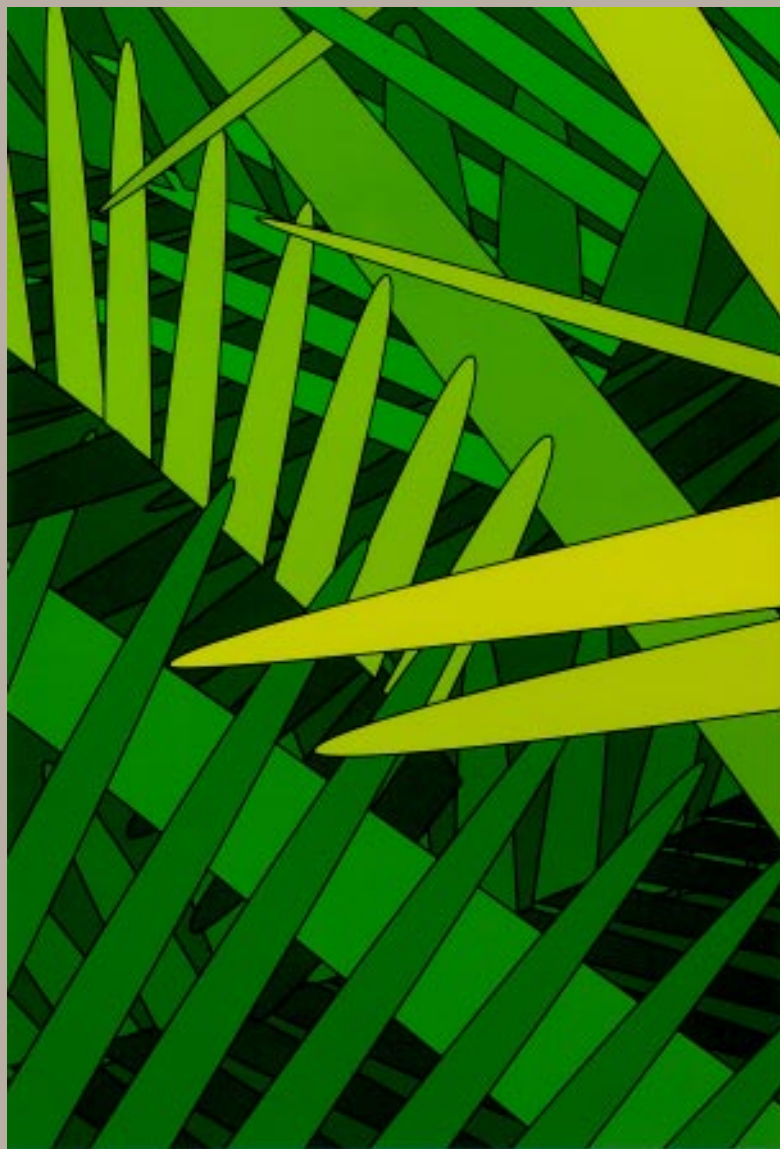


Sago palm

Metroxylon sagu Rottb.

Michiel Flach



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Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention has been given to minor (or underutilized or neglected) crops, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible, i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically. It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity. In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

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Michiel Flach

Wageningen, 30 August 1996

Introduction

The true sago palm *Metroxylon sagu* Rottb. has been described as humankind's oldest foodplant (Avé 1977), and the earliest account of the plant that reached western countries dates back to the 18th century (Rumphius 1750). The trunk contains starch, used by the plant as a reserve food for flowering and fruiting. This starch has long been a staple food for humans in South-East Asia, and as with most other palms, nearly all the other parts of the plant are used for subsistence. It is mainly grown in areas of the developing world, and has often been viewed as a 'poor man's' crop.

Numerous attempts have been made to develop cultivation of sago palm, and some commercial production of the genus can be found around Singapore, in Johor in West Malaysia, and in the Riau archipelago, in Indonesia. Sago palm is also produced commercially in Sarawak, in East Malaysia, where the crop is mainly grown on peat soils. In most other parts of Indonesia, it is used for subsistence.

In the last 25 years, interest in the crop has increased considerably. According to Stanton (1993), one of the first to advocate sago palm research, the advantages of the crop are that it is: (1) economically acceptable; (2) relatively sustainable; (3) environmentally friendly; (4) uniquely versatile; (5) vigorous, and (6) promotes socially stable agroforestry systems.

Attempts are currently being made to harvest the crop from natural stands, particularly in Indonesia, and new plantings on peat soils are being developed in Sarawak and in the Riau archipelago. Indonesia organizes national symposia and international meetings on the genus and its uses are now regularly convened. Sago palm cultivation areas are visited by local scientists, as well as by scientists from Japan, the United Kingdom and the Netherlands.

The present work is intended to provide an overview of existing knowledge of the genus, with special emphasis on its genetic resources. It will be shown that, although knowledge on this interesting crop is increasing, this is still somewhat haphazard and incomplete. Considerable research is still needed, to transform sago palm into a well-accepted industrial raw material.

1 Names and taxonomy

1.1 Vernacular names

The word *sago* is originally Javanese, and means starch containing palm pith. In quite a number of languages, however, the word has become a common name for all sources of starch. In the region in which the Indonesian-Malay language is spoken, the word *sago* is used to mean the starch of any palm (Schuiling and Jong 1996). Many palms contain starch in their trunks¹. But of the *Metroxylon* genus, only the palms of the species *sagu* are both hapaxanthic (once-flowering) and soboliferous (suckering). This means that the bole may contain a large quantity of starch, and that the plant is not killed by harvesting, but continues to grow². Hence, its vernacular English name is 'true sago palm', in French, *sagoutier*, and in German, *Sagopalme*.

In Indonesia, a number of different names for the genus exist: *pohon rumbia* or (*pohon*) *sagu* (in the national Indonesian language, Bahasa Indonesia); *kirai* (in Sudanese, spoken in West Java); *ambulung* or *kersulu* (in Javanese) and *lapia* (in Ambon and Seram, local languages of Moluccas). In Irian Jaya, the Indonesian western half of New Guinea, a large number of local names for sago palm exist. Heyne (1950) gives an extensive account of the vernacular names for the genus in all the various Indonesian languages (including that of Irian Jaya). On the other half of the island, Papua New Guinea, where the Pidgin word for sago palm is *saksak*, many different local names are also found.

In Malaysia, where a language comparable to Bahasa Indonesia is also spoken, the same word as in Indonesian, *rumbia*, is used. In Sarawak, in Melanau, the local name for sago palm is *balau*, and in the Philippines, it is *lumbia*. The vernacular names used in Burma (*thagu-bin*), Cambodia (*sa kuu*) and Thailand (*sa khu*) all bear a close resemblance to *sagu*.

1.2 Taxonomy

The true sago palm belongs to the family Palmae Jussieu, subfamily Calamoideae Griffith, tribe Calameae Drude, subtribe Metroxylinae Blume and genus *Metroxylon* Rottboell (Uhl and Dransfield 1987). Sarkar (1970) gave the chromosome number of *M. sagu* and *M. rumphii* Mart. as $n=16$ but Verhaar (1976) established the chromosome number of *Metroxylon sagu* as $n=13$ in about 30 cells in metaphase of a number of plants derived from seedlings from the Botanical Garden in Singapore. Rauwerdink (1986), who also examined plants collected in Papua New Guinea, verifies the number found by Verhaar.

1 *Cycas rumphii* is also known as sago palm, but is not a palm. In India, sago palm is the vernacular name for sugar palm (*Arenga pinnata* (Wurmb) Merr.).

2 Palms of the genus *Eugeissona* are also both hapaxanthic and soboliferous. These dryland palms, growing on stilt roots, are used for starch extraction by a number of tribes in Borneo (Kalimantan).

Table 1a. The genus *Metroxylon* (Beccari 1918).

