

The starch density in mature palms (stages 7 to 9) is in agreement with those reported by Lim and Tie (1991) and Holmes *et al* (1984) of 0.16 - 0.18 g cm^{-3} but does not exceed the 0.20 - 0.33 reported by Kraalingen (1984a). This is probably due to varietal difference in starch content or different moisture content in the starch.

5.5.2.2 Variation in moisture content along the trunk

The moisture content in the pith is negatively correlated with the starch content (r^2 = -0.85). This indicates that a newly formed sago palm has a high water content. As starch is deposited, the water is gradually replaced. When starch is mobilised in mature palms, the starch is again replaced with water.

5.5.2.3 Variation in the density of pith along the trunk

Although the starch density along the entire palm trunk varied considerably at some growth stages, the density of fresh pith and trunk appeared to be rather constant throughout the length of the entire trunk at all the growth stages. It shows that the densities of the fresh pith and trunk are largely determined by the combined attributes of moisture and starch content. Regardless of the growth stages, regions of high starch content along a palm trunk are counterbalanced by lower moisture content (and vice versa), contributing to a rather constant density of the pith along the whole length of the trunk.

5.5.3 Variations in starch content, starch density, moisture content and fresh pith density among sago palms at different growth stages

5.5.3.1 Starch content and density

The highest starch content was found at stage 9 (flowering) although the difference between stages 7 to 9 was insignificant. This is in agreement with the report of Johnson and Raymond (1956) that maximum starch yield occurs after flowering but before fruit development. It also supports the findings of Sim and Lim (1987) and Lim (1991) that starch yield is the highest at these growth stages.

At a particular growth stage, the starch content in the pith is about 15 to 20% higher than that in the trunk. A similar trend was also noted for starch density. This difference is due to the discard of the bark during starch extraction.

Starch content varied from 1.85 to 23.6% in the pith of sago palms at different growth stages. Harvestable palms at growth stages 7 to 9 normally contain 19 to 20% of dry starch in the trunk (21 to 25% in the pith) which would give a starch yield within the range of those published by Sim and Ahmed (1978) and Sim and Lim (1987).

5.5.3.2 Moisture content of pith and trunk

The moisture content of pith and trunk decreases as the palms become more mature and increases again as the starch is depleted. This indicates the replacement of water by starch as discussed in 5.5.2.2 earlier. The average moisture content of the trunk at the various development stages shows a similar trend of variations as compared to that of the pith. However, the average moisture content of the bark is higher only in young development stages. It is maintained at 52 to 60% thereafter. This indicates that water in the newly formed bark is replaced by other dry matter. However, the reverse replacement does not happen once the bark is mature.

5.5.3.3 Density of fresh pith and trunk

In general, high pith density is found in palms at growth stages 7 to 9, coinciding with the stages containing the highest starch content. The pith density correlates well with its starch content ($r^2 = 0.94$).

The density of the trunk varied in an identical manner to that of pith density but with slightly higher value due to the higher density of bark. The density of the fresh trunk is highly correlated with the starch content in it ($r^2 = 0.93$). A regression equation $y = 184.5x - 125.2$ can be established to predict the starch content (y) from the trunk density (x). This equation can be applied to the grading of sago logs at factory gate before they are bought for processing as the approximate density of logs can be gauged by their buoyancy (Schuiling *et al.* 1992). Flach (1980) reported that a good quality sago palm log has a density of at least 0.75 which is close to the range of 0.76-0.79 at stage 7-9 in this study. However, this criterion of log grading should be used in combination with other parameters such as freshness of logs (Schuiling et al 1992), texture and visual characteristics of the pith and bark, which are better indications of the sago palm's maturity.

5.5.4 Sizes of starch granules

Sago starch granules are mainly ovoid. Truncated granules are also found, more common in mature than the young palms. The lengths of starch granules observed in this investigation range from 8 to 96 μm. The average length is about 40 μm, smaller than those of 50-60 μm reported by Seidemann (1966). Starch granules of various sizes are found in all the growth stages. However, in young trunks, the proportion of small granules is higher than in the older trunks, in agreement with the report of Fujii *et al.* (1986). More small granules are also found at the top portions of the trunk in stages 3 and 7.

5.5.5 Starch yield and estimated yield per unit time

An average yield of above 200 kg per palm was obtained at growth stages 7 to 9. This is higher than that reported in Batu Pahat, Johore by Flach & Schuiling (1989). The finding concurs with that of Sim and Lim (1987) and Lim (1991), that starch yield is highest (but insignificantly different) among these three growth stages of one-year separation. For maximum starch yield, palms should be harvested during these stages.

The maximum yield per unit time is insignificant between stages 7 to 9. From an agronomic point of view, it will be advantageous to harvest palms at the full trunk growth (stage 7) as this will promote the growth of the follower palms by the reduction of competition for light and nutrients at an earlier time. On the other hand, flexibility enables the harvest of palms to be timed for periods of high prices within this time frame (Lim 1991).

Harvesting palms earlier than stage 7 will be wasteful as this is the time of most active starch accumulation and the yield per unit time is significantly lower. Fujii *et al.* (1986) reported that the smaller grain size of starch from young palms made it more difficult to settle in processing thus leading to poorer starch recovery and yield.

In this study, palms only attain growth stage 7 at 11.5 years after planting. On mineral soils, palms can attain harvestable stage earlier as reported by Lim (1991), Flach (1973), Flach and Schuiling (1989).

It is also evident that palms harvested at the fruiting or dying stage will give lower starch yield. However, most of the starch is retained in over-matured palms with damaged flowering structures. This implies that harvesting of sago palms can be delayed (if necessary) by removing the inflorescence during flower formation.

5.6 CONCLUSIONS

5.6.1 Longitudinal variations in starch content, starch density, moisture content and fresh pith density along the trunk at each growth stage

Starch is accumulated progressively from the base of the trunk upwards, initiating as early as the trunk formation stage. However, in the early stages of trunk development, the starch content is low and is mainly confined to the lower portion of the trunk. From the full trunk development stage onward, the pith is filled with maximum mean starch content of 22% and density of 0.17 g cm^{-3} respectively. The high content and density of starch remain rather constant throughout the whole length of the trunk until the flowering stage. Thereafter, the level of starch decreases sharply, with a more pronounced dip at the topmost and bottommost positions of the trunk. This has been interpreted as the mobilization of most of the starch for fruit development.

The moisture content of the palm trunk is at its maximum in young palms. It decreases as the palm becomes more mature and as starch is being accumulated in the trunk. The fresh pith and trunk densities, on the contrary, remain rather constant along the entire trunk of the palm in a particular development stage. This is likely due to the counter-displacement of moisture and starch contents in the trunk.

5.6.2 Variation in starch content, starch density, moisture content and fresh pith and trunk densities among sago palms at different growth stages

The mean content and density of starch increase steadily from the trunk formation to the full trunk growth stage. The most active starch accumulation occurs between stages 5 to 7, at the rate of 75 to 80 kg per palm per year. Starch content is at its maximum of about 200 to 220 kg per palm from the full trunk development (stage 7) to flowering stage (stage 9). Once fruits are formed, the starch content drops rapidly at about 130 kg per palm per year from the flowering to fruit maturing period.

The density of fresh pith and trunk also increases steadily from stages 3 to 6 and levels off at stages 7 to 9 before declining at stages 10 to 12. The maximum densities of fresh pith and trunk are 0.75 and 0.79 respectively, coinciding with the stages of highest starch level in the trunk. The moisture content, on the contrary, is lower during these stages and higher in the younger and over-mature palms where the starch is less.

The total starch yield and estimated yield per unit time are highest between stages 7 and 9. However, palms are best harvested at full trunk growth to enable an early economic return and early reduction of competition for light and space with the follower palms.

In general, this study provides an understanding on the temporal and spatial distribution as well as the pattern of accumulation of starch and moisture along the entire length of the sago trunk. It also provides information on the variations of starch and moisture contents as well as the density of trunks in palms at different stages of trunk development. Evidence is also given on the mobilisation of starch for fruit development. Correlation analysis between the density and starch content of the trunk enables the formulation of a system for sago log grading based on buoyancy. An understanding on yield in relation to the corresponding development stages also enables the harvesting of a palm at the correct stage for maximum agronomic and economic returns.

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CHAPTER 6

FLOWERING BIOLOGY OF SAGO PALM

6.1 INTRODUCTION

Understanding the flowering biology of the sago palm is a prerequisite to its improvement through breeding and selection work in the future. It will also help in the establishment of seed gardens which would serve as an important supplementary or alternate source of planting material.

To study the gigantic terminal inflorescence of the sago palm in details, scaffolds are constructed up to the level just below the inflorescence. Scaffolds were built for a total of nine selected flowering palms from 1988 to 1994. The efforts and time spent on this project exceed the other authors reviewed in this chapter who mainly based their investigations on herbarium specimens or on live sago palms over a much shorter period.

To facilitate the understanding of some uncommon terms used in this study, a description of the flowering structure and the terminology, based on Beccari (1918), Tomlinson (1971) and Schuiling (1990) is given. An illustration of a full-grown inflorescence with its flowering structures is shown in Fig. 1a-1g.

A full-grown inflorescence consists of a central stalk called ax0 (ax for axis), which is the terminal extension of the trunk. The primary (first-order) branches produced from the ax0 are named ax1. The secondary (second-order) branches produced from the ax1 are named ax2. The flower bearing finger-like structures (third-order branches) are the ax3. These are also known as the rachillae (Tomlinson, 1971) or spikes (Beccari, 1918). Flower buds are produced in pairs on the ax3. Each pair of flower buds is enclosed in a cup-like scale called bracteole (Beccari, 1918). Tomlinson (1971) further differentiates these into inner and outer bracteoles. Globose fruits covered with imbricate scales develop on the bracteoles upon fruit set.

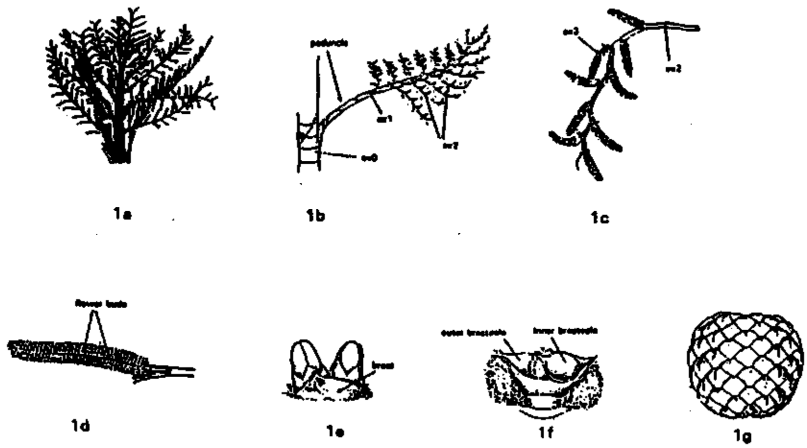

Fig. 1. Drawings of flowering structure illustrating the terminology used in the text. **1a.** A full-grown inflorescence. **1b.** A first order inflorescence branch (ax1) produced from ax0, (after Schuiling, 1990). **1c.** A second-order branch (ax2) bearing the spikes or rachillae (ax3). **1d.** An ax3 bearing flower buds. **1e.** A pair of flower buds subtended by a bract. **1f.** A bracteole with flower buds removed. **1g.** A mature sago palm fruit. (Diagrams 1c-1f after Tomlinson, 1971).

6.2 LITERATURE REVIEW

Reports on the floral biology of the sago palm (*Metroxylon* spp.) can be traced back to Beccari (1918) but since then, little new information has been added to the subject. Beccari (1918) reported that in *Metroxylon* Rottb., two types of flowers are found in a pair enclosed in a bracteole and they are externally quite the same. One is the staminate and the other hermaphrodite in appearance but physiologically female. Male flowers open before the female and female flowers open only after the fall of all the staminate ones. He concluded that flowers of *Metroxylon* are monoecious[1] and proterandrous[2] (= protandrous) on the same spike. The female flowers are likely to be pollinated after all the staminate flowers have disappeared.

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1 with unisexual flowers but borne on the same plant

2 stamen shedding pollen before the stigma is receptive

Fifty-three years later, Tomlinson (1971) made a study of the flowering process on a mature specimen of *Metroxylon vitiense.* He reported that the flower pair consists of a staminate and a hermaphroditic flower rather than pseudo-hermaphrodite as the stamens on both flowers appear identical. Uhl (1987) reported that the hermaphroditic flowers are similar to the staminate in their calyx, corolla and the stamens. However, the hermaphroditic flowers are somewhat flatter and the filaments are fused proximally to form an androecial tube surrounding the ovary. Tomlinson (1971) estimated that 917,280 flower buds were present in a single palm of *Metroxylon vitiense* and the number could be double in *Metroxylon sagu* due to its larger size and greater number of flowering branches. However, he was unable to observe the mode of pollination in his specimen.

Kiew (1977), examined a specimen of *Metroxylon sagu* and reported that each spike is covered with 24-28 spirals of 9-10 pairs of flowers. The number was estimated at 120,960-376,320 which would produce about 2,500 mature fruits. The flowering period lasts about two months and the time taken from development of the inflorescence to the formation of ripe fruits is about two years.

Studies made by Utami (1986) on three sago palms in Pandeglang, West Java revealed that sago palm is monoecious and self-pollinated. Each palm produced an inflorescence consisting of 5-6 first-order branches with 9-10 second-order branches on each first-order branch, and 12-16 rachillae per second-order branch. About 200-240 buds are found on each rachilla. This produces 108,000-232,400 flower pairs in a palm. The flowers are arranged in pairs, one (staminate flower) with under-developed pistil but functional stamens and the other 'female flower' with under-developed stamen but functional pistil. The author reported that the staminate flower in a pair opens first, and lasts 3-4 days. About two cm^3 of nectar per flower is produced only by the staminate flowers from 1030 to 1700 hours with a peak at 1300 hours, flooding the flower pairs. Most of the nectar drops, with a small portion being sucked up by visiting insects. The female flowers, which open on the last day of the staminate opening in the flower pair, also last 3-4 days. The duration of flower opening on a rachilla is about one month and on each branch 4-5 months. Overlapping of flower opening is likely within the rachillae, branches and inflorescence.

Utami (1986) further reported that rachillae covered with wire gauze and cellophane produce 1-4 full-sized fruits whereas those uncovered produced 3-15 fruits (no mention of seed) and concluded that insects might play an important role in fruit set. The insects caught were *Apis indica, Trigona iridipennis, Rygchium haemorrhoida, Anomala breviceps* and *Drosophila melanogaster*. The timing and the number of visiting insects are positively correlated with the time and abundance of nectar secretion.