Taxa	Distribution
Eumetroxylon (18 rows of scales on the fruit)	
1. <i>M. sagus</i> Rottb. (forma typica)	Malay islands
1.1. var. <i>molat</i> Becc.	Seram†
1.2. var. <i>peekelianum</i> Becc.	North PNG
1.3. var. <i>gogolense</i> Becc.	North PNG
2. <i>M. rumphii</i> Mart. (forma typica)	Malay islands
2.1. var. <i>rotang</i> Becc.	West Seram†
2.2. var. <i>longispinum</i> Becc.	Ambon†
2.3. var. <i>sylvestre</i> Becc.	West Seram†
2.4. var. <i>ceramense</i> Becc.	Seram†
2.4.1. subvar. <i>platyphyllum</i>	West Seram†
2.4.2. subvar. <i>rubrum</i>	West Seram†
2.4.3. subvar. <i>album</i>	West Seram†
2.4.4. subvar. <i>nigrum</i>	West Seram†
2.5. var. <i>micracanthum</i> Becc.	Seram†
2.5.1. subvar. <i>tuni</i>	West Seram†
2.5.2. subvar. <i>makanaro</i>	West Seram†
2.6. var. <i>buruensis</i> Becc.	Buru†
2.7. var. <i>flyriverense</i> Becc.	Fly river PNG
Coelococcus (24-29 rows of scales on the fruit)	
3. <i>M. squarrosum</i> Becc.	East Seram†
4. <i>M. warburgii</i> Heim.	New Hebrides
5. <i>M. upoluense</i> Becc.	Samoa
6. <i>M. vitiense</i> Benth et Hook.	Fiji
7. <i>M. amicarum</i> Becc.	Carolines
7.1. var. <i>commune</i> Becc.	
7.2. var. <i>maius</i> Becc.	
8. <i>M. salomonense</i> Becc.	Solomon islands
9. <i>M. bougainvillense</i> Becc.	Bougainville

† Moluccan islands, from which Beccari obtained material.

Beccari (1918) distinguishes two groups among the nine species of *Metroxylon*. He worked with materials (mainly fruits and parts of the leaves) obtained from the areas mentioned in Table 1a. Some names are derived from the names given by local people to the material he received, i.e. *molat*, *rotang*, *tuni* and *makanaro*. Beccari divides his species *squarrosum*, from East Seram, into seven varieties, but considers

them barely distinguishable (these varieties are therefore not shown in Table 1a). Three of the species designated by him are both hapaxanthic (the bole ends its life by flowering and fruiting) and soboliferous (the plant tillers or suckers), i.e. *sagu*, *rumphii* and *squarrosom*. The distinction between *rumphii* and *sagu* is that the first species contains all the spiny, and the second, the all non-spiny palms. In the species *squarrosom*, Beccari found 24 rows of scales on the fruit and in *sagu* and *rumphii* he found 18 rows. This forms the basis of his division of the genus into two subgroups, *Coelococcus* (containing those species with 24 rows) and *Eumetroxylon* (containing those with 18 rows).

Rauwerdink (1986) studied live specimens in the Sepik area in Papua New Guinea, for a period of about 6 months, and subsequently, herbarium materials. He found a high level of variation in the number of scales in fruit samples, and also that spininess could be explained as a simple inherited character. On the basis of these findings, he included the species *rumphii* and *squarrosom* Becc. within the species *sagu*. He then divided the species of the genus *M. sago* into the four formae defined below, according to the characteristics of their spines.

1. *sagu*: leaf sheaths and petioles are unarmed at all ages of the plant. The plant is completely smooth.
2. *tuberosum*: the base of the leaf sheath is covered with knob-like structures at all ages of the plant. All other parts are perfectly smooth.
3. *micracanthum*: from an early age onwards, the leaf sheath, petiole and rachis are covered with spines, not longer than 4 cm. Bracts of the inflorescence are smooth, or with only scattered spinules.
4. *longispinum*: the leaf sheath, petiole and rachis are covered with spines that are over 4 cm and up to 20 cm long. Bracts of the inflorescence show spinules, which are scattered or in transverse series.

According to Rauwerdink's valid classification, the current two synonyms for the species are *M. rumphii* and *M. squarrosom*. Rauwerdink classified *M. bougainvillense* from Bougainville as synonymous with *M. salomonense* from the Solomon islands, and does not mention *M. upoluense* from Samoa. As can be seen, according to Rauwerdink's classification, the genus contains only five species instead of nine (summarized in Table 1b). Out of these, only one is hapaxanthic and soboliferous, i.e. *M. sago*. Except for *M. amicarum*, which is pleoanthic, the other species are also hapaxanthic. None is soboliferous. For a concise description of the genus see Schuiling (1996).

Rauwerdink's (1986) treatment of the genus has the advantage of being simple and straightforward. The disadvantage is that all Beccari's (1918) varieties and subvarieties, distinguished on the basis of sago palm growers' observations, disappear. Renewed and continued research in field of taxonomy is therefore needed. Modern methods such as zymogram techniques, as applied by Hisajima *et al.* (1995), will be useful. The recent research in this field by Boonsermsuk *et al.* (1996) was done with material from southern Thailand only, and needs to be repeated with material of much more geographically diverse origin.

Table 1b. The genus *Metroxylon* according to Rauwerdink (1986).

Taxa	Distribution
1. <i>M. sagu</i> Rottb.	Malay islands
2. <i>M. warburgii</i> Heim.	New Hebrides
3. <i>M. vitiense</i> Benth et Hook	Fiji
4. <i>M. amicarum</i> Becc.	Carolines
4.1. var. <i>commune</i> Becc.	
4.2. var. <i>maius</i> Becc.	
5. <i>M. salomonense</i> Becc.	Solomon islands

2 Botanical description

2.1 General description of the palm

The true sago palm (*M. sagu*) is a pinnate-leaved palm occurring in the hot humid tropics of South-East Asia and Oceania. The scientific name is derived from *metra*, meaning pith or *parenchyma*, and *xylon*, meaning *xylem*. In some varieties, after the leaf dies, the sheath may adhere to the bole, the part of the trunk below the crown, while in other varieties, the sheath drops. Without leaf sheaths, boles have a diameter of 35-60 cm and reach a length of 6-16 m. The bole stores starch in its central parenchyma, at 10-25% of its fresh weight of 1-2 t. Healthy palms under good conditions carry approximately 24 leaves or fronds. The higher the number of fronds the crown carries, the larger the diameter of the trunk. Each month, one new frond appears out of the growing point, and the oldest one dies. Including the leaf sheath, each fully grown frond is 5-8 m long and carries 100-190 leaflets. Some leaflets may reach a length of 150 cm and a width of up to 10 cm.

The palm is soboliferous; it produces tillers or suckers (Fig. 1a). Once planted, a regular succession of suckers is produced from the lowest part of the trunk, forming a cluster in various stages of development. Occasionally, suckers may be formed higher up on the bole.

The palm is also hapaxanthic: each bole heralds the end of its life cycle by developing a huge branched terminal inflorescence, with a large number of fruits (Fig. 1b). The starch stored in the bole is meant for the production of flowers and fruits. After the formation of fruits, the trunk decays, and one or more of the suckers from the cluster takes over. Figure 2 contains a schematic drawing of the life cycle of a palm, with a relatively short seed-to-seed life of 12 years.

Only under prolonged flooding does the palm form pneumatophores, roots functioning as respiratory organs, on top of the soil. Many varieties of the palm are covered by spines, on the rachis, on the leaf sheaths and some even on leaflets and on bracts in the inflorescence. Unarmed varieties are also found, however.

2.2 Life cycle

Understanding the growth and development of the sago palm is essential for cultivation but also for harvesting from natural stands. It is also necessary for both taxonomy and breeding of the sago palm.

A preliminary model of growth and development of a sago palm is given in Table 2. For the model, a palm cultivar with a relatively short growth duration, obtained through propagation, by means of suckers, has been chosen. Planting is rather uniform. In this model, the ideas of Corner (1966) concerning palm growth have been applied. Palm growth is strictly regular. There are as many unfolded leaves visible in the crown as there are developing, still folded, within the growing point. The newest leaf, the spear leaf, appears midway between the developing leaves in the growing point and those visible in the crown. Tomlinson (1990) doubts that this growth model is valid for all palms. It does apply to the sago palm in the bole-forming

stage, although possibly not as strictly as Corner assumes. Only if the number of leaves increases or decreases is the number of developing leaves within the growing point larger or smaller than in the visible crown.

In plants with a terminal inflorescence, flowering starts after a fixed number of leaves has been formed. In the case of rice, banana and sisal, for example, this naturally only holds within certain limits. The sago palm is assumed to follow this flowering pattern, and the duration of the bole growth stage can thus be estimated by counting the number of leaf scars on the bole at flower initiation. In our palm, grown under optimum ecological conditions, and with uniform planting material, there were 54 leaf scars. At a production rate of one leaf per month, this would correspond to a physiological age of 54 months. Deviations from this number in other palms might form an interesting research topic.