Tuwan (1991) reported that staminate and hermaphroditic flowers are present in her *M. rumphii* Martius, *M. sylvester* Martius and *M. longispinum* Martius. The estimated number of flowers in these 'species' range from 856,000 to 2,074,000. These 'species' possess pollen grains of different shapes. Differences in pollen morphology have also been reported in *Metroxylon amicarum* and *M. salomomense* (Thanikaimoni 1970). In the classification of Beccari (1918) the *M. sylvester* Martius and *M. longispinum* Martius are varieties of *M. rumphii* rather than species. Based on the heterozygous spine characters of seedlings produced from a spiny palm, Rauwerdink (1986) suggests that these taxa should be classified as formae of *Metroxylon sagu* rather than variety or sub-variety.

6.3 MATERIALS AND METHODS

6.3.1 Selection of palms for pollination studies

Spineless sago palms (*Metroxylon sagu*) at various stages of flowering were studied over a five-year period from 1988 to 1994. A more detailed study was carried out in nine palms where platforms on scaffolds were constructed at the base of the inflorescence structure. The palms selected were healthy, possessing about 12-15 functional fronds with no damaged or diseased inflorescence structures. Scaffolds were constructed before the commencement of flower opening. The locations and dates of scaffold construction are shown in Table 1.

Table 1. The location and dates of scaffold construction

Palm no.	Date of construction	Date of flower opening	Approx. location	Remarks*
1	Sept 88	Oct 88	Along Oya/Dalat Road, 6 km from Oya town	Palms 1 & 2 were in different flowering stage
2	Nov 88	Jan 89	50 m from palm no. 1	
3	Dec. 88	Jan 89	Kampong Teh, Dalat	Isolated
4	Jan 90	Sept 90	Kampong Teh, Dalat	Isolated
5	Mar 90	Sept 90	Kampong Bakong	Palms no. 5 & 6 were in similar flower development stage
6	Mar 90	Oct 90	14 m from palm no.5	
7	May 91	July 91	Near Sg. Talau Station	Isolated
8	Apr 92	May 92	Along Mukah/Oya Rd 1 km from Mukah	A palm in similar stage 500 m away
9	Apr 92	July 92	Near Kg.Tanam, Dalat	Isolated

* Isolated at a distance of greater than 500 m

Palm 1 was used for a preliminary study of the flowering biology whereas data recording on palm 7 was incomplete. Only experiments conducted on palms 4, 5, 6, 8 and 9 are reported in this study.

6.3.2 Scaffold construction

A scaffold was constructed around the designated palm with a platform just below the inflorescence structure (Plates 12 and 13). The platform area varied with the size of the whole inflorescence, and was approximately 10 to 15 m^2. Local materials such as 'nibong' (*Oncosperma tigillarium*) trunk was used for the posts and a combination of split 'nibong' trunk and jungle wood were used for making the platform and other structures.

Bushes, grass and other obstacles were cleared around the base of the designated palm. Mature 'nibong' trunks of diameter 15-20 cm and length 12-15 m were erected by six to eight persons manually at the four corners of a square approximately 8 m by 8 m. The erected posts were allowed to lean against the sago palm. Two men then climbed up the sago palm to fix the horizontal beams for the platform at a height just below the inflorescence. Galvanised wire was used to secure one end of the beam to a post resting on the sago palm. The post (tied to one end of the beam) was then pulled away from the palm by a rope so that the other end of the beam was at the right position to be tied to another post. Similarly, the four posts were tied and joined by the ends of the four beams, enclosing the sago palm trunk. The positions of the posts were adjusted by means of pulling the ropes attached to them whereas the height of the platform was adjusted by raising or lowering the relevant posts. Horizontal supports were then fixed at the base of all the four posts at the ground surface to prevent them from sinking and to keep them in position. The frame work was strengthened by fixing diagonal and additional horizontal beams to the posts and the palm trunk at various positions. Bolts and nuts were used to further secure the attachment points of the platform beams to the posts.

After the framework was fixed, a platform was built just below the inflorescence. Railings were built on the sides and a simple ladder was made with quality jungle wood to connect the platform to the ground.

With a team of 6-8 skilled workers, a week is required for a scaffold to be completed. Depending on the material used, such a scaffold can last for about two to three years and a maximum of four people can be accommodated on the platform at one time.

6.3.3 Estimate of flowers in inflorescence

An estimate of the total number of flowers was done in five palms (numbers 4, 5, 6, 8 & 9) at first flower opening when most of the flowers were quite well developed. The numbers of ax1, ax2 and ax3 were counted in all the five palms whereas the average number of flower buds in each ax3 was estimated based on twenty random samples. The total estimated number of flower buds in each palm was calculated as follows:

Total flower number = total number of ax3 x average number of buds in the ax3 sample

6.3.4 Bagging of inflorescence

After a few preliminary trials on the choice of materials for pollination bags, semi-transparent nylon material of about 200-300 μm mesh was chosen. Each bag, measuring about 45 cm by 60 cm, was made with a zip opening. This could comfortably enclose an ax2 (Plate 14). It was more rigid than muslin cloth so that the sides did not often cling to a flower structure. Besides, it provided a relatively airy environment inside.

Bagging experiments were carried out on palms 2 and 3 as follows:

(a) Bagging of three ax2 at random in each palm throughout the flowering and fruiting period. Bagging started before flower opening. The slit on the closed zip was sealed with grease to prevent insect passage.

(b) Bagging of three ax2 in each palm as described above, but the bags were opened from the first sign until the end of anthesis in the enclosed ax2. Thereafter, the bags were closed throughout.

(c) No bagging was done for the control. Three ax2 from each palm were chosen for fruit assessment.

6.3.5 Time course and duration of flower opening

6.3.5.1 First opening of staminate and hermaphroditic flowers

The date of first opening of staminate and hermaphroditic flowers was recorded in palms 4, 5 and 6 by visual examination of each of the flowering branches including the ax3. Flower opening is denoted by the break opening of the calyx and sepals with the stamen and/or pistil well exposed. The mid points of flower opening and fruit set, defined here as the achievement of roughly 50% of flower opening and fruit set respectively, were visually estimated as the processes extended over a period of several weeks involving an enormous number of flowers.

6.3.5.2 Duration of flower opening and fruit set

In palms 8 and 9, the time course of flower opening was recorded on a specially designed form. Each form has 31 columns for the date of each month, and about 40 rows for recording the opening of the staminate and the hermaphroditic flowers in each second-order flower branch (ax2). One form per month was used for each ax1 that contained about 14 to 19 ax2. Visits were made at the platform daily in the early afternoon from the first to the last day of flower opening. Each ax2 was visually examined for the presence of newly opened staminate and hermaphroditic flowers. A tick was made at the appropriate position in the recording form, reflecting the date, the flower type and the ax2 on which the flower opened. When flower opening was extended over a month, a fresh form was used for each ax1 to continue the recording until the end of anthesis. In this manner, the date and duration of flower opening in each ax1 and ax2 could be traced.

6.3.6 Daily sequence of flower opening and mode of pollination

The time course of daily opening of staminate and hermaphroditic flowers was monitored in selected ax3 in palm 8 over three consecutive days. The sequence of bud opening, anther rupturing and nectar secretion was monitored throughout the day. Recording on the dates of fruit sets in the hermaphroditic flowers was also carried out.

Visits by animals and insects were monitored closely for three consecutive days from 0630 to 1800 hours on palm 8. The arrival of insects and other animals was timed and their activities monitored. Samples of visiting insects were caught and kept in 70% alcohol. They were identified by entomologists of the Department of Agriculture, Sarawak.

Three types of the most abundant insect visitors were caught around midday from the flowering palm. They were immobilised with chloroform and examined for the presence of pollen on their bodies with a dissecting microscope.

6.3.7 Examination of pollen

6.3.7.1 Characteristics of pollen

Anthers and pollen grains were collected from newly opened staminate and hermaphroditic flowers. The characteristics of pollen grains were examined with a dissecting microscope at 30 times magnification. After insect visits, rachillae with flowers were inspected for the presence of pollen. A miniature battery-operated light scope with 30 times magnification was frequently used to examine flowers on the intact sago palm for the presence of pollen.

6.3.7.2 Germination of pollen

Pollen and nectar were collected from un-bagged newly opened staminate and hermaphroditic flowers. The pollen was kept in 10% sucrose solution for six hours in a small bottle. Examination of pollen and pollen tube growth in nectar and 10% sucrose solution was made at 40 times magnification using a light microscope. Before examination, the bottle was agitated and a drop of the suspension placed on a glass slide covered with a slip.

6.3.7.3 Determination of pollen size

Fifteen preserved pollen grains (in 10% formalin + acetic acid) from a spineless cultivar were examined (under the microscope in the original solution on a slide with a cover slip). On another occasion, 20 of the pollen grains from a spiny cultivar were examined in distilled water on a slide with a cover slip. A microscope (Leitz) with a calibrated 12.5X eye piece and 10 X objective lenses was used to determine their sizes. Only one sample from each cultivar was examined.

6.3.8 Assisted self-and cross-pollination

6.3.8.1 Selfing

Six healthy ax2 with dense flower buds in palms 4, 5 and 6 were bagged before flower opening as described in 6.3.4(a). Hermaphroditic flowers in anthesis from three ax2 of each palm were pollinated with pollen of staminate flowers and the other three with pollen of hermaphroditic flowers from the same palm. Anthers of staminate and hermaphroditic flowers were collected from newly opened flowers enclosed in pollination bags from the same palm to minimise contamination caused by visiting insects. The anthers were succulent, shiny and purplish or orange in colour. Pollination was done at mid day during the peak opening period of the hermaphroditic flowers. The bags were opened carefully to prevent entry of insects. The nectar droplet was removed by suction, and the stigma pollinated by rubbing gently with the respective kinds of anthers collected. Pollinated flowers were inspected with a small light scope to ensure that pollen was deposited on the stigma. They were identified with a red paint dotted beside it. The bags were closed thereafter and the pollinated flowers allowed to develop with those without assisted pollination.

The total number of fruits and seeds in the entire palm served as the control experiment. This was assessed at 16 months after anthesis when fruits were approaching maturity. Fruit containing seeds could be distinguished by their relatively larger size and more rounded appearance at the base. However, a final assessment was made after fruit drop by crushing them to look for seeds.

6.3.8.2 Crossing

Three healthy ax2 were chosen from each palm 5, 6, 8 and 9 during peak flower opening. Three rachillae in each ax2 were selected while the rest was removed by a pair of secateurs. The rachillae were inspected at about 0900 hours before commencement of new daily flower opening that normally starts at 1100 hours. The ax2 (each containing three rachillae) were enveloped in pollination bags after all the previously opened flowers were removed. Emasculation was carried out between 1000 and 1230 hours on each hermaphroditic flower before it was fully opened. This was to minimise contamination by pollen from the same flower as anthers would slowly burst open during flower opening. Staminate flowers found opening within the bag were also removed. Emasculated flowers were inspected for pollen contamination using a portable light scope at 30 times magnifications. Contaminated and all the unopened flowers were removed to exclude selfing. The emasculated flowers were pollinated by gently rubbing with pollen collected from a different flowering palm and the bag was closed immediately after pollination. This was done during peak flower opening so that more newly opened hermaphroditic flowers were available.

Collection of pollen for crossing was done from another palm in anthesis. A suitable ax1 was usually brought down by a climber and a chosen ax2 would be selected, wrapped in moist paper and sent to the recipient palm for immediate pollination. In palms 5 and 6 which were in close proximity, pollen was collected from the bagged inflorescence to avoid possible contamination by pollen from the same palm brought over by insects. Only anthers with mature pollen as described in 6.3.8.1 were used.

Besides the man-assisted selfing and crossing, bagging experiments identical to those described in 6.3.4(a) and (b) were included in palms 8 and 9 as cross checks. The results of selfing and crossing were assessed 16 months later. The fruits were harvested, checked for the presence of seeds by crushing them. Seed-bearing fruits could be recognised by the presence of a hard endosperm enclosed in the fleshy layer whereas the sterile ones contain only a thick and soft fleshy structure.

6.3.9 Pattern and duration of fruit growth

The total fruit yield and the duration of fruit development from anthesis to mature fruit drop was followed in five palms. In palms 3, 4 and 5, the increase in the size of fruits was monitored. Fruit diameter was measured with a veneer caliper at two-week intervals, starting from fruit set. Three replicates of five fruits each from each palm was recorded.

6.3.10 Assessment of seed-bearing to seedless ratio in sago palm fruits

A brief survey of fruiting sago palms was made in Kuching, Mukah and Balingian areas. Only reasonably matured fruits which had attained a size of about 40 mm in diameter were sampled. As most of the inflorescence was more than 10 m above the ground, fruit samples were taken in one of the following ways:

(a) Felling of the sago palm

(b) Vigorous shaking of the fruiting branches. A weight was tied to one end of a nylon rope of about 5 mm diameter. This was thrown over the fruiting bunches and allowed to come down. Both ends of the rope were held together and pulled repeatedly and vigorously to shake off the fruits.

(c) By catapult shooting. This was done when palms were too tall or had too many obstacles around it to allow shaking.

Samples collected were examined for the presence of seeds as described in 6.3.8.2.

6.4 RESULTS

6.4.1 Estimate of flower number in inflorescence

The estimate of the number of flower buds per palm, just before opening of the inflorescence, ranged from 276,000 to 864,000 (Table 2). The range of ax3 was from 1313 in palm 5 to 3427 in palm 9. The number of flower buds in each rachilla varied greatly in each and also between palms. The mean ranged from 121 to 273 per rachilla.

Table 2 Estimated number of flower buds in five sago palms. The ax1, ax2 and ax3 numbers were counted and the number of buds per ax3 estimated from the mean of the bud number of 20 randomly selected ax3.

Palm no.	No. of ax1	No. of ax2	No. of ax3	Av. no. of flower buds per ax3 (mean ± sd)	Estimated no. of buds per palm
4	18	278	3165	273 ± 86	864,000
5	15	173	1313	210 ± 65	276,000
6	16	177	1443	216 ± 80	312,000
8	17	255	2848	242 ± 73	689,000
9	19	334	3427	121 ± 67	418,000

6.4.2 Bagging experiments

Seedless fruits were formed in all the treatments (Table 3). There was no significantl difference in the number of fruits formed in each treatment.

6.4.3 Time course of flower opening

6.4.3.1 First opening of staminate and hermaphroditic flowers

In palm 4, the staminate flowers opened 3 to 4 weeks earlier than the hermaphroditic flowers (Fig.2). In general, flowers of both types opened successively from the proximal (lower) ax1 to the distal (upper) ones. The time separation in the initial flower opening from the first ax1 to the last was about three weeks in staminate and two weeks in hermaphroditic flowers. The intensity of flower opening was very low at the start and increased to about 50% within two weeks in most of the ax1. Thereafter, the intensity decreased again. During the intense flower opening period, fruit set occurred 3-4 days after the opening of hermaphroditic flowers. Overlapping of staminate and hermaphroditic flowers was observed within the palm but the main flower opening period was, to a large extent, separated temporally, progressing orderly from the proximal to the distal ax1.

Table 3 The average number of fruits and seeds per ax2 formed from three bagging treatments.

Treatment	Av. no. of fruits and seeds set (mean ±sd)			
	Palm 2 fruits	Palm 2 seed	Palm 3 fruits	Palm 3 seed
Bagging throughout flower opening	19.3 ± 3.2	0	9.0 ± 2.6	0
Bagging throughout but open during anthesis	17.3 ± 6.5	0	10.0 ± 4.0	0
No bagging	20.7 ± 3.3	0	11.0 ± 5.2	0
S.E.(dif.)	3.7		3.3	
C.V. (%)	24.0		40.9	

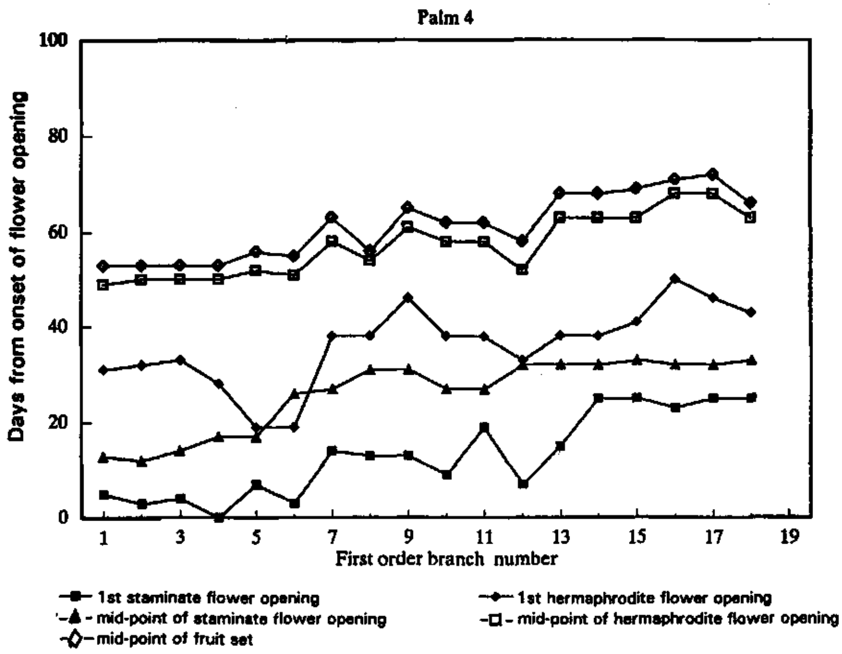

Fig 2. Progression of flower opening and fruit set in the first-order branches of palm 4.

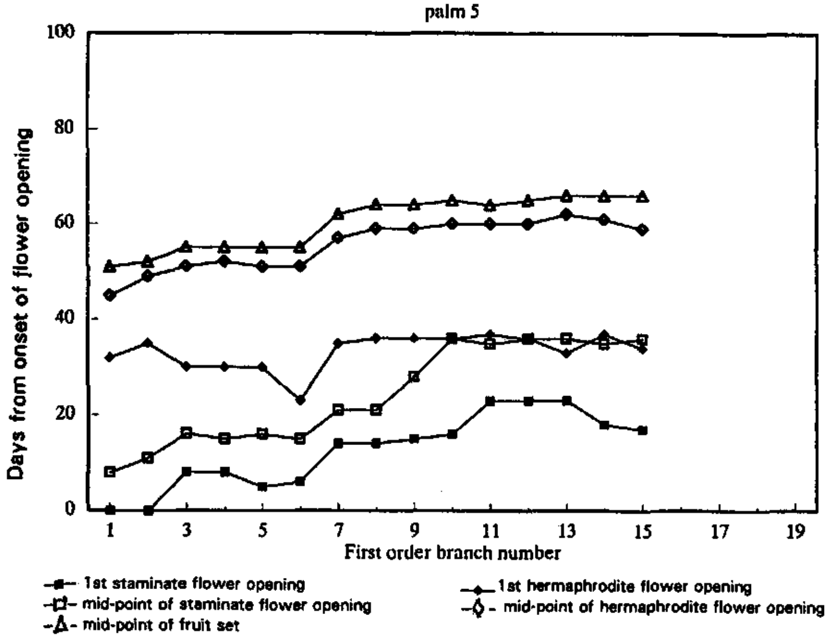

Fig 3. Progression of flower opening and fruit set in the first-order branches of palm 5.

The pattern of flower opening in palm 5 was similar to that of palm 4 (Fig.3). Fruit set within a week of opening of the hermaphroditic flowers. The temporal separation between the midpoints of opening in the staminate and hermaphroditic flowers was 2 to 4 weeks, without overlaps in the ax1 and the whole inflorescence.

In palm 6, most of the hermaphroditic flowers opened prematurely, possessing under-developed anthers. These abnormal hermaphroditic flowers had short and underdeveloped stamens with short filaments and pale anthers (Plate15). The opening of each flower was very slow, extending from a few weeks to over a month. They were very different from the normal hermaphroditic flowers in palms 4 and 5 which had larger and conspicuous orange to yellow anthers on extended filaments. Initial opening of staminate and abnormal hermaphroditic flowers overlapped in all the ax1 (Fig. 4). However, the midpoint of fruit set was about a month later than the midpoint of opening of abnormal hermaphroditic flowers. Opening of hermaphroditic flowers occurred in two pulses. Both were in much smaller intensity than those observed in palms 4 and 5. One commenced with the initial opening of staminate flowers and the other towards the end of all flower opening, about a week before the main fruit set.

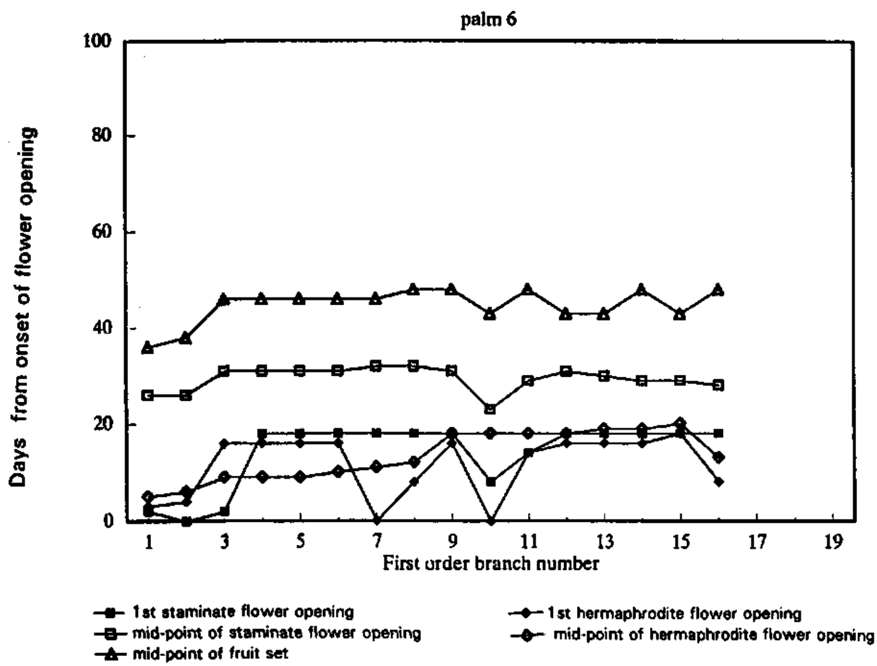

Fig 4. Progression of flower opening and fruit set in the first-order branches of palm 6. Note that the midpoint of (premature) hermaphroditic flower opening occurs before the mid opening of staminate flowers.

6.4.3.2 Duration of flower opening and fruit set

In palm 8, the duration of staminate flower opening was approximately one month in the palm and 25 days in each ax1. For hermaphroditic flowers, the duration of opening in the whole inflorescence was similar to that in each ax1 of about 50 days (Fig. 5). Anthesis of staminate or hermaphroditic flowers in most ax1 was synchronised. Overlap in the opening of both flower types was obvious. However, the peak opening of staminate and hermaphroditic flowers, as reflected in 50% anthesis, only overlapped to a slight extent between the proximal and distal ax1. The peak of opening progressed gently upward from the lower to the upper ax1. This means that although the duration of flowering is synchronised in the ax1, the peak opening is later in the upper ax1 than the lower ones. Fruits were set three to four days after opening of the hermaphroditic flowers.

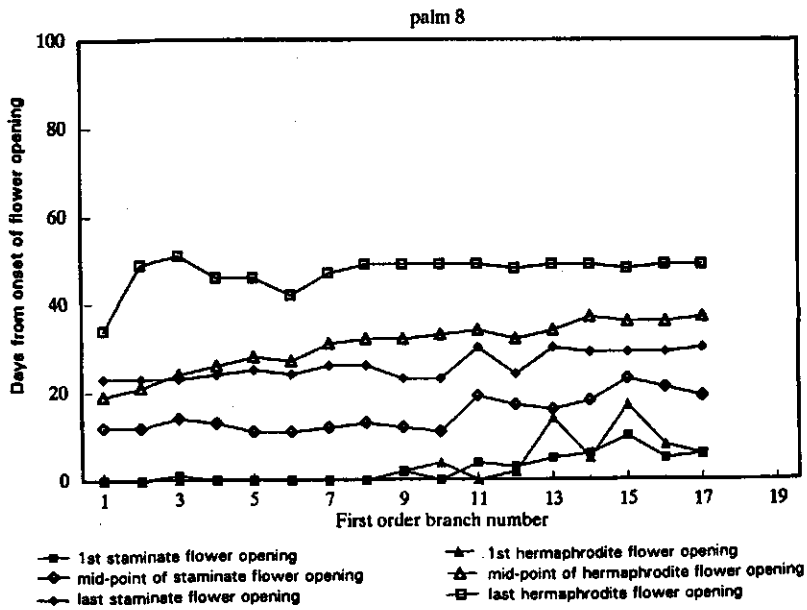

Fig 5. Progression of flower opening ~~and fruit set~~ in each first-order branch of palm 8. Overlaps of staminate and hermaphroditic flowers occur but the mid points of opening are largely separated.

In an ax1, the peak opening of staminate flowers occurred 9-14 days after its first opening whereas for hermaphroditic flowers, the peak appeared 23-30 days later than the first opening. From recordings, and working backward on observations throughout anthesis, the proportion of staminate flowers were estimated at 20-30% of the total flowers in palm 8. It was estimated that 70-80% of flowers of each kind opened during these peaks. The opening of staminate flowers was slightly more dispersed, with three peaks close together in a week whereas the opening of hermaphroditic flowers was concentrated at a single peak (Fig.6).

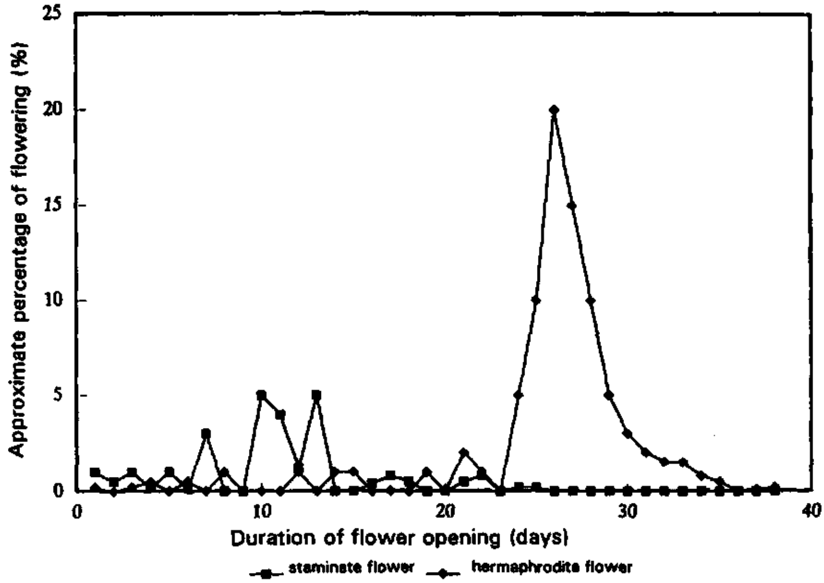

Fig 6. The spreading of flower opening in an ax1 of palm 8. Note that the peaks of staminate and hermaphroditic flower opening are separated. Opening of staminate is earlier and more scattered than the hermaphroditic flower which is concentrated on a single peak. Similar patterns of opening are observed in other ax1.

In palm 9, the vast majority of hermaphroditic flowers opened prematurely as described in palm 6. The duration of the abnormal hermaphroditic flower opening stretched over a period of three months (Fig.7). However, all the under-developed stamens turned brown and died during the lengthy opening period. The normal hermaphroditic flowers were only visible in small numbers, opening scatteredly in a single pulse in the last two weeks of the opening period.

Male flowers were very few (estimated at less than 1% of the total flowers) and none was found in the four lowest ax1. They opened over a duration of four weeks, about two months after the commencement of premature opening of abnormal hermaphroditic flowers.

Some fruits were set earlier than the opening of staminate and normal hermaphroditic flowers. However, most of the fruit set was found at the end of anthesis. Despite the premature opening of the abnormal hermaphroditic flowers with under-developed stamens, seedless fruits were formed and developed normally as those of palms 4 to 8.

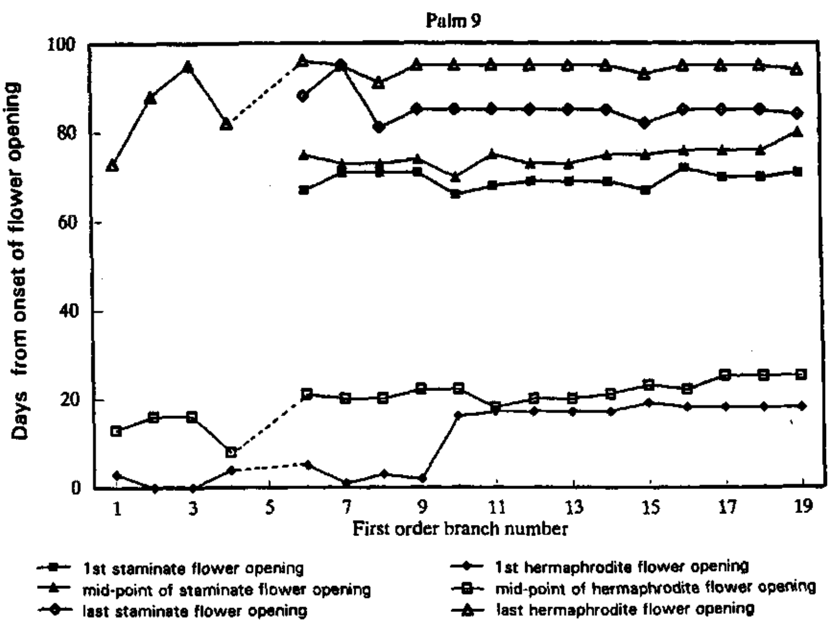

Fig 7. Progression of flower opening ~~and fruit set~~ in each first-order branch of palm 9. The abnormal hermaphroditic flowers opened about two months earlier than the staminate flowers. No staminate flower was found on ax1 nos.1-4. Ax1 no. 5 was broken and this is not recorded.