In the sago palm cultivar used for our model, leaf production in the rosette stage, that occurring before formation of a visible bole, was established to be 2 leaves/month, on average. During this stage, the leaves become progressively larger (Flach 1977). After flower initiation, the leaves become progressively smaller, and the average speed of leaf formation is also assumed to increase to 2 leaves/month. The value of such a model is as yet limited, however; the figures given in Table 2 are only averages, intended to show deviations around a mean. It is assumed that the speed of leaf formation is more constant than leaf longevity. This implies that, with a constant lack of plant nutrients, leaf longevity will decrease sooner, whereas the speed of leaf formation will remain constant far longer. Sudden and fierce changes in ecological conditions, e.g. prolonged flooding, will cause a more rapid reduction in the speed of leaf formation.



1a



1b

Fig. 1a. A clump of sago palm tillers or suckers, approximately 3 years after planting of the first large sucker.
Fig. 1b. The inflorescence of a sago palm after cutting of the bole, Sepik River Basin, Papua New Guinea.

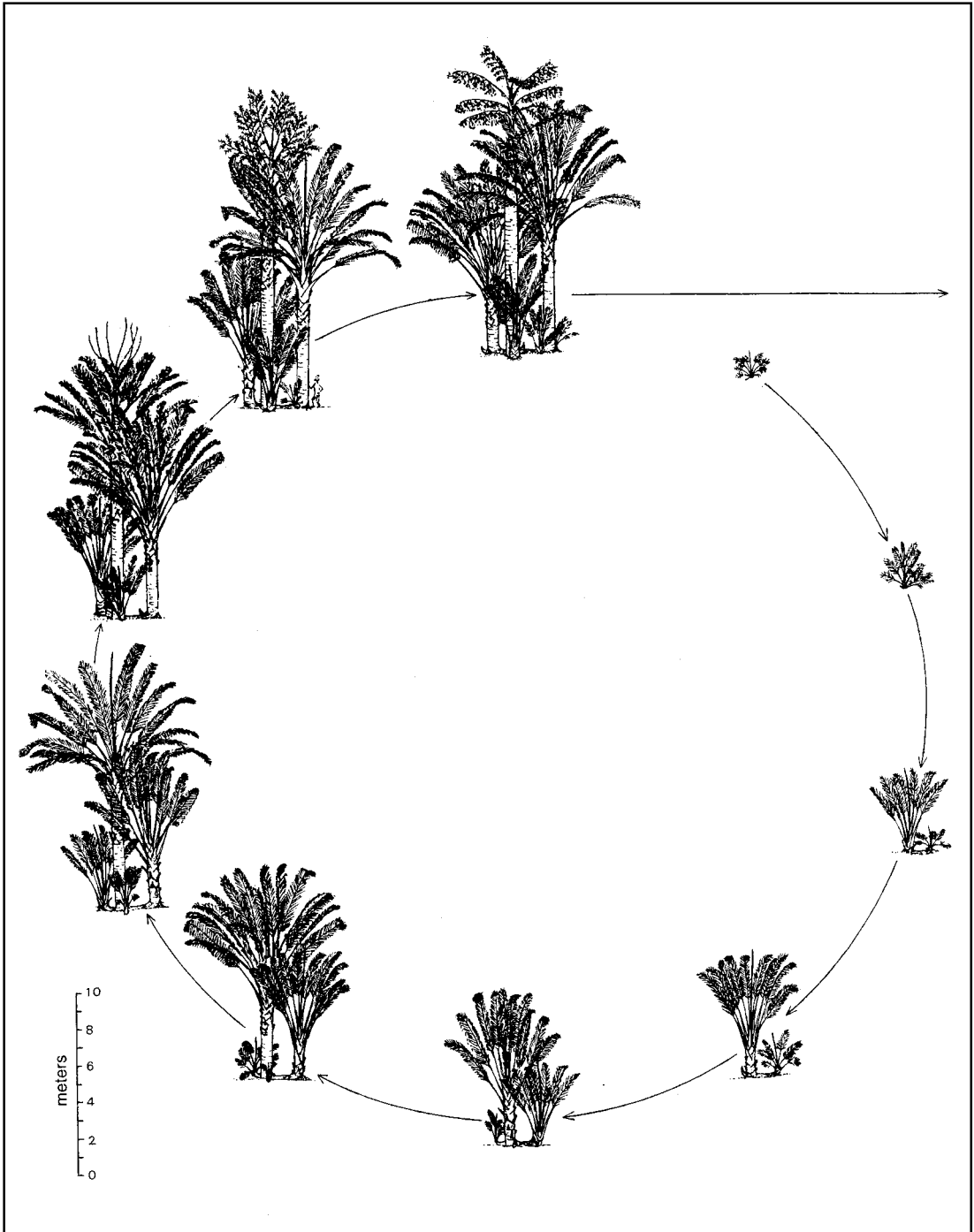


Fig. 2. Growth cycle of a sago palm with a seed to seed life of approximately 11 years (drawing by Schuiling from Schuiling and Flach 1985).

Table 2. Summary of data for a sago palm with a seed-to-seed life of approximately 11-12 years, growing under optimum ecological conditions (adapted from Flach and Schuiling 1989).

<i>Rosette stage</i>	
Average no. leaves formed/month	2
Estimated total no. leaves formed	90
Estimated duration of rosette stage, from seeding (months)	45
<i>Bole formation stage</i>	
Optimum no. leaves in crown (n)	24
No. leaves in growing point (n)	24
No. days between successive leaves (p)	30
Estimated optimum leaf age in days (n X p)	720
Approximate no. leaf scars visible on the bole at inflorescence initiation	54
Total no. leaves in the crown and on the bole at inflorescence initiation (approximate no. leaves in the crown (24) plus leaf scars on the bole (54))	78
Estimated duration (months)	54
<i>Inflorescence stage</i>	
No. leaves already present at initiation	24
No. leaves formed/month	2
Estimated total no. leaves formed	24
Estimated duration (months)	12
<i>Fruit-ripening stage (months)</i>	24

In the population of the sago palms of Sarawak, East Malaysia, the number of leaf scars on the stolon does not appear to influence bole age, as given by the number of leaf scars on the bole (derived from counts received from Jong, (pers. comm., 1994) The number of leaf scars was established on 20 unharvested trunks, which decayed after fruit ripening. The sample was selected on sight, and along roads. At the inflorescence initiation, the distance between leaf scars becomes greater. The average duration of the bole-formation stage, as measured by the number of leaf scars on the dead trunk before widening of the leaf scars, was 75.2 leaf scars, corresponding to 75 months (6.5 years). Subtraction of the average number of 21.3 leaves present at flower initiation gives 54 leaf scars at bole formation (4.5 years), albeit with a standard deviation of 1 year. The number of leaf scars on the stolons (the horizontal trunk parts) varied considerably. However, this did not influence trunk age, as measured by number of leaf scars.

There are other types of sago palms with a longer growth duration. The bole-formation stage may be extended considerably, from 4.5 years, as in the bole used in the model, to up to 16 years. Such boles are not only taller, but also possess larger leaves. It may well be that the other stages of growth, i.e. the rosette and flowering stages, are then extended too.

2.3 Growth of an ideal planting

The leaf area of feathered palm leaves can be approximated in the following way. The number of leaflets (*a*) is counted. Then the largest leaflet's width (*b*) and length (*c*) are recorded. The area of the complete leaf is calculated by means of the formula given below:

$$\text{Leaf area} = a \cdot b \cdot c \cdot 0.5.$$

The factor 0.5 is only an approximation. Experiments show that it may be closer to 0.6. In a planting at 7 x 7 m, there will be 204 palm clusters/ha. Every 18 months, one sucker is allowed to grow. Just before the first trunk is harvested, after 4.5 years of bole growth, there are 3 palm crowns in a cluster. The crown of the leader palm contains 24 mature fronds, each with 8 m² of leaf area. The two other crowns contain 18 leaves, each measuring 6 m², and 12 leaves, measuring 4 m², respectively. Each cluster thus contains 348 m² of leaf, and occupies a total of 49 m². This leaf area index (LAI) is thus 7.1. Just after cutting of the leader bole, the leaf area drops to 156 m² and the LAI becomes 3.5. The largest follower bole then takes over, increases in leaf area and also in circumference, and starts to grow more rapidly. So do some of the other follower palms, which explains why boles in a planting show an increase in circumference at approximately two-thirds of their length.