6.4.4 Daily sequence of flower opening and mode of pollination

6.4.4.1 Staminate flowers

Opening of staminate flowers was monitored in palms 4, 5, 6 and in a few other palms in earlier occasions. More detailed observations were made on palm 8 during its peak opening period. The sequence of opening in palm 8, similar to other palms, is reported here.

Staminate flowers started to open at about 1030 hours. A bud was fully opened within 20-30 minutes. The sepals split at the fusion and moved apart. The anthers emerged from the opened flower and extended above and away from the centre of the flower. They were light purple and burst open gradually before the filaments were fully extended. Within about 30 minutes from the start of opening, the anthers were fully exposed and spread out on top of the sepals (Plate 16). The exposed anthers turned to orange and yellow gradually in the next hours. The number of visiting insects increased gradually especially the stingless bees (*Trigona itama* and *T. apicalis*) which were estimated at about a thousand by 1000 hours. Some wasps (*Vespa tropica*) were also found.

The peak of daily opening was around 1100-1200 hours. About 5-10% of the total buds opened randomly in most of the intensely flowering rachillae. Nectar appeared at 1130 hours and gradually formed droplets drowning the centre cavity of the opened flower by 1200 -1230 hours. Nectar droplets even fell to the platform too. The number of stingless bees appeared to be doubled by midday. The number of wasps also increased to about forty. Insect visitors moved from one opened flower to another and wasps were seen to suck up nectar. Some honey bees (*Apis dorsata*) arrived at about 1230 hours and also sucked up the nectar droplets.

Very few honey bees were around by 1500 hours but the population of other insects remained steady. Some nectar was still apparent on the newly opened flowers although wilting of the anthers was seen in most flowers. At 1700 hours, most of the anthers appeared wilted and were supported above the flowers by the filaments. A few stingless bees and wasps remained.

A follow up observation was made at 0800 hours on the following day. Anthers which had opened the previous day were soggy although still well supported on rather firm filaments. Some opened staminate flowers had abscised completely with the calyx and sepals, and were pushed out of the bracteole. Freshly fallen staminate flowers were scattered on the platform, flower structures and in the pollination bags. Few of the staminate flowers from the previous day remained on the rachillae. These, when disturbed, fell off easily from the rachillae.

The opening of new staminate flowers and arrival of visiting insects were similar to that of day one.

A visit on the third day confirmed the overnight abscision of opened staminate flowers. Other activities were a repetition of day one.

6.4.4.2 Hermaphroditic flowers

The daily sequence of flower opening was monitored for three consecutive days in palm 8, from 0700 to 1800 hours during the peak of hermaphroditic flower opening. There was no rain during the period. Flower opening was quite synchronised on all the ax1 of this palm. Record of the sequence of flower opening and animal visits was as follows:

Day one

0070-1000 hours

Only very few flowers started to open. The sepals split open slowly at the fusion, exposing the anthers partially. The anthers were light purple and the filaments were not yet visible as the opening was incomplete by 1000 hours. Only stingless bees were present and their number increased gradually to a few hundred.

1000-1100 hours

Opening picked up steadily after 1000 hours. The semi-opened flowers observed earlier also opened in the same way as described in staminate flowers. The stigmata and pistils were fully exposed within 30 minutes. The anthers were less purplish than those of the staminate flowers but burst open similarly. The appearance and shape of anthers were visually identical to that of staminate flowers (Plate 17).

Apart from about a thousand stingless bees, a few flies and wasps were observed.

1100-1200 hours

This is the most active opening period in the day. The buds opened in the same manner as described above. Opening of hermaphroditic flowers was random in any ax2 and rachillae (Plate 18). In some rachillae, more than 50% of the flower buds opened on the same morning whereas in others, 20-30% of opening was more common. By 1130 hours, nectar was secreted in most of the newly opened flowers. The quantity increased steadily and it was collected at the centre of the flower to form a droplet. The pistil including the stigma was completely drowned in the droplet (Plate 19).

The stingless bee visitors increased to a few thousands. They made brief stops on an opened flower before proceeding to the next. The number of wasps also rose but totaling less than a hundred. A wasp was clearly seen to suck up a drop of nectar in seconds. A few smaller bees and some flies (unidentified) joined the crowd. Some small birds with long beaks arrived from 1145 to 1200 hours but only made a transient stop.

By 1200 hours, the nectar in newly opened flowers began to overflow from the centre of each flower. Droplets started to fall on the platform. This was enhanced by a light breeze.

1200-1300 hours

The nectar secretion continued and droplets fell on the platform and the ground. The anthers turned pale orange in most of the flowers. A few flowers were still incompletely opened. The stingless bees were estimated at 3000-4000 around the entire palm inflorescence. The population of wasps and other minor insect visitors remained constant.

Spectacularly, a swarm of honey bees (*Apis dorsata*) estimated in the thousands, arrived at the palm at 1215 hours. It was clearly seen that honey bees were sucking the nectar. A single bee could suck up a droplet of nectar in a second or two as the wasps did. By 1235 hours, not a drop of dangling nectar could be found in the estimated 50,000 newly opened flowers in the entire palm. The bees stayed on, with other insect visitors, visiting from one flower to another. The honey bees and wasps appeared to feed on the pollen too. Pouches full of pollen were seen on the pollen baskets of some stingless bees. Some birds arrived but did not land.

1300-1400 hours

The honey bees, stingless bees, wasps and other unidentified insect visitors remained in constant numbers. These insects were busy moving around flowers. No new opening of flowers was noticed. No nectar was seen as it was consumed by insect visitors.

1400-1500 hours

The insect population appeared similar as in the early hours. However, the honey bees were leaving by 1415 hours and the whole swarm completely vanished by 1430 hours. The extended anthers appeared withered and curled up. Most other insects remained at 1500 hours.

1500-1800 hours

The stingless bees remained in the thousands with 30-40 wasps and a few flies. Nectar oozed out again in many flowers and some nectar started to fall by 1530 hours. However, the amount of nectar secretion was greatly reduced. More stingless bees left after 1630 hours. Most anthers were wilted and shrinking although the orange coloured filaments remained erect. A few hundred of the stingless bees were still around the flowers by 1800 hours although most insects had disappeared.

Day two

0700-1000 hours

Anthers of the flowers that opened on day one appeared soft, soggy and pale brown although the filaments were still somewhat extended. Those that had opened before day one had collapsed filaments and the anthers were resting or hanging loosely outside the opened flowers. When checked at 30 times magnification, apparently ungerminated pollen was found on the stigma of every flower opened on day one. A few flowers opened partially overnight.

Insect visitors were only confined to a few hundred stingless bees. Some wasps arrived between 0900-1000 hours.

1000-1800 hours

The opening time, the nectar secretion and the insect visitors were a repetition of the previous day. The swarm of honey bees started to arrive at 1200 hours and left by 1450 hours, carrying out identical activities as on the previous day.

Nectar droplets were found from the newly opened flowers, and not in the ones opened the day before. However, it could not be ascertained whether a small quantity of nectar was still secreted from the old ones because they still attracted some insect visitors.

Day three

The same events were repeated as in days one and two. Honey bees came at 1200 and left at 1430 hours. Other visiting insects arrived and left in a very much similar manner. Nectar droplets were only found in the newly opened flowers.

6.4.5 Insect identification

The main insect visitors caught foraging on the sago palm inflorescence during anthesis were *Trigona itama, Trigona apicalis, Apis dorsata* and *Vespa tropica*.

Examination of bees (*Trigona* spp. and *Apis dorsata*) showed that pollen was sticking on the head, legs and wings. Only the stingless bees(*Trigona* spp.) had pollen on the pollen baskets.

6.4.6 Pollen examination

6.4.6.1 Characteristics of pollen

(i) Pollen from prematurely opened anthers

The anthers of prematurely opened flowers were small and pale yellow, filled with oval shaped pollen. The pollen was apparently smaller and lighter yellow than the normal mature ones that is light purplish, succulent and shiny. These pollen grains are presumed to be premature and die later within the unopened anther.

(ii) Pollen from newly opened staminate flowers

When the light purple anthers were excised from the semi-opened flower and examined microscopically, they opened within a few seconds, revealing the shiny and succulent oval pollen, in lumps clinging to the side of pollen sac. Anthers taken from a few unopened (but presumably mature) buds also behaved similarly.

(iii) Pollen of newly opened hermaphroditic flowers

Apart from the slightly lighter colour, anthers and pollen of newly opened hermaphroditic flowers were visually identical to those of staminate flowers when examined with a dissecting microscope.

Rachillae sampled at 1345 hours and examined under a dissecting microscope showed that very few pollen grains were left on the anthers of opened flowers. Most of the pollen sacs were quite empty and the anther was dehydrated. Pollen was also seen all over the flower parts, including the stigma, sepals and on nearby flower.

6.4.6.2 Pollen germination

Examination of pollen was made at 40 times magnification with a light microscope six hours after collection. Germinating pollen from both types of flowers either kept in 10% sucrose solution or in nectar, was found at very low frequency. Around 10-20 germinating pollen grains could be detected in a droplet of suspension that contained a few hundred pollen grains.

Germinating pollen grains with pollen tubes of different lengths and with nuclei were visible in droplets of nectar collected from un-bagged flowers.

6.4.6.3 Pollen size determination

The measurements of fresh and preserved pollen (in 10 % formalin and acetic acid) collected from the spiny and spineless cultivar are shown in Table 4.

Table 4 Pollen size of preserved spineless and fresh spiny sago palms.

	Av.length (μm) (mean ± sd)	Av. width (μm) (mean ± sd)
Preserved pollen spineless cv	39.7 ± 6.3	26.5 ± 4.2
Fresh pollen spiny cv	45.1 ± 3.8	29.2 ± 2.1

In the preserved sample, the pollen was mostly oval. Occasionally, round ones were observed. In the spiny sample examined with distilled water, a mixture of oval and triangular pollen was observed. The sizes of the latter were not determined as they appeared to be abnormal.

6.4.7 Man-assisted self- and cross-pollination

6.4.7.1 Selfing

All the man-assisted pollination resulted in seedless fruits (Table 5). The average number of fruits per ax2 was between 10.7 and 26.7. In the control (Table 8) where flowers were exposed to insect visitors, no fruit was formed in palms 4, 5 and 6 but palm 8 registered a 5.1% seed set.

Table 5 Fruit and seed set in assisted selfing experiments. Only seedless fruits were set in all treatments.

Palm no.	Source of pollen	Av.no. of flowers pollinated per ax2	No. of mature fruits formed in bagged ax2 (mean ± sd)	No. of seed set in bagged ax2
4	staminate	37	3.3 ± 1.5	0
	hermaphrodite	45	4.3 ± 2.1	0
5	staminate	21	0.7 ± 0.6	0
	hermaphrodite	48	1.7 ± 0.6	0
6	staminate	41	4.7 ± 0.6	0
	hermaphrodite	44	3.7 ± 1.5	0
8	staminate	51	5.3 ± 1.6	0
	hermaphrodite	43	6.0 ± 1.0	0

6.4.7.2 Crossing

In the man-assisted cross-pollination, fruits were set but without seeds in all the 5 palms (Table 6). In cross check experiments in palm 8, bagging throughout flowering and fruiting yielded no seed-bearing fruit but those exposed to insect visitors during anthesis gave low percentages of seed-bearing fruits (Table 7).

Table 6 Fruit and seed set in sago palms with man-assisted pollination during anthesis. No seed-bearing fruit was set.

Palm no.	Sources of staminate pollen	Av. no. of flowers pollinated per ax2	No. of mature fruits formed per ax2 (mean ± sd)	No. of seed-bearing fruits formed per ax2
5	palms 4 & 6	87	7.3 ± 3.1	0
6	palms 4 & 5	58	5.3 ± 0.6	0
8	others	125	7.7 ± 1.5	0
9	others	34	4.3 ± 1.5	0

Table 7 Comparison of fruit and seed set in ax2 of palm 8 in which the inflorescence was bagged throughout, with those in which the bags were opened during anthesis to allow insect visits.

Treatment		No. of mature fruits formed per ax2	No. of seed set per ax2	% seed set per ax2.
Bagging throughout experiment	1)	14	0	0
	2)	28	0	0
	3)	20	0	0
Bags opened during anthesis and closed thereafter	1)	22	3	14
	2)	23	0	0
	3)	31	1	3.2

6.4.8 Pattern and and duration of fruit growth

In palm 3, the fruit growth was monitored for about 17 months until some fruits were mature. Data of later stage of fruit growth in palms 4 and 5 were missing. Increase in fruit size was most rapid during the first 24 weeks and after that, the increase was gradual (Fig. 8). A slow rate of increase in fruit size was still noticed at 17 months when fruits started to mature and fall.

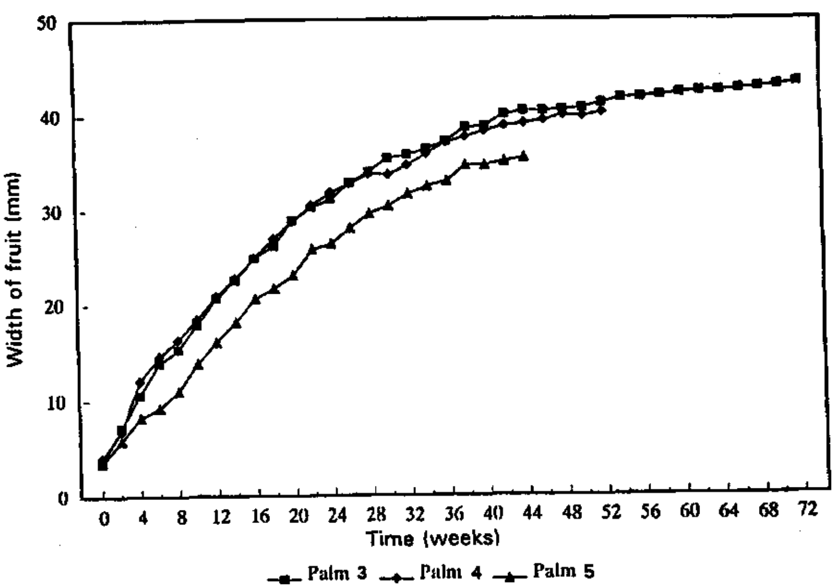

Fig. 8 The growth of sago palm fruits. Data of later stages of fruit growth in palms 4 and 5 were missing.

The number of fruits grown to maturity in each palm ranged from 2174 in palm 5 to 6675 in palm 8. The duration from the opening of the first staminate flower to the last day of fruit fall ranged from 19 to 23 months. Except for palm 8 which produced 5.1% of seed-bearing fruits, the other 4 palms produced only seedless fruits (Table 8).

Table 8 A summary of the dates of anthesis, fruit drop, duration of fruit growth and the numbers of seedless and seed-bearing mature fruits formed in palms 4, 5, 6, 8 and 9.

Palm no.	Date of first staminate flower opening	Date of last fruit fall	Duration of fruit growth (months)	Total no. of mature fruits formed	Total no.of seeds set	% of seed set
4	19.9.90	17.8.92	23	5875	0	0
5	29.9.90	24.5.92	20	2174	0	0
6	31.10.90	20.5.92	19	3272	0	0
8	1.5.92	14.1.94	20	6675	343	5.1
9	15.7.92	22.2.94	19	2876	0	0

6.4.9 Assessment of seed-bearing to seedless ratio in sago palm fruits

In the main sago producing areas of Mukah District (Sibu Division), two-thirds of the palms sampled contained seed-bearing fruits. The percentage of seed-bearing fruits in each of these palms ranged from 4.1 to 74.6% (Table 9). In the Kuching Division, six palms out of 20 produced seed-bearing fruits. The percentage of seed-bearing fruits in the palms (that produced seeded-fruits) ranged from 1 to 6% (Table 10). Although more seeds were usually found in palms fruiting at about the same time in proximity of other palms, some seeds were also set in palms isolated from one another in flowering time and in distance of greater than 500 m.

Table 9 Fruit sampling to determine the percentage of seed-bearing fruits in sago palms in Mukah District

Palm no.	No. of fruits sampled	No. of seed-bearing fruits	% of seed-bearing fruits	Location of sampling	Remarks*
1	88	64	72.7	Jebungan	Palms 1, 2 & 3 were
2	104	38	36.5	"	at same fruiting stage
3	86	45	52.3	"	within 20 m from each other.
4	125	0	0	Kg. Musjid	All 4 palms were at
5	108	5	4.6	"	similar stage within
6	118	24	20.3	"	250 m from each
7	56	0	0	"	other.
8	174	0	0	Balingian	Isolated
9	84	5	6	"	Palms 9, 10 & 11 were in
10	131	71	54.2	"	in similar stage 70 m
11	86	11	12.8	"	from each other.
12	125	0	0	Tg. Lapeh	Isolated
13	3862	2880	74.6	Near Airport Mukah	Isolated
14	120	6	5	Tg. Lapeh	Isolated
15	138	24	17.4	Tg. Lapeh	Isolated
16	106	0	0	Tg. Lapeh	Isolated
17	123	5	4.1	Kg. Suyong	Isolated
18	52	0	0	Kg. Suyong	Isolated
19	50	0	0	Sg. Apai	Isolated
20	83	11	13.3	Kg. Suyong	Isolated
21	116	8	6.9	Kg. Lintang	Isolated

*Isolated = separated in flowering stage or distance of more than 500 m.
Tg.=Tanjong (river bend), Kg.=kampong (village), Sg.=sungai (river).

Table 10 Fruit sampling to determine the percentage of seed-bearing fruits in sago palms in Kuching Division

Palm no.	No. of fruits sampled	No. of seed-bearing fruits	% of seed-bearing fruits	Location of sampling	Remarks*
1	2049	74	3.6	Padawan	Isolated
2	120	0	0	29 Mile K/S Rd.	Isolated
3	250	0	0	Padawan Rd	Isolated
4	374	0	0	Bau Road	Palms 4 & 5 were at similar fruiting stage
5	97	2	2.1	"	95 m from each other
6	135	7	5.2	Lundu	Isolated
7	3520	218	6.2	Sematan	Isolated
8	257	0	0	Lundu/Sia Rd	Isolated
9	427	0	0	Santubong	Isolated
10	168	0	0	Batu Kawa	Isolated
11	279	8	2.7	16 Mile K/S Rd	Palms 11, 12, 13 & 14 were from the same
12	133	0	0	"	swamp fruiting at about the same time. Furthest
13	1852	0	0	"	separation between palms was 400 m.
14	179	0	0	"	
15	526	5	1	Sungai Pinang	Isolated
16	315	0	0	Siburan	Isolated
17	209	0	0	"	Isolated
18	119	0	0	"	Isolated
19	387	0	0	Jembusan	Palms 19, 20 & 21 were from the same
20	469	0	0	"	location within 250 m from each other
21	365	0	0	"	at similar fruiting stage.

*Isolated = separated in flowering stage or distance of more than 500 m.

6.5 DISCUSSION

6.5.1 Estimate of flowers in inflorescence

In the spineless cultivar of sago palm found in the study area, the number of flower buds just before anthesis ranged from 276,000 to 864,000. The estimate is close to the actual number because the exact number of ax3 was counted. Besides, the abortion of flower buds is almost complete at this stage as explained in the following paragraph.

During flower bud growth, abortion of buds occurred until flowering. One of the flower buds in a pair abscised and was pushed out of the bracteole, probably to give sufficient space for the development of the other one. The abscised can either be a staminate or a hermaphroditic flower and can be from either side of the flower pair. When the buds attain maturity, flower pairs are very few. A bracteole usually contains a single mature bud. Abortion of both staminate and hermaphroditic flower buds in one bracteole is also common, leaving empty bracteoles on some parts of the rachilla. Paired flower buds (Beccari 1918, Tomlinson 1971, Kiew 1977, Utami 1986, Uhl and Dransfield 1987, Tuwan 1991) was uncommon on a rachillae approaching anthesis.These are mainly found in young flower buds in this study. It is probably that the specimens these authors examined were at a younger stage where abortion had not taken place, or that such abortion did not occur in the specimens they studied.

Tomlinson (1971) estimated the number of flowers in *M.vitiense* to be 917,280, of which half were hermaphroditic flowers. He speculated that the number could be double in *M. sagu* due to its greater size. The present study on *M. sagu* showed that the number was smaller than those speculated by Tomlinson and those estimated by Tuwan (1991) in the 'species' she used. Nonetheless, the flower estimates made in this study generally agree with those of Utami (1986) and Kiew (1977) although the estimate of the latter was on the low side.

In the current study, the maximum number of buds encountered in a rachilla just before anthesis was over 400. Thus for palm 4 that has 3427 rachillae, it is possible to produce 3427 x 400 = 1,370,800 flowers. In the young stage when the flowers are still in pairs, the number could be double. However, the actual observation in the field is that the density of buds in a rachilla is very variable, as reflected from the random samples in this study (Table 2).

6.5.2 Bagging experiment

The insignificant difference in the number of fruits formed with and without bagging in both palms shows that the type of bagging used in this study did not affect fruit set and development.

Fruits were set in the hermaphroditic flowers. However, throughout fruit development, they were successively aborted, probably due to over-crowding. Two months after fruit set, most rachillae contained 20-50 fruits. After 16 months when the fruits were approaching maturity, an average of two full-sized seedless fruits were left per rachilla, with a range from 0-5. This is lower than the figures of 1-4 in a bagged rachilla and 3-15 in an un-bagged rachilla reported by Utami (1986). She concluded that insects were important to promote fruit set. It was not mentioned whether the fruits contained seeds.

In this study, insect visitors were abundant but did not enhance fruit set as suggested by Utami (1986). Seedless fruits were set in all the treatments and in the whole inflorescence of both palms, suggesting that sago palms are parthenocarpic. Formation of seedless fruits in this study made it inconclusive whether the sago palms were cross-pollinated. Although insect visitors were present, it was not certain whether they were capable of transferring pollen or whether compatible pollen was present for cross-pollination then. This ambiguity stimulated further investigation and is discussed in a later section.

6.5.3 Time course of flower opening

6.5.3.1 <u>First opening of staminate and hermaphroditic flowers</u>

Two different types of initial flower opening were observed. One was represented by palms 4 and 5 where normal staminate and hermaphroditic flowers were present on the same palm. This shows that sago palms are andromonoecious. The other type was represented by palm 6 where normal staminate and a mixture of normal and abnormal hermaphroditic flowers were found.

In palm 6, the initial flower opening was irregular, with most of the abnormal hermaphroditic flowers and a small pulse of normal hermaphroditic flowers opening before and concurrently with the opening of staminate flowers. The overlaps in the opening of staminate and hermaphroditic flowers indicate that the cultivar used in this research are not strictly protandrous as reported by Beccari (1918) for his cultivars.

6.5.3.2 <u>Duration of flower opening</u>

The duration of opening in a palm inflorescence ranged from 50 to 100 days. This is shorter than five months in a branch reported by Utami (1986). In most of the flower branches of ax1 to ax3, a peak opening was observed within the duration of opening. Flowers and fruits of different development stages do occur adjacently on some ax2 or ax3, but most of the fruits set from peak flowering were quite uniform.

Although the initial opening of staminate and hermaphroditic flowers overlapped in palm 8, their midpoints of opening were similar to those of palms 4 and 5. In palm 8, the general opening of staminate and hermaphroditic flowers overlapped but the midpoints of their openings only overlapped to a slight extent between the proximal and distal ax1.

In palms 4, 5 and 8, the midpoints of fruit set followed closely with the midpoint of opening of the hermaphroditic flowers. This suggests that most fruits were set after the opening of the normal hermaphroditic flowers. Although overlaps in the midpoints of opening of staminate and the abnormal hermaphroditic flowers occurred in palms 6 and 9, the pistils of these flowers were largely immature and physiologically non-functional at peak opening. This should not be considered as true overlaps physiologically.

From the above, evidently sago palms in this study are largely but not strictly protandrous, a different observation from that mentioned by Beccari (1918). Also, the sago palm is andromonoecious, with staminate and hermaphroditic flowers on the same inflorescence.

6.5.4 Daily sequence of flower opening

The timing of opening of staminate flowers, secretion of nectar, and the timing of insect visits was similar to the report by Utami (1986). The major insect visitors encountered in this study, *Trigona* and *Apis* spp., are also found by Utami. *Trigona* spp. has also been reported to visit inflorescence of *Iriartea ventricosa* (Henderson 1985,'86). This suggests that insect visitors play an important role in the pollination of palms, including the sago palms.

The opening of staminate flowers in this study only lasted one day and they were abscised the next day before noon. This is in contrast to the findings of Utami (1986) and Tuwan (1991) that opening of staminate flowers lasted 3-4 days. The amount of nectar was estimated at about two drops per flower, roughly 0.05 cm^3 rather than 2 cm^3 as described by Utami (1986).

Six types of birds (unidentified) were trapped during anthesis of one palm. They had long pointed beaks and some were seen to suck nectar. Dissection of their stomach contents showed that they also preyed on stingless bees.

Apart from the fusion of filaments at the proximal end, the stamens of newly opened hermaphroditic flowers are identical to those of staminate flowers at 30 times magnification. The hermaphroditic flowers also open in a similar manner to the staminate flowers. This confirms that normal stamens are present in the flower pairs (Tomlinson 1971,'90; Uhl and Dransfield 1987) which Beccari (1918) and Utami (1986) considered physiologically female. The secretion of nectar by the newly opened hermaphroditic flower was in contrast to the report of Utami (1986) that nectar was only secreted by staminate flowers. Probably, the flowers she examined possessed non-functional stamens as reported by Beccari (1918), and flowers of this kind are unable to secrete nectar. The prematurely opened abnormal hermaphroditic flowers investigated in this study were also unable to secrete nectar.

From the current study, the proportion of opened staminate flowers were estimated to be 20-30% in palm 8 and around 1% in palm 9. This indicates that staminate and hermaphroditic flowers were not present in equal ratio as speculated by Tomlinson (1971).

Observations made in this study coupled with the reports of Beccari (1918), Tomlinson (1971) Utami (1986) and Tuwan (1991) infer that three biological types of flower combinations are found in the sago palm viz.:

(i) Male (staminate) and pseudo-hermaphrodite or female (Beccari 1918, Utami 1986 and Tuwan 1991)

(ii) Staminate and hermaphrodite (Tomlinson 1971, and this study)

(iii) Staminate and abnormal hermaphrodite - the latter opens prematurely and the stamen dies during opening (this study).

Whereas type (i) has not yet been encountered in Sarawak, types (ii) and (iii) are common. Type (ii) can be found in individual palms and type (iii) are found in combination with type (ii) in the same palm as represented in palms 6 and 9 in the current study. It may well be that the type (iii) actually is the same as type (i) which eventually opens before the buds are mature.

6.5.5 Pollen examination

Pollen from staminate and hermaphroditic flowers was succulent and sticky in appearance, suggesting that they are most likely to be insect pollinated. The smaller size and pale colour of the pollen from prematurely opened abnormal hermaphroditic flowers were apparently non-functional because no nectar was secreted during the opening. Very few insects visited such flowers at opening.

After insect visits, the presence of pollen all over the flower parts including the stigmata of opened flowers and the body parts of bees (*Trigona* and *Apis* spp.) shows clearly that sago palms are insect pollinated. That most of the pollen sacs were quite empty after insect visits indicated that the pollen was partly scattered to other flower parts and probably also taken away or eaten by these insects.

The presence of germinated pollen in 10% sucrose solution and nectar showed that some viable pollen grains were around to pollinate the flowers on palm 8. As pollen was collected from un-bagged flowers of staminate and hermaphroditic types, it cannot be certain that the germinated pollen is from the same palm and not brought in by pollinators. The very low frequency of germination casts some doubt on the viability of pollen from the apparently normal staminate and hermaphroditic flowers from palm 8. It is regretted that pollen in nectar was not collected from the bagged flowers to find out if it is viable.

As the size of pollen of the spineless and spiny cultivars were collected on different occasions and kept in different ways, it is not appropriate to compare their sizes to differentiate the variety. Their size is greater than that of about 30 by 15 μm described in all the taxa of *Metroxylon* (Thanikaimoni 1970). Recticulate ornamentation on pollen grains of different species (Thanikaimoni 1970, Sowumni 1972, Tuwan 1991) could not be detected. Some triangular pollen grains similar to those of *'M. sylvester* Mart.' as described by Tuwan (1991) were seen during determination of fresh pollen size of the spiny cultivar. However, it was uncertain whether these pollen grains were defective or dehydrated as the normal oval shaped pollen were present in larger proportion.