2.4 Inflorescence

Inflorescence development was studied in depth by Schuiling (1991). He used nine inflorescences of five different palm types as the subject of his research. The generative stage, from its initiation in the apex to the maturation of the fruits, takes at least 3 years. A fully grown inflorescence is branched to the third order; after flower initiation, the apical growing point acquires a different shape. The vegetative apex of the growing point is concave. In the generative stage, it is convex (see also Kraalingen 1984).

The emergence of the branches of the inflorescence is phased. The second-order branches do not emerge before most of the first-order branches are fully extended. The branches of the first order emerge in sequence, from the lowest one upward. The development of the second-order buds seems to stop until all first-order branches have reached their full size. Whether the third-order branches also show a synchronization was not studied, although this appears to be the case. The generative phase of a larger palm probably takes longer than that of a smaller one. For further information, see Schuiling (1991).

2.5 Flowering

Tomlinson (1990) describes the flowering of *Metroxylon* spp. The palm possesses complete and male flowers, which form a dyad. The two flowers do not differ in size, but, in the male flower, the gynoecium is reduced to a pistillode. The functional gynoecium is trilocular, but generally two ovules abort. Inner and outer bracteoles are conspicuous, but there are two further bracteoles enclosing the complete flower. Figure 3 shows the flower of *M. vitiense*.

Jong (1995) made a thorough study of the flowering of nine sago palms in Sarawak. Scaffolds were constructed around the inflorescences of the palms for observations over a period of 5 years. Individual inflorescences were studied for periods of 2-7 months. Earlier studies, over far shorter periods, were done by Kiew (1977) and Utami (1986). In the early stages of flower development, the flower buds are found in pairs. One flower is staminate, the other complete. By the time of anthesis, single flowerbuds are found in each bracteole. Thus, one of the flowers aborts before anthesis. Usually, more male flowers abort than complete flowers. In three out of the seven palms investigated, abnormal complete flowers were encountered. These opened prematurely.

Flower opening of an inflorescence took 30 days for male flowers and 50 days for the complete ones. Staminate flowers opened up 2-4 weeks before the complete ones. The abnormal complete flowers remained open for a period of 3 months. Their stamens shrivelled quickly and the pollen appeared abnormal. The male flowers shed pollen to a large extent before the complete ones become receptive, but some overlap occurs. Male flowers started to open up around 1030 hours. Peak daily opening is between 1100 hours and 1200 hours. After one day, most of the male flowers had abscised and fallen off. Each day, between 5-10% of the male flowers opened. Complete flowers showed the same time sequence. They apparently possess normal pollen. Jong (1995) compared his results with those of Beccari (1918), Tomlinson (1971), Utami (1986) and Tuwan (1991). He postulates that there are three types of flower combinations:

1. Staminate and pseudo-hermaphrodite (Beccari 1918; Utami 1986; Tuwan 1991)
2. Staminate and hermaphrodite (Tomlinson 1971; Jong 1995)
3. Staminate and abnormal hermaphrodite (Jong 1995)

Type (1) has not been encountered in Sarawak. According to Jong (1995), it may well be that type (3) is the same as type (1), eventually opening before the buds are mature.

2.6 Pollen

Rauwerdink (1986) examined the sculpture of the pollen in the species *M. sagu*, *M. salomonense*, *M. vitiense*, *M. amicarum* and *M. warburgii*. He studied pollen grains with the scanning electron microscope and the light microscope. All taxa analyzed are disulcate³: they possess two germination pores. The grains are oval, ca. 30 μm

3 Rauwerdink uses the term 'dicolpate', erroneously. According to Dransfield (pers. comm., 1996), 'dicolpate' should be replaced by disulcate in monocotyledonous plants.

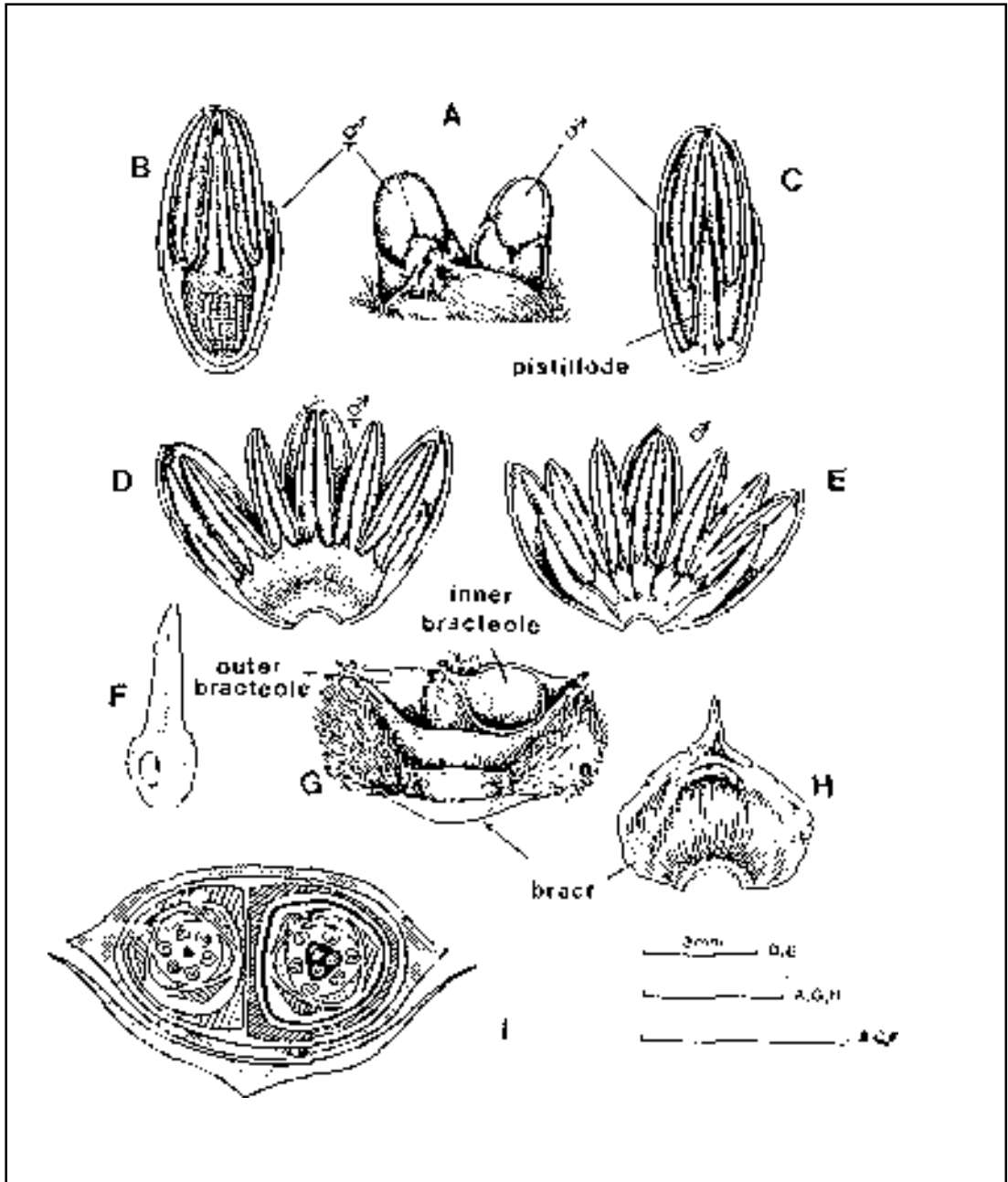


Fig. 3. *Metroxylon vitiense*: floral dyad analyzed and dissected. (A) Dyad from without; (B) perfect flower bud with floral envelope partly removed; (C) male flower bud prepared in the same way; (D) perfect flower bud opened out and gynoecium removed; (E) male flower prepared in the same way; (F) gynoecium in L.S.; (G) dyad with flowers removed, only larger inner and outer bracteoles visible; (H) bract; (I) diagramme of dyad to show four bracteoles. (Reprinted with permission of Oxford University Press).

long and $15 \pm \mu\text{m}$ wide. Based on the sculpture of the exine, two groups can be distinguished. The first consists of *M. salomonense* and *M. vitiense* and has a reticulate ornamentation on the equatorial sides. The lumina of the reticulum diminish in size toward the sulci, which results in a tectum perforatum. The other group consists of *M. sagu*, *M. amicarum* and *M. warburgii* and displays a tectum perforatum over almost the total surface. According to Rauwerdink, it is not possible to relate the two types of pollen grains to the present taxonomy of the genus.

Jong (1995) examined pollen grains in Sarawak. Fresh pollen of a spined palm had a length of $45.1 \pm 3.8 \mu\text{m}$ and width of $29.2 \pm 2.1 \mu\text{m}$. This is considerably larger than the grains studied by Rauwerdink. Pollen of a smooth palm (preserved in 10% formalin and acetic acid) showed a length of $39.7 \pm 6.3 \mu\text{m}$ and a width of $26.5 \pm 4.2 \mu\text{m}$. He reports the pollen of the preserved sample to be oval, but occasionally some round ones were observed. The fresh sample was examined in distilled water. It gave a mixture of oval and triangular pollen. The triangular pollen appeared to be abnormal and was therefore not examined.

Tuwan (1991), an undergraduate student from Pattimura University in Ambon, Moluccas, Indonesia, found differences in pollen morphology between *ihur* (Beccari's (1918) *M. rumphii* var. *sylvestre*), *makanaro* (Beccari's *M. rumphii* var. *longispinum* subvar. *makanaro*) and *tuni* (Beccari's *M. rumphii* var. *longispinum* subvar. *tuni*). Her findings, however, could not be confirmed by her tutor (Anema 1994, pers. comm.), and it may well be that she found and misinterpreted the triangular pollen that Jong (1995) also found.

Jong (1995) reported that the anthers from prematurely opened flowers were small and pale yellow. The pollen itself was small and lighter yellow than that from the mature newly opened staminate flowers. The latter were light purple, succulent and shiny. Under a dissecting microscope, the pollen of newly opened hermaphrodite flowers was visibly identical to the pollen from male flowers. The anthers, however, were slightly lighter in colour. No information is available on the

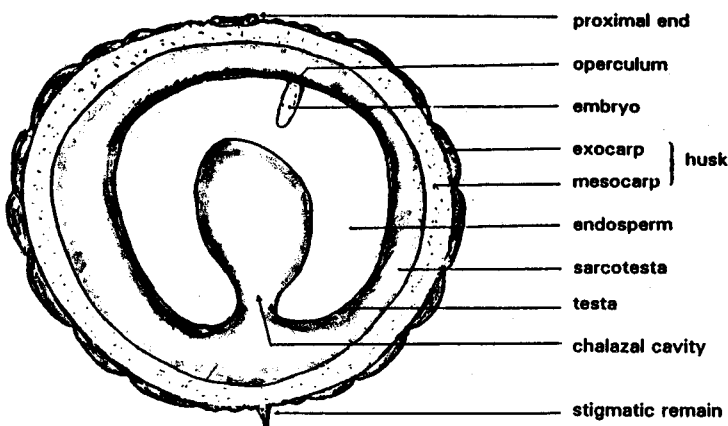


Fig. 4. A vertical section of a seed-bearing sago palm fruit showing the scaly husk, the sarcotesta and the endosperm (from Jong 1995).

storability of pollen.

2.7 Fruit and seed

The structure of the fruit is presented in Figure 4, taken from Jong (1995). The fruit is covered by neat vertical rows of imbricate scales, covering a thick spongy mesocarp. The embryo is basal and embedded in a horseshoe-like homogenous endosperm. Parthenocarpic fruits, often from sterile palms, are filled with only spongy mesocarp. But these supposedly sterile palms occasionally give some seeded fruits. Parthenocarpic fruits are usually considerably smaller than seeded fruits. Schuiling (1995) reports that *sagu makanatol*, from the Moluccan island of Saparua, has parthenocarpic fruits consisting of three segments.

Jong (1995) presented an overview of literature and did some research on seed germination. Seeds only germinate when fully ripe, and ripeness is only shown by a large fruit size and a straw-coloured husk. At opening of the husk, the seed in the fruit should show a hard stony endosperm and a dark brown testa. Germination can be promoted by removal of the husk and loosening of the operculum, but seeds start germination immediately when the fully ripe sago palm fruits are stored in a moist environment. After storage under dry conditions, the seeds quickly lose their viability.

3 Centre of diversity

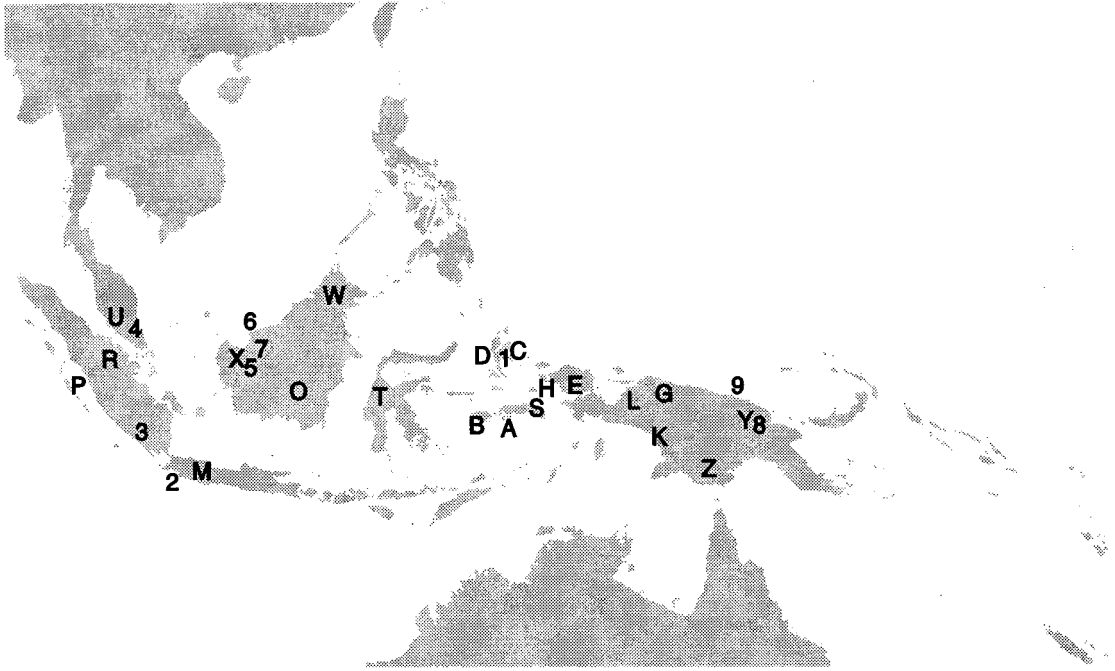
3.1 Wild stands

Beccari (1918) put the centre of diversity of *M. sago* in the Moluccan islands in Indonesia. Vast wild stands of sago palm occur on the island of New Guinea, both in Irian Jaya, the Indonesian part, and in the independent state of Papua New Guinea. In the author's opinion, New Guinea should be considered as the centre of diversity. Flach (1983) gave a rough estimate of the wild and cultivated area covered with good sago palm stands. His views are updated in Table 3. The location of the areas is shown on the map in Figure 5.

Table 3. Rough estimate of area (ha) covered with good quality sago palm stands.

	Wild stands	(Semi-)cultivated stands
Papua New Guinea, total	1 000 000	20 000
Sepik province	500 000	5 000
Gulf province	400 000	5 000
Other provinces	100 000	10 000
Indonesia, total	1 250 000	148 000
Irian Jaya, total	1 200 000	14 000
Bintuni	300 000	2 000
Lake Plain	400 000	—
Southern Irian	350 000	2 000
Other Districts	150 000	10 000
Moluccas	50 000	10 000
Sulawesi	—†	30 000
Kalimantan	—	20 000
Sumatera	—	30 000
Riau islands	—	20 000
Mentawai islands	—	10 000
Malaysia, total	—	45 000
Sabah	—	10 000
Sarawak	—	30 000
West Malaysia	—	5 000
Thailand	—	3 000
Philippines	—	3 000
Other countries	—	5 000
Total	2 250 000	224 000

† No wild stands.