6.5.6 Assisted self- and cross-pollination

6.5.6.1 Selfing

Observations on timing of flower opening, presence of insect visitors and characteristics of pollen suggest that pollination should be done around 1200-1400 hours. Pollen should be collected from the light purplish or light orange/yellow anthers from freshly opened normal flowers. All these steps were carried out and after pollination, it was also made sure that pollen was present on the stigma. Despite this and regardless of the pollen source and methods used, no seed was set in the man-assisted selfing experiment. This reflects that the pollen or stigmata are either naturally defective, pollen or stigmata damaged during pollination, or some kind of self-incompatibility existing between the pollen and the pistil. Judging from the insect-pollinated flowers throughout the inflorescence which also produces seedless fruits in palms 4,5 and 6, it is likely that the timing and method of pollination used was appropriate. Seedlessness is likely a result of natural defectiveness of the sexual organs or of self-incompatibility. These findings contradict the report of Utami (1986) that sago palms are self-pollinated.

The formation of seedless fruits supported earlier results from palm 2 and 3 and showed that parthenocarpy occurs in sago palms.

6.5.6.2 Crossing

Formation of seedless fruits from man-assisted crossing was unexpected. For palms 6 and 9, the abnormal opening could have led to the wrong timing of pollination which has to be carried out when the stigmata are receptive.

Palms 5 and 6 stood at a distance of only 14 m and the numerous visiting insects could surely have transferred pollen from one palm to the other. However, in the entire inflorescence of both palms, no seed-bearing fruits were formed. It is probable that they are closely related, possibly both being vegetatively propagated from the same parent and thus incompatible. For reasons yet unknown, neither man-, nor insect-assisted pollination in palm 4 yielded any seed-bearing fruits.

Some light is shed by the study on palm 8. Although the manual crossing and continuous bagging experiments produced no seed-bearing fruit, 0-14% of seed-bearing fruits were obtained in bagged flowers that was allowed to be pollinated by insect visitors during the whole flower opening period. Besides, 5.1% of seed-bearing fruits were formed in this palm that was heavily visited by insects during anthesis. This provides strong evidence that seeds are only set through cross-pollination, different from self-pollination as reported (Utami 1986). However, the finding of insect assisted pollination is in agreement with the report of Utami (1986).

In palm 8, flowers sampled after insect visits showed that all of them had pollen on their stigmata. However, only 5.1 % of the fruits contained seeds. This shows that the pollen in a vast majority of the stigmata did not result in seed set. It is most probable that most of the pollen is from the same palm and it is unable to induce seed set.

Thus, it appears that the failure of inducing seed set in the man- or insect-assisted pollination was due to the absence of compatible or non-defective pollen at that time. Further investigation along this line is essential to provide further understanding of this subject.

6.5.7 Fruit and seed set and duration of fruit growth

The growth of the sago palm fruit follows a normal curve. The sigmoid growth curve of palms as represented in *Jubaeopsis caffra* (Robertson 1977) was not clearly visible. Fruit size continues to increase at a slow rate until the fruit drops.

The duration of fruit growth from anthesis to last fruit drop varied from 19 to 23 months in the five palms. The total number of mature fruits ranged from 2174 to 6675 per palm and most of these were seedless. This gave an average of 0.8 to 2.3 fruits per rachilla. The estimated fruit yield of about 2500 (Kiew 1977) was within this range. In general, a sago palm in this region with heavy fruiting can produce about

5000 fruits, each of about 4 to 5 cm in diameter.

6.5.8 Assessment for seed-bearing to seedless ratio in sago palm fruits

Whereas in some locations it is true that palms flowering at about the same stage in proximity enhances seed set, this phenomenon is not always seen in other locations as reflected by the sampling results. Isolated fruiting palms have been found to produce many seed-bearing fruits too.

In the Kuching Division, fruiting palms produce few seed-bearing fruits even with several palms flowering at the same time within the vicinity. This could probably be due to incompatibility of closely related palms as they could have been established vegetatively from the same parent. In the main sago producing areas of Mukah District, the palms are probably more diverse in genotype and thus able to produce more seed-bearing fruits.

Near to Mukah airport, palms were usually found to bear seed-containing fruits in 1987. However, during recent sampling, sago palms in the same location were hardly found to contain seeds. It is speculated that for seeds to be set, cross-pollination with compatible pollen is important. Insect pollinators bringing in the compatible pollen at anthesis is also essential.

6.6 CONCLUSIONS

The flowering biology of sago palms was investigated in the Dalat and Mukah Districts of Sarawak. In the early stage, flower buds are found in pairs on the rachillae. One of them is a staminate and the other a hermaphroditic flower. During flower bud development, abortion occurs successively. By anthesis, mainly one bud is found in each bracteole. Apparently, more staminate flower buds have been aborted than the hermaphrodite ones. Before anthesis, the number of flower buds ranged from 276,000 to 864,000 in the five sago palms investigated. Bagging of inflorescence throughout flowering period and partial bagging to allow insect visits during anthesis yielded fruits without seeds, denoting the parthenocarpic development of fruits.

Sago palms are andromonoecious. Two types of flowering situations are found. In the first type, both staminate and hermaphroditic flowers are present in a palm. In the second, staminate and a mixture of hermaphroditic and abnormal hermaphroditic flowers are encountered. The abnormal hermaphroditic flowers open before they are mature, with non-functional stamens which wither during opening.

In general, staminate flowers open 2-4 weeks earlier than hermaphroditic flowers and progress gradually from the proximal to the distal ax1. Fruit set 3-4 days after the opening of hermaphroditic flowers. The duration of flower opening in the whole palm is roughly one month for staminate flowers and 50 days for hermaphroditic flowers. In palms with premature flower opening, the duration can be extended to over 3 months. To a large extent, the sago palms are protandrous but such a condition is not exclusive as overlapping of opening in staminate and hermaphroditic flowers does occur.

The peak of daily opening of staminate and hermaphroditic flowers is between 1030 and 1230 hours. The anthers of staminate and hermaphroditic flowers are apparently identical and open in the same manner. Each flower takes about 30 minutes to open completely from the bud stage. Freshly opened flowers have light purplish anthers which gradually turn light orange and yellow. Nectar is secreted around midday in both newly opened staminate and hermaphroditic flowers. Large numbers of insect visitors, predominantly the *Trigona* spp. and *Apis dorsata*, are found during flower opening with the greatest number at around 1200-1430 hours. Each staminate flower opens for one day and is aborted and forced out of the bracteole before the next noon. The hermaphroditic flowers remain open for 2-3 days after which fruits are set.

Examination of pollen at 30 times magnification indicates that fresh pollen from staminate and hermaphroditic flowers are apparently identical. The anthers burst open to expose the succulent and sticky looking pollen before the flower opens completely. The pollen of the abnormal hermaphroditic flowers at opening is smaller and pale, apparently premature and non-functional. Examination at 1400 hours shows that pollen is scattered over the bodies of visiting insects and over most parts of opened flowers including the stigmata. The pollen grains are oval and averaged 26.5 by 39.7 μm in preserved sample from a spineless palm, and 29.2 by 45.1 μm in a fresh pollen sample from a spiny cultivar.

In man-assisted self- and cross-pollination, the results in one palm provide strong evidence that sago palms in the study area are obligatorily cross-pollinated and pollination is assisted by insects. The failure of seed formation in most palms is speculated to be caused by a lack of compatible or fertile pollen for pollination during anthesis.

The growth of sago palm fruits follows a normal curve. The total number of mature fruits produced in five palms ranged from 2174 to 6675 each, of which only seedless fruits were found in four palms. Parthenocarpy is common as shown in sampling carried out in Kuching and Mukah areas. The duration of fruit growth from anthesis to last fruit drop ranges from 19 to 23 months.

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CHAPTER 7

GERMINATION OF SAGO PALM SEEDS

7.1 INTRODUCTION

Although open pollinated sago palm fruits are quite abundant in Sarawak, use of seeds for propagation is only confined to some smallholder farmers for gap filling or on a trial basis. Use of suckers is preferred as farmers claim that seedlings are slower in establishment by about one to two years when compared to suckers. Since the establishment of a sago palm plantation in Mukah, shortage of planting material is experienced and the use of seedlings has increased slightly.

Because of the interest in large scale sago palm cultivation by the State Government of Sarawak, another 40,000 hectares of plantation sago have been planned for the next decade. This has prompted the exploitation of seeds as an alternative or supplementary source of planting material to cater for the expanding sago palm industry.

As sago palm seeds are reported to germinate poorly, methods to increase their germination were investigated in the following experiments:

(a) Germination capability of seeds in different stages of maturity
(b) The effect of removing husk (exocarp and mesocarp) and fleshy tissue (sarcotesta) on seed germination
(c) Germinability of seeds in response to some physical and chemical treatments
(d) Germinability of seeds at different levels of humidity.

7.2 LITERATURE REVIEW

The sago palm fruit (Fig.1) is covered in neat vertical rows of imbricate scales (exocarp), just outside a thick, corky or spongy mesocarp. The endocarp is undifferentiated. The seed is basally attached, covered in a thin to thick layer of sarcotesta. The embryo is basal, embedded in a horse-shoe like homogeneous endosperm (Uhl and Dransfield 1987).

The poor germinability of sago palm seeds has been reported by several workers (Johnson and Raymond 1956, van Kraalingen 1984, Flach 1984, Jaman 1985, Alang and Krisnapilly 1985). Johnson and Raymond (1956) reported that viable seeds are not easy to obtain and seedlings from good seeds are very mixed in type. In experiments by Jaman (1985), germinability was generally improved when sago palm fruits were de-husked and dipped in water. However, van Kraalingen (1984) found that none of the seeds germinated in a similar treatment and suggested that the right stage of maturity was important for germination.

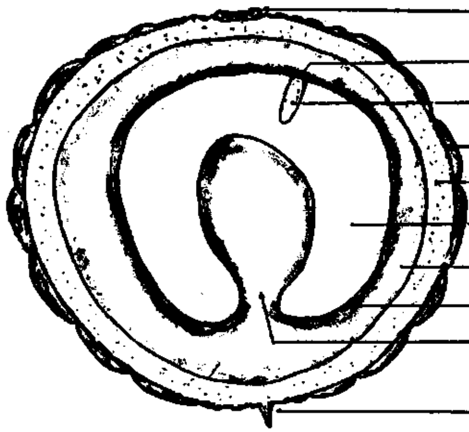

Fig. 1 A vertical section of a seed-bearing sago palm fruit showing the scaly husk, sarcotesta and the endosperm.

Alang and Krishnapillay (1985) also suggested that seed maturity is important for germination, and the most reliable method is to remove the fruit tissues and plant the seeds with the proximal end uppermost. They also reported that the sago palm seeds are very prone to desiccation. The use of fully matured seeds was also reported by Schuiling and Flach (1985). These authors recommended that for best germination, the seeds should be placed on the top of soil in a thin layer of water that does not cover them completely.

In designing this experiment, it is assumed that dormancy exists in sago palm seeds. Some common physical and chemical treatments promoting the germination of seeds in other plant species (Bewley and Black, 1978) were applied to the sago palm seeds.

7.3 MATERIALS AND METHODS

7.3.1 Germinability of seeds at different stages of maturity

7.3.1.1 Seed preparation and selection

Sago palm fruits at different stages of maturity were harvested. The husk and fleshy tissue or outer-integument were then removed by hand or by a medium-hard metal brush. Seeds at the following stages were selected for comparison of their germination ability.

Stage 1- Seeds with semi-hard endosperm; testa not distinct.
Stage 2- Seeds with solid endosperm; testa white and slimy.
Stage 3- Seeds with hard endosperm; testa partially brown.
Stage 4- Seeds with hard endosperm; testa totally brown.
Stage 5- Seeds with hard and bony endosperm; testa thick and dark brown.

7.3.1.2 Germination test

Four replicates of twenty seeds from each stage were buried to a depth about 2 cm in a tray (30 cm x 50 cm x 25 cm) with the embryo-end positioned just above the sand level. Drainage holes were drilled on the sides of the tray about 1 cm from the bottom. The sand trays were placed in a plant house at 25 -35° C and watered daily. Germination counts were made at weekly intervals for the first five weeks and later at biweekly intervals until 15 weeks.

7.3.2 The effects of removing husk and fleshy tissue on seed germination

Mature and seeded sago palm fruits at stages 4 and 5 were treated as follows:
(i) Husk removed, leaving the fleshy tissue intact (-H +F).
(ii) Both the husk and the fleshy tissue removed (-H -F).
(iii) Whole fruit with husk and the fleshy tissue undisturbed.

Four replicates of twenty fruit from each of the above treatments were germinated on wet sand trays as described in experiment 1.

7.3.3 Responses of seed germination to some physical and chemical treatments

De-husked and de-fleshed sago palm fruits (stages 4 and 5) were treated as follows:
(i) Loosening of operculum (fibre plug) - the plug was carefully loosened using a fine needle.
(ii) Warm water treatment - seeds were placed in polythene bags and submerged in a water bath automatically regulated at 40° C for 48 hours before the germination test.
(iii) Cold treatment - seeds were placed in polythene bags and kept in a fridge at 2-4° C for 48 hours before the germination test.
(iv) Brief treatment with concentrated sulphuric acid (H_2SO_4) - seeds were placed in a plastic container and treated with concentrated H_2SO_4 for three minutes and then rinsed thoroughly with water before the germination test.
(v) Chemical treatments - seeds were soaked in a 10^{-3} M gibberellin (GA) and 10^{-4} M auxin (IAA) respectively for 48 hours before germination tests.
(vi) Control - no treatment.

For each treatment, four replicates of twenty seeds each were tested for their germinability.

7.3.4 The effects of different levels of humidity on the germination of sago fruit

This experiment is intended to find out a practical and simple method of seed germination that can be carried out in the field. In the absence of humidity detecting instrument, polybags punched with different number of holes to represent the different humidity levels were used.

Sago palm fruit at stages 4 or 5 were divided into four replications of twenty each and subjected to the following treatments.

(i) Partially submerged with the proximal end of the fruit just above the water level.
(ii) In a 30 cm x 45 cm polythene bag sealed completely.
(iii) In a 30 cm x 45 cm polythene bag punched with 10 holes (of diameter 6 mm)
(iv) In a 30 cm x 45 cm polythene bag punched with 20 holes (of diameter 6 mm)
(v) In a 30 cm x 45 cm polythene bag punched with 30 holes (of diameter 6 mm)
(vi) In a 30 cm x 45 cm polythene bag punched with 50 holes (of diameter 6 mm)
(vii) In an open tray.

The experiment was done in a plant house at 25-35^0 C. Enclosure of seeds in polythene bags punched with different number of holes was assumed to create different levels of humidity under which sago seeds would germinate. Germination counts were made at weekly intervals for nine weeks.

7.4 RESULTS

7.4.1 Germination of seeds at different levels of maturity

Young sago palm seeds at stages 1 and 2 hardly germinated at all (Fig.2). The rate of germination then increased with increasing seed maturity. Seeds at maturity stages 3, 4, and 5 recorded final germination of 19, 35 and 40% respectively at 15 weeks.