Regions	Letter on map	Towns and cities	No. on map
Indonesia			
Moluccan islands			
Ambon	A		
Buru	B		
Halmahera	C	Kao	1
Ternate	D		
Irian Jaya			
Bintuni	E		
Lake Plain	G		
Salawati	H		
Southern Irian	K		
Waropen Coast	L		
Java	M	Bogor	2
Kalimantan (Borneo)	O		
Mentawai islands	P		
Riau islands	R		
Seram	S		
Sulawesi	T		
Sumatera		Benkulu	3
Malaysia			
West Malaysia			
Johor	U	Batu Pahat	4
East Malaysia			
Sabah	W		
Sarawak	X	Kuching	5
		Mukah	6
		Sungai Talau	7
Papua New Guinea			
Gulf prov. (Fly river)	Y		
Sepik River Basin	Z	Angoram	8
		Wewak	9

Fig. 5. Main sago palm areas and all other locations mentioned in this publication.

The vast wild sago palm stands on the island of New Guinea are described by Flach *et al.* (1986b). The overall vegetation has been described by CSIRO (1968) and Pajmans (1980). The total area in which sago palm dominates in Irian Jaya may well be over 6 million ha. In general, the natural stands occur under either permanent flooding, or flooding during part of the year and the remainder of the year with a sufficient water supply. Often the sago palm stands border on sometimes pure stands of nipa palm (*Nypa fruticans* Wurmb.). Nipa is a vegetation found in brackish tidal swamps.

In the part of the swamp under deep and permanent flooding with fresh water only, grasses grow. Under less deep and permanent flooding, one finds sago palms that remain in the rosette stage, and in addition, some small, stunted sago trunks among the grasses. Such trunks yield little starch. On the drier areas, the trunks, increasing in size and age at flowering, contain more starch and grasses disappear. The drier the area, the higher the number of dicotyledonous trees found in the vegetation. There, the sago palms have to compete with them, and both trees and palms become taller. Eventually, the trees shade out the palms.

All wild areas are a tangled mass of densely growing plants, in which sago palms dominate. Often the leaf sheaths adhere to the boles. Old, dry and broken leaves hang between and on other palms. Palms in all stages of growth are to be found, fighting for space, most of them spiny. It appears that most palms multiply by suckers. On the soil, old decaying stolons are present. On wet spots, pneumatophores can be seen. Only occasionally, palms reach the trunk-forming stage. Some palms show inflorescences or fruits. Groups of germinating seeds are occasionally found, mostly in a thin layer of water. Old decaying palm trunks remain standing until they break up.

In drier areas, the sago palms are mostly limited to undergrowth under a cover of dicotyledonous trees. Where light reaches the undergrowth, trunks may start growing and end up flowering and fruiting, competing with the other trees for light. The build-up of the area is a matter of competition between the various plants. This explains the differences between the estimates in Table 3 of over 2.2 million ha of good natural stands, and the figure of 6 million ha total stands. The drier the area, the greater the number of productive sago palms that may be partly harvested by the local population living in or around the area.

3.2 Semi-cultivated stands

In the author's opinion, the other areas mentioned in Table 3 (semi-cultivated stands) are probably planted. On soils that are reasonably fit for productive stands, an old planted area that is not regularly pruned and cleaned acquires the same appearance as a wild stand. In areas with large wild stands, there are generally also areas planted with specially selected palms. Such areas are not usually cleaned or pruned, and are thus semi-wild (Fig. 6). Local sago growers always say that they inherited the cultivated varieties from their ancestors. Areas containing planted sago palms are usually located near the sites of old villages, and varieties are still collected and



Fig. 6. A semi-wild stand seen from the riverside, in the Sepik River Basin, Papua New Guinea.

exchanged, both with neighbours and with people from more distant areas. In a village at Bien river, in the Sepik River Basin in Papua New Guinea, a single palm brought along by a villager who visited Fiji is growing right in the centre of the village. The palm does not sucker, and is probably *M. vitiense* Benth et Hook.

In such semi-cultivated stands in Irian and Papua New Guinea, the local inhabitants harvest whenever the starch content per bole is highest. In fact, they are not growers, but collect starch, just as they do from plants growing in wild stands. If asked, they say that they are aware that for a high production per unit time and area, harvesting should be done around flower initiation. They are also aware that they should grow cultivars with a short growth period. Their yields usually vary from 150 to 400 kg of dry starch per harvested trunk.

In Indonesia, harvesting from semi-wild stands is also done on the Mentawai islands, west of Sumatra. Here also, all the sago palm population was probably originally planted.

3.3 Diversity

The number of sago palm varieties decreases from the centre, New Guinea and the Moluccas, toward the borders of the area of dispersion. At the limits of the area of dispersion, e.g. the Mentawai islands and southern Thailand in the west, southern Philippines in the north, and in Oceania, east of Papua New Guinea, it is probable that

only one variety is present. For Thailand, this has been confirmed by the zymographic research of Boonsermsuk *et al.* (1996). In the vast wild stands in swampy areas on the island New Guinea, quite a number of varieties probably still grow undetected. Further observations on sago palm diversity are to be found in section 5, **Genetic diversity and folk taxonomy.**

3.4 Dispersal to other areas

Around 1985, under the auspices of the Food and Agriculture Organization of the United Nations (FAO) in Rome, Italy, and in cooperation with Wageningen Agricultural University, in the Netherlands, a programme began for the dispersal of sago palms to countries in other parts of the world. After quarantine in Wageningen, seedlings were sent to a number of countries, accompanied by a booklet on the crop (Schuiling and Flach 1985). Among the countries supplied were the Latin America countries of Costa Rica and Brazil. In Zaïre, in Africa, the seedlings were planted in a Unilever research station. Plants were also sent to Vietnam and planted at Can Tho University. The evaluated results of these plantings are not available.

4 Properties and uses

4.1 Properties of the palm

The boles have always been used to obtain starch as a staple food for humans. If there are plenty of trunks, they are harvested when the fruits are being formed. During fruit formation, there are still some functional leaves and starch accumulation proceeds, albeit at a decreasing rate. The lowest part of the bole becomes just about empty, as the starch is deposited higher in the bole (Kraalingen 1984, 1986). In the lowest part of the bole, the number of vascular bundles is greater and the bundles are harder than in other parts. For this reason, the lowest part of the bole (measuring 50-100 cm) is left in the field. This is the time of the highest production of starch per bole and also the highest yield per unit of labour. There may also be differences between palm types with respect to the number of vascular bundles.

Table 4 compares the composition of sago palm boles with inflorescence in a fairly large bole from Irian Jaya (Colon 1958) and a small bole from Sarawak (Research Branch 1974-1994).

Table 4. Analysis of sago palm boles from Irian Jaya (Colon 1958) and Sarawak (Research Branch 1975-1994).

	Irian Jaya			Sarawak		
	Weight (kg)	Proportion of total weight (%)	pith weight (%)	Weight (kg)	Proportion of total weight (%)	pith weight (%)
Trunk	1250	100		875	100	
Cortex	400	32		225	25.7	
Pith	850	68	100	650	74.2	100
Starch	250	20	29	164	18.7	25.2
Water	425	34	50	347	39.7	53.4
Remainder	175	14	21	139	15.9	21.3

The bark is extremely hard. The pith is easier to grate than any other starch crop, e.g. cassava roots. The starch settles easily because of its large average size. If dried, the starch can be stored without difficulty. Often it is stored wet, in water, where it disintegrates slowly. If stored wet outside water it acquires a peculiar lactic acid smell.

In a subsistence economy, roughly 150-160 hours of work are needed to produce enough starch for one person for a full year (1 kg air-dry starch/day or approximately 10 000 kJ) (Ohtsuka 1983).

4.2 Properties of the starch

Sago starch contains 27% amylose (the linear polymer) and 73% amylopectin, the branched polymer (Ito *et al.* 1979). Kawabata *et al.* (1984), however, give the amylose content of sago starch as 21.7%. This may be an indication that it is possible to breed for amylose content. Kawabata *et al.* (1984) found a grain size distribution of 16.0-25.4 μm . Jong (1995), however, found a mean length of almost twice as much, of ca. 40 μm . It is probable that the grain size increases with age of the trunk, until initiation of the inflorescence.

The maximum viscosity amounts to 960 Brabender units, and gelatinization temperature is 70°C. Viscosity decreases with deterioration of the starch quality, owing to microbial activity (Cecil 1986). In the modern starch industry, starches can be modified to quite an extent. Provided there is a regular supply of cheap, clean and non-corroded starch, sago will be clearly competitive to all other starches, and for some purposes, it may even be preferred.

4.3 Uses of sago palm

The many uses of the sago palm are presented in Figure 7. Most of the other starches can be put to the same use as sago palm starch.

4.4 Traditional starch extraction

For starch extraction, trunks are cut that are considered to be fell-ripe (Fig. 8a). Extraction usually takes place in the field where the trunks grow, and the top with the leaves attached is left behind. Sometimes, the growing point is opened up for eating of the 'cabbage'. If a waterway is available, the bole may be floated out to the village. The bole or a part of it is then split into two halves, or the upper half of the 2-4 cm layer of bark is cut off (Fig. 8b). The soft but fibrous pith is then rasped, usually by means of an adze armed with a sharpened piece of hardwood (nowadays pipe) on its end (Fig. 8c). Occasionally, bushknives are used for the same purpose.

Reasonably clean water must be available. Sometimes a hole is dug to obtain groundwater. A sago palm leaf sheath is hung, quite high up. At its lower end, the lowest part of a leaf sheath of a coconut palm is fastened to it as a sieve. Some rasped pith is put in the sago sheath and mixed thoroughly with water. After kneading the pith, water loaded with starch streams through the sieve, leaving fibre behind in the sieve. The starch is usually caught in an old canoe or some other suitable vessel (Fig. 8d). The excess water runs over the sides, and the starch settles on the bottom of the vessel. The ground pith is washed with water until virtually no starch comes out of it, i.e. until the water running through the sieve remains clear. The pith is then discarded and the procedure is repeated. After a day or so, the pith remnant gives off an acidic smell caused by the starch remaining in it. If starch is extracted in the village, pigs and chickens come to eat it.

All refuse remains in the grove. As starch consists of nearly pure carbohydrate, only little soil fertility is lost from the fields.

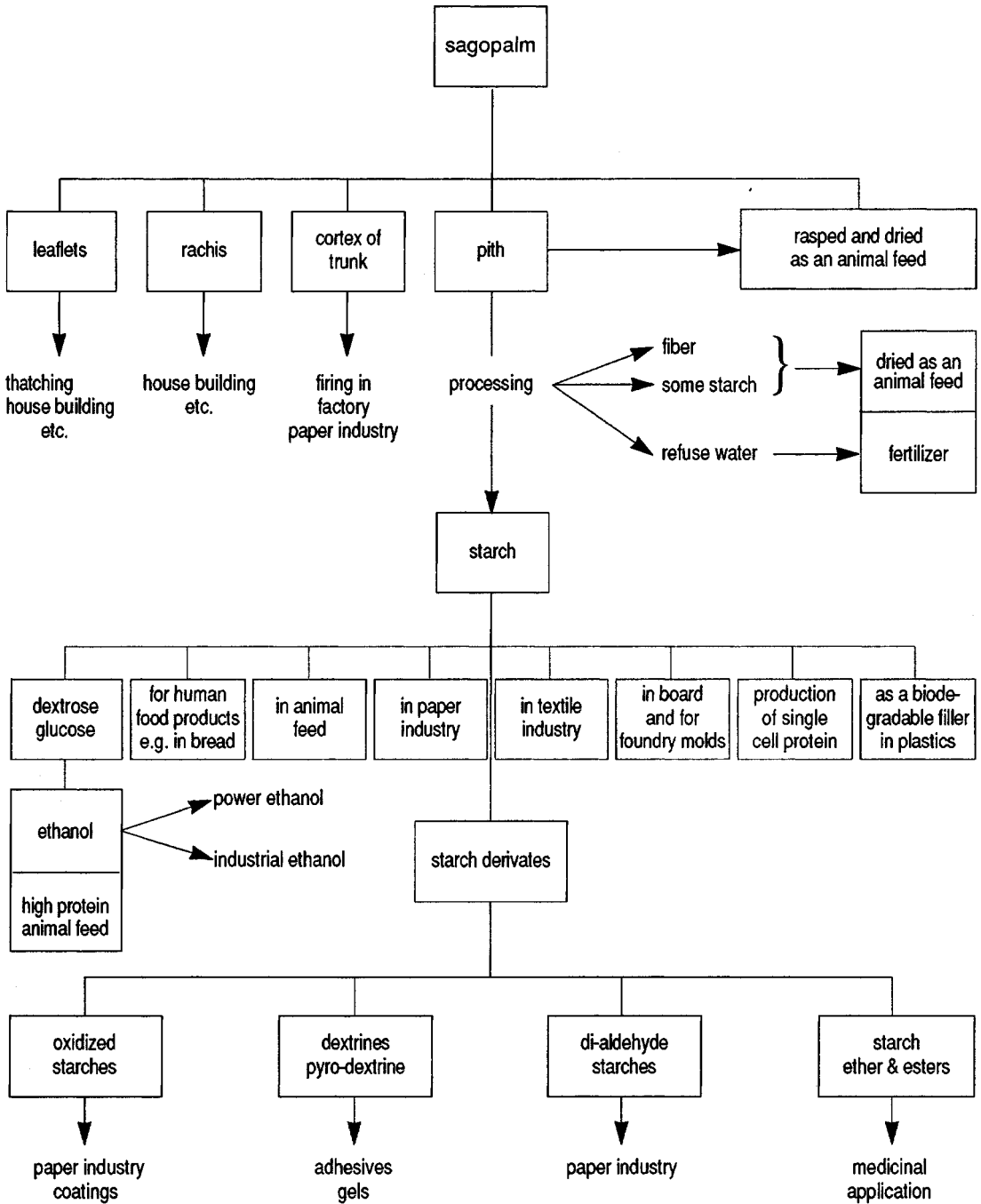


Fig. 7. The many uses of the sago palm (drawing by D.L. Baay, from Flach 1983).

The starch is mostly stored while still wet, under water, in baskets made of sago palm leaflets. Storage under water slows down starch deterioration. The baskets may have different shapes and capacities, often containing from 8 to 10 kg of wet starch.

In Sarawak, kneading is mostly replaced by trampling with the feet on a hanging mat. Rasping with an adze may occasionally be replaced by rasping with a board covered with nails. The board then is moved by two persons. As Flach (1995) states: "Most striking is the knowledge of sago palm growers. It is probably passed on from parent to child, through many generations. The farmers are eager to discuss or answer interested questions. For the sago palm grower, the crop is the staff of life, interwoven with belief and religion. Anybody really interested in the crop is really welcome, anybody who wants to interfere with it is met with suspicion and anger."

Despite the interest of sago growers, all reports show that, even in areas that traditionally subsist on sago starch, its consumption as a food is declining. The replacement of sago starch by the more balanced cereals which also keep better, because of their low water content, appears to be inevitable in the longer run. Sago starch shows far more promise as an industrial feedstock (see **Prospects**).

4.5 Traditional preparations

The most common method of preparation for consumption is to pour hot water over the slightly sour wet starch, and stir it with a stick or a spoon. The resulting glue-like mass is eaten with some fish and vegetable dishes, for example.

When travelling, people often bring a *tumang*, a basket made of sago leaflets, containing wet starch. A ball of wet sago starch is taken out of the basket and rolled in hot ashes. After some time, the black layer is peeled off and the brown layer beneath it is eaten, together with the cooked mass underneath the brown layer. The process is then repeated.

It is also common to bake sago starch into *lempeng*, in forms made of baked clay (*forna*). The *lempeng* are usually made entirely of starch, but they may occasionally contain other foods as well, such as ground peanuts or other pulses. They are dipped in tea, coffee or other fluids before consumption.

In the Moluccas, during festive periods, a kind of cookie is often prepared — *bagea*. These contain sago starch combined with ground seeds of the kenari tree (*Canarium commune*). Many other preparations can be found, e.g. cooking in a piece of bamboo, or in banana leaves, mixed with fish and vegetables (*sinole*).

In West Malaysia, sago pearls are prepared. To make these, slightly wet starch is pressed through a sieve. The small particles of wet starch are then rolled around and heated in a pan with a round bottom until the outside has been gelatinized. The pearls are subsequently dried, sorted and sold. These pearls are often used to prepare the 'three palm pudding': sago pearls, cooked in coconut milk, and topped off with sugar from the sugar palm (*Arenga pinnata*). In Sarawak, pearls are prepared from sago palm starch, mixed with rice bran.