7.4.2 Effects due to de-husking and removal of fleshy tissue

Removal of husk only and removal of husk plus fleshy tissue increased the speed and number of sago palm seed germination (Fig.3). In the presence of husk and fleshy tissue, germination commenced after the fifth week and reached only 13% after 15 weeks. In contrast, germination of de-husked and de-fleshed seeds commenced at least three weeks earlier, with 42% and 35% germination respectively after 15 weeks.

In general, de-husked and de-fleshed seeds germinated more readily in the first 12 weeks than those which were only de-husked. However, more de-husked seeds germinated after the 12th week.

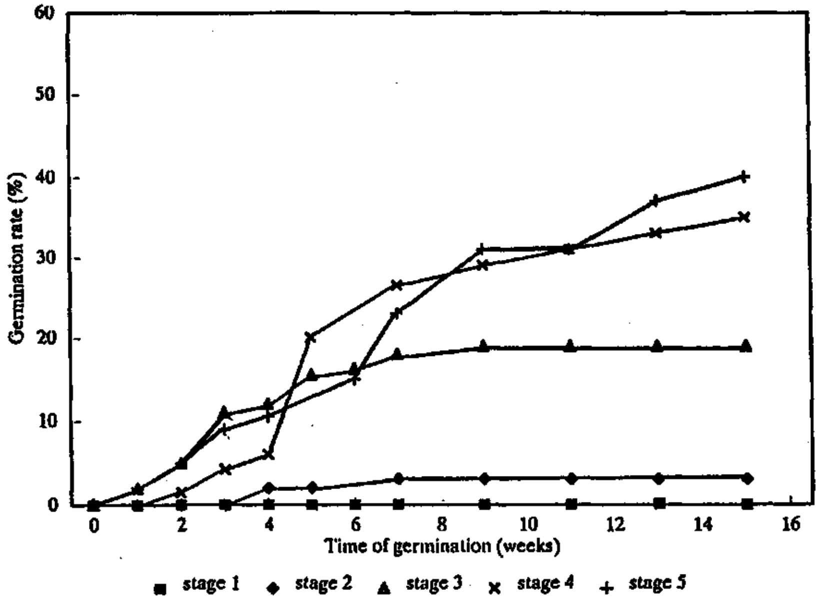

Fig. 2 Time course of germination of sago palm seeds at different stages of maturity (stage 1 being the youngest and stage 5 the oldest).

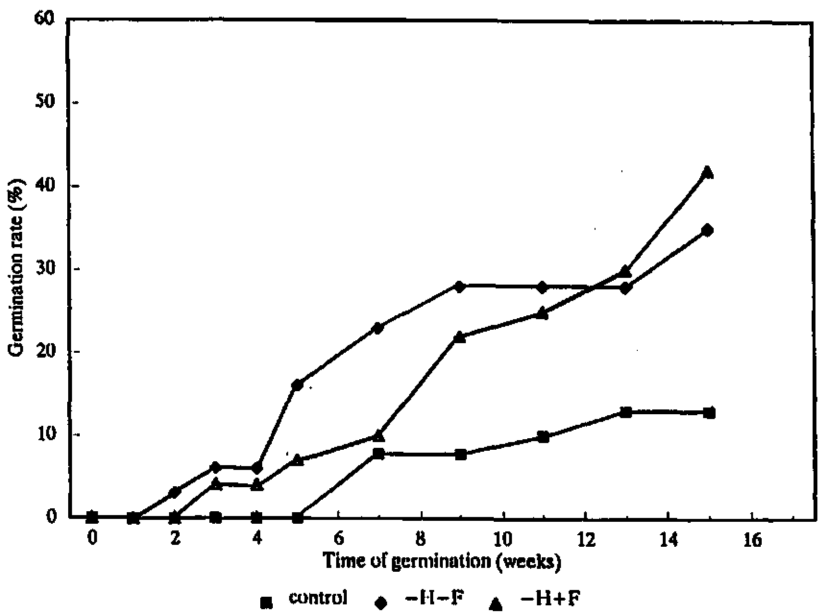

Fig. 3. Seed germination response of sago palms to de-husking and removal of fleshy tissue

7.4.3 Effects due to some physical and chemical treatments of seeds

Loosening of the operculum as well as treatment with 10^{-3} M GA increased the rate and number of sago palm seed germination (Fig.4). Brief treatment with concentrated H_2SO_4 was fatal to the seeds whereas chilling decreased the speed and reduced the number of seed germination. Compared to the control, IAA promoted and accelerated germination. Warm water treatment, on the other hand, decreased the speed and number of the initial seed germination.

7.4.4 Effects of different humidity levels on the germination of sago palm fruits

The germination of intact sago fruit as denoted by the emergence of shoot through the husk, was largely influenced by the different humidity levels in polythene bags punched with 0, 10 or 20 holes (Fig. 5). Seed germination declined sharply at lower humidity in bags punched with more holes. None of the seeds germinated when they were left on open trays completely exposed to the air. Under excessively wet conditions by which the fruits were partially submerged in water, only 1.7% of them germinated.

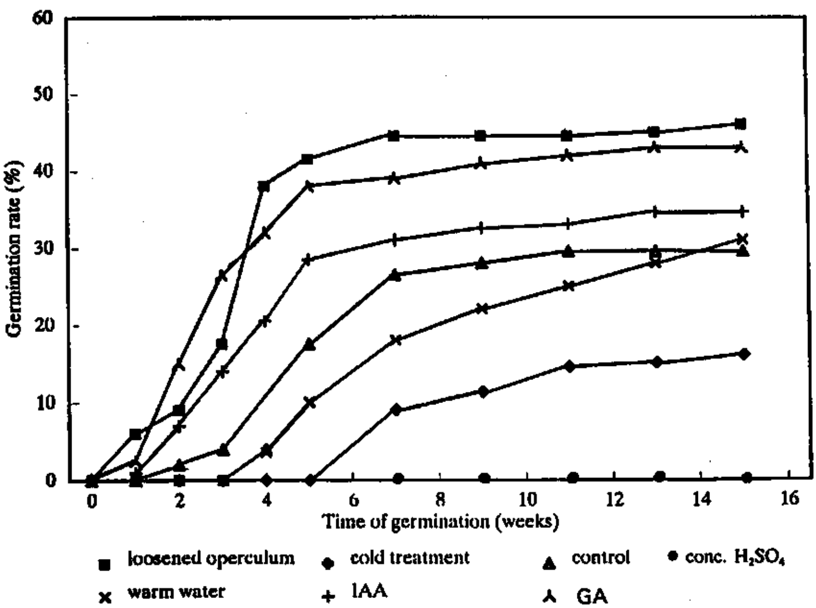

Fig. 4 Response of seed germination of sago palm to some chemical and physical treatments.

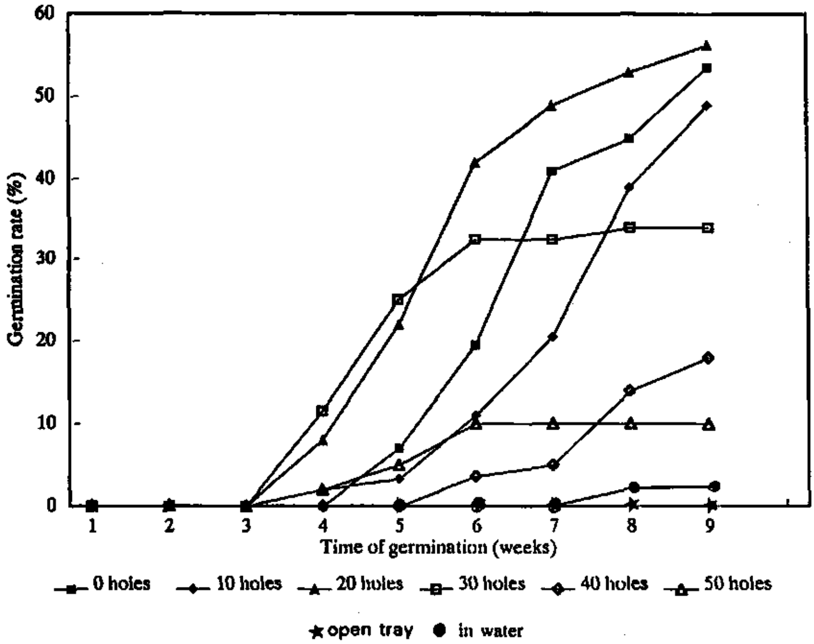

Fig. 5 Germination of sago palm seeds at different levels of humidity. The humidity decreased with the number of holes punched on the polythene bags.

7.5 DISCUSSION

7.5.1 Seed maturity and germinability

Seed maturity is considered to be an important factor governing the capacity for germination in sago palm seeds (Alang and Krishnapillay 1985, Jaman 1985, Schuiling and Flach 1985). The present study provided further evidence that the capacity for germination in sago palm seeds increased steadily with maturity. In the field, mature fruit can be recognised by the straw-coloured husk and large fruit size (Kiew 1977, Alang & Krishnapillay 1985). Another way to find out the maturity is by opening the mature fruit. The seed is mature if a hard stony endosperm with a brown or dark-brown testa is present.

7.5.2 Effects of husks and tissue on germination

Previous work showed that the removal of husk enhances the germination of sago palm seeds (Jaman 1985). In the present study, the removal of husk only or husk plus fleshy tissue enhanced and accelerated germination.

After 15 weeks, most of the ungerminated intact fruit had viable seeds with firm husk and fleshy tissue. In contrast, the fleshy tissue of de-husked fruit had mostly decomposed. Low viability was noted in the remaining ungerminated fruits that were de-husked or de-fleshed. Most of the embryos of these fruits were brown and dead.

The beneficial effects of removing husk and fleshy tissue in accelerating germination suggest that some kind of germination inhibitor is probably present in the seed coat and fruit tissue. Removal of these structures reduces such inhibitors to a certain level through leaching and decomposition, thereby promoting the initiation of germination.

7.5.3 Responses of seed germination to some chemical and physical treatments

The germination of sago palm seeds is promoted by loosening the operculum and soaking with gibberellic acid. It is suspected that loosening of the fibre plug probably lifted the pressure exerted on the emerging embryo. The promotion of germination by gibberelic acid can possibly be due to the stimulation of enzyme activities as reported in rice (Roy 1973), pepper and tomato (Varga and Stumpf 1979), or increased respiration (Nagy 1982). Perhaps, endogenous inhibitors are present and these block the gibberellin-mediated germination response as reported in other plant species (Wareing, Van Staden and Webb 1972).

Other treatments effective in promoting germination in seeds of various other plant species are not effective in promoting the germination of sago palm seeds. This is probably due to differences in seed structure and differences in the ecological niche in which sago palms grow. It may also be due to differences in the co-adapted requirements for germination to ensure survival of the species under specific conditions.

7.5.4 Germination at different levels of humidity

The polythene bags punched with different number of holes are quite satisfactory in providing roughly different levels of humidity inside where the fruits germinate. As compared to de-husked and de-fleshed fruit, intact sago palm fruits generally require a longer lag period of about three weeks to commence germination. To enable satisfactory germination, intact fruit must be kept in an environment where the humidity level is not excessive but high enough to prevent the desiccation of the entire fruit as it is recalcitrant. Under such a condition, decomposition of the husk and fleshly tissue occurs and germination proceeds smoothly with shoots emerging from the decomposing tissue and husk. This finding supports the reports of Schuiling and Flach (1985) that germination requires high humidity but differs in the excessive moisture conditions recommended by them.

Coupled with the poor germination, little decomposition of husk and fleshly tissue occurs in fruit partially submerged in wet sand tray. Even under excessively humid conditions in sealed polythene bags, commencement of germination is somewhat delayed. Besides, fungal growth is encouraged, killing some germinating seedlings.

Under lower than optimal humidity conditions, decomposition of tissue and concurrent germination occurs in the first two to three weeks. However, gradual desiccation prevents further germination. Examination of desiccated fruit after the nine-week test period showed that many seeds did germinate but the shoots and roots died of desiccation within the husk. This observation agrees with Alang and Krishanpillay (1985) that sago palm fruits are very prone to desiccation.

The observation that seed germination proceeds with the decomposition of fruit tissue again implies that some kinds of germination inhibitors are present in the fruit. These inhibitors are gradually broken down during the process of fruit tissue decomposition thereby facilitating seed germination.

Having shown that a damp environment is essential for the germination of sago palm fruit, trials were carried out to germinate sago fruit in bulk. Several batches of a few hundred mature fruit each were placed in a semi-permeable Hessian-sack and kept in a shaded and damp environment. Consistent germination of 50-70% was normally obtained within eight weeks, showing that this method can be conveniently and effectively used to germinate sago palm fruit in bulk.

In all the experiments conducted above, seeds collected from the same mother palm are found to spread out their germination over a duration of several weeks. Such spreading of germination is advantageous in ensuring the survival of the species. It is probably governed by the presence of different levels of endogenous germination inhibitors in different individual seeds.

Seedlings derived from open pollinated seeds are very variable, which agrees with the reports of Johnson and Raymond (1956). Irrespective of whether the parent palm is spiny or spineless, both spiny and spineless seedlings are produced. Again, there was variability in the length and density of spines, the growth vigour and the capability to produce suckers (Jong 1989). Thus, if seedlings are to be used for propagation, culling should be done to reject those with undesirable characteristics.

7.6 CONCLUSIONS

Germination of sago palm fruits or seeds is feasible if they are sufficiently mature and the environment is sufficiently moist to prevent desiccation. Although germination can be promoted by the removal of husk or fruit tissue, loosening of operculum or treatment with GA, it is more practical and effective to germinate intact sago palm fruit by keeping them in partially enclosed moist environment such as that of a damp Hessian sack.

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CHAPTER 8

GENERAL CONCLUSIONS

8.1 Contributions of the current study to sago palm cultivation in Sarawak

A better understanding has been gained on the various critical factors affecting the survival of sago palm suckers in the nursery. Adoption of the findings and recommendations from this study is expected to increase the survival rate of sago palm suckers in plantations by about 10 - 40%. This will lead to a substantial reduction in losses due to sucker mortality. Setting the establishment cost per sucker at RM 3.50, this means the reduction of RM 72 to RM 290 per hectare.

Although smaller suckers are slower in establishment by a few months, they establish equally well in terms of survival rate and general growth when compared to the larger ones. The use of smaller suckers of 7- 10 cm in base diameter (2-5 kg) rather than the larger ones will be more advantageous in financial terms. They are more abundant, easier to extract from the parental palm, easier and cheaper to transport, handle and plant in the field. This shall reduce the price hike and temporary shortage of planting material as experienced.

The spacing trial has provided valuable information for recommending the most appropriate planting density of sago palms in large plantations and smallholders, to maximise crop yield per unit area. Planting at close spacing does not only incur a higher establishment cost but also results in suppression of quantitative and qualitative trunk production of inferior quality. Overly sparse planting in many smallholder gardens results in low number of stands and hence inefficient yield per unit area. Optimum trunk production is obtained with about 100 palm clusters per hectare.

The distribution of starch in sago palms of different growth stages enables the harvesting of sago palms at the desirable stage for maximum yield per unit time. This will promote and accelerate the development of follower palms for subsequent round of harvesting. Harvesting before full trunk growth or after fruit development stage results in low starch yield. The pattern of starch accumulation in a sago palm from the base upwards shows that palms should be harvested as close to the ground level as possible to avoid wastage. The relationship established between the starch content, moisture content and trunk density has provided useful guide to grading of sago logs for starch extraction based on their buoyancy.

Flowering biology of the sago palms, although basic, is an important prerequisite for future breeding work as similar study on the subject is scanty. The findings in the sequence of flower opening, mode of pollination and fruit development will find more direct and practical applications in controlled breeding or hybridisation, essential for varietal improvement of the sago palm. It will also support the establishment of seed gardens as an alternate source of planting materials for sago palm cultivation.

The finding on sago seed germination is significant for breeding palms which can produce seeds with better germination. In this way it may promote the use of seedlings as alternate planting materials for large scale cultivation.

8.2 Problems to be addressed for sago palm cultivation on peat

Since the intensification of sago research by the Department of Agriculture, Sarawak, in 1982, research work undertaken includes agronomy, botany and starch quality improvement. Whilst starch processing and quality improvement has been relatively well investigated, research on agronomic and botanical studies requires lengthy data collection due to the long growth cycle of the sago palm. Nonetheless, information is emerging on the general growth and development of these palms on deep peat. Agronomic practices like field preparation, nursery practices, plant spacing, sucker regulation, weeding, pest control and harvesting are ready for adoption. These will improve the efficiency of cultivation and crop yield. Clues are also emerging on the nutrition and fertilizer requirements of sago palms.

Despite the progress made, many problems remain to be solved to improve the growth and development of sago palms on deep peat. Two most important problems have been identified.

The most critical is the problem related to the poor growth of sago palms on deep peat under intensive cultivation system. The palms are retarded, slow in trunk formation, pale and dull looking. Their fronds die prematurely resulting in greatly reduced number of leaves on the crown. Sago palms in such a state of growth are expected to be extremely low in starch yield.

The other important factor hindering the development of sago palm cultivation is the long immaturity period of 10 to 15 years. Gauging from progress made for rubber and oil palm through intensive research and development, it should be possible to reduce the immaturity period to about 6-8 years through good agronomic practices, breeding and selection.

As the sago palm is a brand new plantation crop, many other problems are anticipated in the course of plantation development. These yet unknown problems need to be tackled as and when they arise.

8.3 Scope for further research in support of sago palm development in Sarawak

From symptoms of palm growth and the notoriously poor nutrient status of peat, It is very likely that severe nutritional disorders occur in these palms. The nutrient status in the fronds needs to be determined to ascertain the deficient nutrients. Research on the rates and methods of fertilizer application should be looked into immediately. This is of paramount imporance in view of the Sarawak Government's plan to expand sago plantation on deep peat.

To reduce the immaturity period of sago palms, work initiated in cultivar selection and evaluation will be continued. Breeding (conventional and mutation), *in vitro* genetic manipulation or genetic engineering to produce desirable palms should be explored.

Other basic studies in agronomy, botany, and soil essential in supporting the long term growth and development of sago palm should also be investigated. The yet unknown problems should be addressed as they are encountered.

8.4 Adoption of proper agronomic practices

Concurrent with research to address the problems in nutrition and long immaturity, the adoption of newly generated cultivation practices in nursery, weeding, scheduled sucker pruning, pest and disease control, processing and correct harvesting will be important to bring about increased yield. Traditional cultivation methods should be revolutionized, thereby improving the efficiency of production to a level that is economically viable and sustainable.

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CURRICULUM VITAE

The author was born on 22 August 1955, in a smallholder pepper and vegetable farming family at Tapah, a small town 40 km from Kuching, Sarawak. Since he was a small boy, he was required to help the family in various farming activities, a usual way of up-bringing of most "country bumpkins". It is this type of family up-bringing that enabled him to cultivate a keen interest in, and be acquainted with, various agricultural activities.

He received his primary education at the Tapah Chinese Primary School and completed his secondary education in 1975 at Dragon School (now called Tun Abdul Razak or TAR College). After two years' working as a teacher, he continued his study at the University of Leicester, England, under a Sarawak Government Student Loan Scheme, and completed his B.Sc. (Hons) in Biological Science in 1981. Between 1982 and 1984, he pursued and obtained his M.Sc. in Plant Physiology at the University of Saskatchewan, Canada, under a scholarship provided by the university.

In 1986, he was recruited as a Research Officer in the Research Branch, Department of Agriculture, Sarawak, specifically to undertake research in sago palms. Since then, he is the officer directly in charge of the Sungai Talau Sago Research Station and also the leader of the sago research team in the Department.

In the course of research in sago, the author got to know Professor M. Flach, and has been working under his guidance as an off-campus student since 1987.

Plate 1
Extremely high mortality rate of sago palm suckers in a nursery. Only a small portion of the suckers survived, as shown by the emergence of fronds

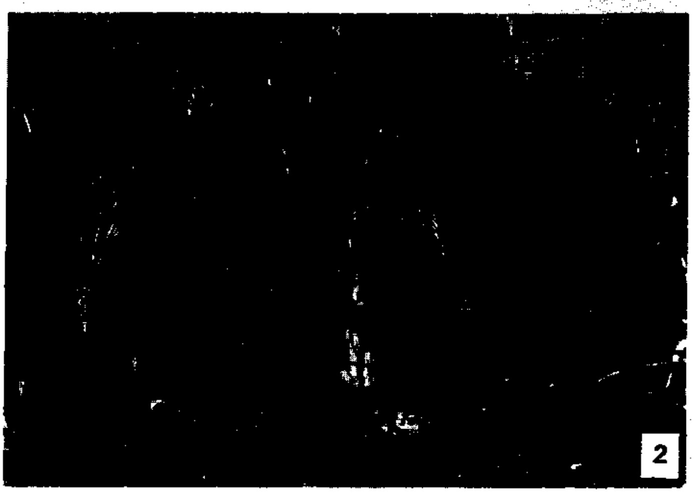
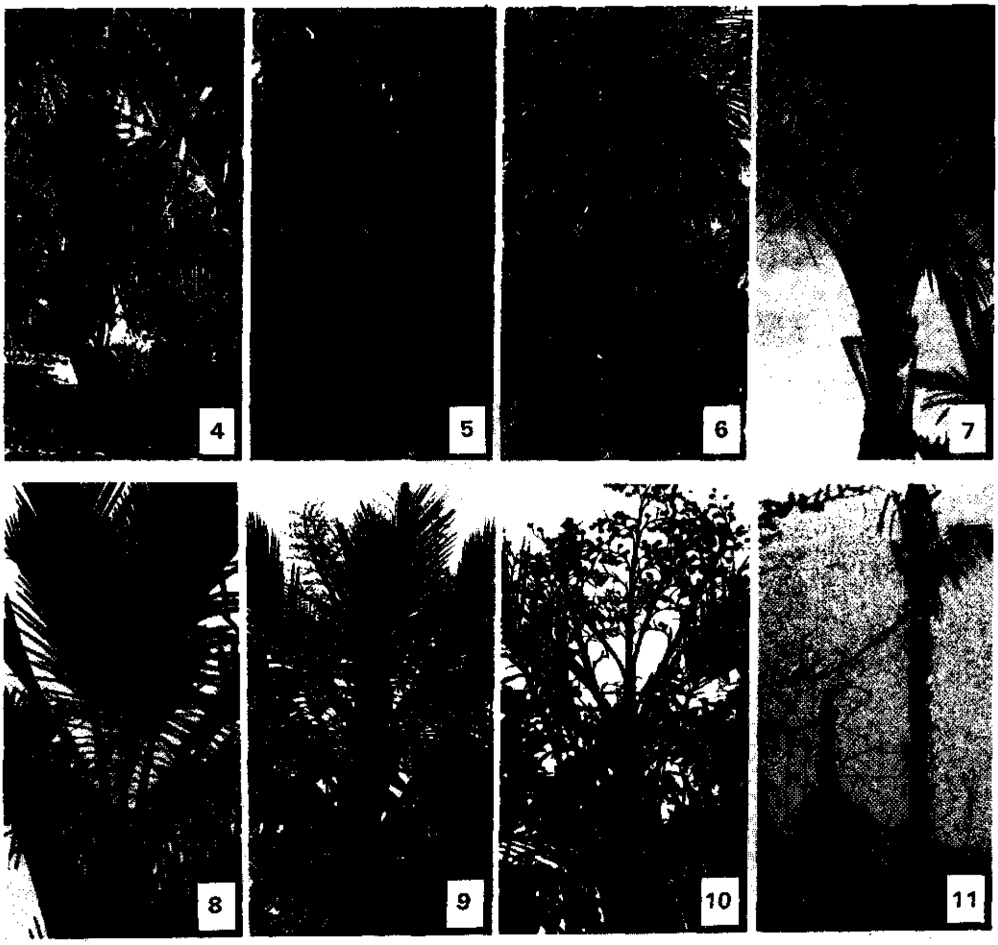
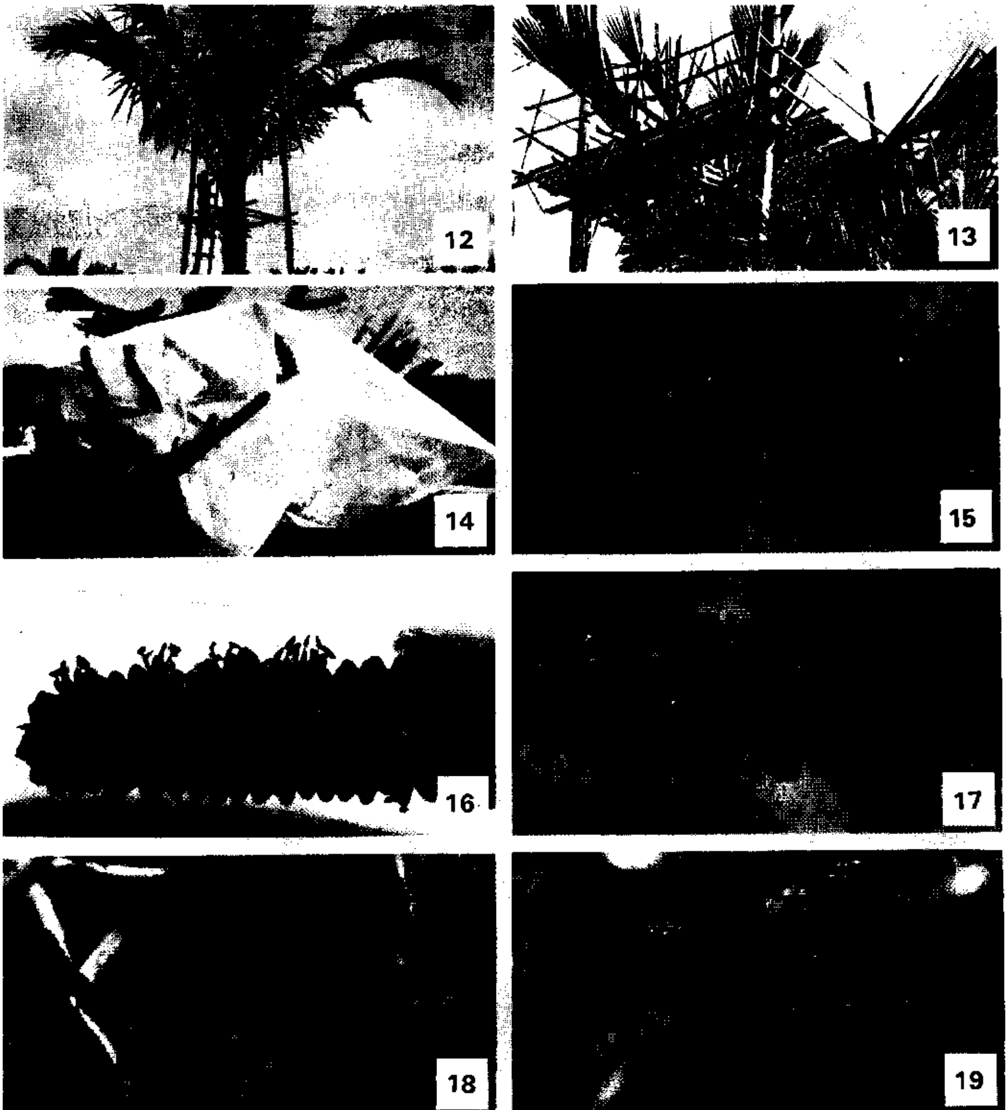


Plate 2
Nine-year old sago palms spaced at 4.5 m x 4.5 m on deep peat. Note that trunk formation and sucker growth are severely suppressed.

Plate 3
Nine-year old sago palms spaced at 13.5 m x 13.5 m on deep peat. Multiple trunks and healthy suckers are produced from most of the palm clusters.



Plates 4-11. Sago palms of different growth stages (refer text for morphological description). **4.** Trunk formation stage. **5.** Young trunk growth stages: 'upong muda' [palm a]; "upong tua" [palm b]. **6.** 50% trunk growth stage or "bibang" [palm a]; and 75% trunk growth stage or "pelawai" [palm b]. **7.** Full trunk growth stage or "pelawai manit". **8.** Bolting stage or "bubul". **9.** Young flowering stage or "angau muda". **10.** Mature fruiting stage or "angau tua". **11.** Dying stage or "mugun"



Plates 12-19: 12. A scaffold constructed around a sago palm to study the flowering biology. **13.** A plateform below the sago palm inflorescence. **14.** A nylon bag used for pollination study. Note that it is semi-transparent and can house an ax2. An airy environment is provided inside the bag. **15.** A prematurely opened abnormal hermaphroditic flower. The opening extends over a month to expose the small and yellow anthers which die during opening. **16.** Fully opened staminate flowers. The anthers are partially wilted and are supported on thick orange filaments. Flowers open randomly on the rachilla. **17.** Fully opened hermaphroditic flowers. The pistil is visible at the centre of the flower. Note the similarity of the stamen to the staminate flower and the large number of open flowers on the rachilla during this peak period. **18.** Peak opening of hermaphroditic flowers in an ax1. About 70-80 % of the hermaphroditic flowers opened during this peak of about one week. Honey bees (*Apis dorsata*) are seen in large numbers foraging on the opened flowers. **19.** Nectar produced by the newly opened hermaphroditic flowers. The nectar collects at the centre and drowns the pistil. Approximately two drops can be produced from each flower.