8a



8b



8c



8d

Fig. 8a. Cut palm bole; the white pith and the black bark can be distinguished easily. The area is flooded during spring tide

Fig. 8b. Debarking of a sago palm log.

Fig. 8c. Chopping up pith in Sepik River Basin, Papua New Guinea. Instruments used: a bush knife and a traditional adze.

Fig. 8d. Traditional sago starch processing in the Sepik River Basin, Papua New Guinea.

4.6 Other uses

Fronds of the palm can be used for thatching. Only the oldest leaves can be removed without negative effects on growth and production. To make thatch, the leaflets are taken off the rachis and are folded over a wooden or bamboo lathe and sewn together (Fig. 9a). For the leaflets to keep, it is important that the midribs do not break but bend. The folded and lathed leaflets then are put on top of a house, partially covering each other. Such a thatched roof may last for 6-8 years. Houses with such roofs are cool, and rain makes less noise on them than it does on zinc roofing. In West Java, the palm is grown especially for leaf production. Average starch production then is only 55 kg/trunk (Haska 1995), compared with 175 kg/trunk for the same variety grown for starch only.

The rachis of fronds often is used for walls, fastened between horizontal posts with lathes on them (Fig. 9b). The bark also may be used as a floor material or as a fuel. The leaf sheaths sometimes are used for mats, and fibre from young leaves may be used for mats.

Ground pith sometimes is used as an animal feed, especially for pigs. When dried, it is also used for horses and for chickens. The rice-straw mushroom (*Volvaria volvacea*) can also be cultivated on refuse from sago extraction. In the Moluccas and possibly also elsewhere, this mushroom is considered a delicacy.

The growing point and the young leaves around it may be used as a vegetable, the palm heart or cabbage. In decaying trunks, grubs, especially *Rhynchophorus* spp., may grow (Fig. 9c). These are considered a delicacy by all sago growers. Sometimes, parts of trunks are even left in the field to be infested. The grubs are eaten fresh or roasted. They contain 6.9% protein, 8.5% carbohydrate, 11.3% fat and 0.7% ash. Their protein is deficient in tryptophane (Mitsuhashi and Sato 1994). The pupae of a small blue butterfly are also eaten, and were offered to the author during a field trip.



9a



9b



9c

Fig. 9a. Shingles sold for thatch close to Batu Pahat, Johor, West Malaysia (photo: D.L. Schuling).

Fig. 9b. A house close to Ambon city, built of the leaf stalks of sago palm (photo: D.L. Schuling).

Fig. 9c. Grubs of *Rhynchophorus* spp., ready for eating fresh.

5 Genetic diversity and folk taxonomy

5.1 General

The treatment of the species, varieties and subvarieties of *M. sagu* by Beccari (1918) has the advantage that it follows the local classification of the genus. His description appears to be a critical review of the available folk taxonomy. Beccari had at his disposal material from Seram, Ambon and Buru, all islands in the Moluccas in Indonesia (see Table 1). He also saw accessions from other parts of Indonesia and Malaysia, two from northern Papua New Guinea, and one from the Fly river in southern Papua New Guinea. Beccari did not find any of the Moluccan varieties in any of the other places. All his varieties and subvarieties appear to be location-specific.

Most of the literature on folk taxonomy is found in ethnological descriptions of populations that subsist on sago palm. Schuiling (1995) reviewed some twenty sources in Indonesia and in Papua New Guinea. He adds the names found by himself on Seram and on a joint visit to other areas (Schuiling *et al.* 1993). In the ethnographic literature, very little information is presented on the appearance of the sago palms.

Schuiling (1995) states at the end of his paper: "In my opinion, we should not argue too much about the scientific taxonomic status of local varieties. If local users of sago palm with lifelong experience in this crop have reason to believe that one sago palm is different from another, it probably is different. We should rather make a concerted effort to preserve as much as possible of the genetic variability of the sago palm which is still out there in the field, before it is too late."

Jong (1995) states: "In my encounters with sago palms in Sarawak, Indonesia, and Papua New Guinea, I feel that characters used by the local inhabitants to differentiate are also important for classification. Some examples are the pattern and shape of spines, fruit anatomy, frond shape and starch colour."

The author agrees wholeheartedly with both statements. Here, only those sources will be reviewed covering areas that have been visited by the author, and also by others with an agronomic background.

5.2 East Sepik

After the survey made by the author (Flach 1981), Rauwerdink (1986) worked in the East Sepik District of Papua New Guinea as a graduate student, under the supervision of the Department of Plant Taxonomy of Wageningen Agricultural University. Later, Kraalingen (1984) worked there for 6 months as a graduate student from the same university, under the supervision of the author. Both supply a number of descriptions. Their observations were followed up by the work of Shimoda (1986) and Shimoda and Power (1986).

Kraalingen summarizes his work as follows. The Imbando language group distinguishes four wild varieties: Wakar 1, 2, 3 and 4, all of which are spiny. The numbers are ranked by their starch yield. In addition, they distinguish eight planted varieties. The planted varieties may only give a few seeds occasionally; Kraalingen calls them sterile.

Table 5. Varieties in East Sepik, Papua New Guinea, arranged according to spininess, length, circumference at breast height (CBH), and estimated bole age at flower initiation.

Varieties†	No. varieties‡	Length (m)	CBH§ (cm)	Bole age¶ (years)
1. forma <i>sagu</i> :	3-4			
*Ambutrun (1)		7.6	158	5.0
*Ambutrun (2)		—	—	—
*Awirkoma††		4.1	136	—
*Kaparang		8.9	114	—
2. forma <i>tuberosum</i> :	2			
*Koma		5.7	120	4.0
Oliatagoe		3.9	129	—
3. forma <i>micracanthum</i> :	3-4			
*Kang(u)rum		7.2	151	6.3
*Makap(u)n		10.3	132	7.2
*Mand(u)m		n.a.	n.a.	—
Waipi‡‡		6.5	113	7.9
4. forma <i>longispinum</i>	10-13			
Wild sago palms:	4			
*Wakar (1)		10.0	133	4.1++
*Wakar (2)		4.2	125	3.2
*Wakar (3)		—	—	—
*Mandénium (Wakar 4)§§		—	—	—
Cultivated palms:	6-9			
*Anum		n.a.	n.a.	5.4
*Ketro		8.2	132	7++
Moiap		8.0	111	6.3
*Ninginamé¶¶		9.6	150	5.8
*Nago#		10.0	129	7.5
Passin		n.a.	n.a.	6.8+
Ukipi		n.a.	n.a.	—
*(Waipi)		—	—	7.9
Wombarang		n.a.	n.a.	—

† All local names are in Imbando, with the exception of 'Passin' and 'Wombarang', which are in Chuimondo.

‡ Total number of varieties: range 18-23.

§ Circumference at breast height.

¶ Estimated at flower initiation.

* Also found by Kraalingen.

+ Probably taller; ++ probably much taller.

†† 'Awirkoma' literally means 'White Koma', which refers to the white powder at the base of the leaf. It is thus remarkable that both 'Koma' varieties end up in two groups, according to spininess.

‡‡ According to Kraalingen, two varieties are called 'Waipi': a long-spined one that looks like 'Ketro', only the spines on the rachis are longer, and a short-spined one, similar to 'Makap(u)n'.

§§ Forms no trunk

¶¶ 'Ninginamé' might, according to Rauwerdink (1986), be identical with 'Wakar (1)' or Indigniamé in Chuimondo.

According to Kraalingen, 'Nago' might actually be 'Anum', but is derived from Chuimondo, in which language the same palm is called 'Nagon'.

Rauwerdink (1986) found that local sago growers distinguish some 20 cultivars in the western part of the Sepik River Basin. He worked with four different language groups. The varieties are presented in Table 5. The length of the bole until the inflorescence of most palms is given, and in addition, the circumference at breast height and the estimated age at flower initiation. The last figure should be regarded with caution: it consists of the age at flowering, calculated from the number of leaf scars and the flowering axes, less the 3 years needed for flower and fruit development. All local names are in Imbando, with the exception of 'Passin' and 'Wombarang' which are in Chuimondo. The varieties also found by Kraalingen are marked with an asterisk. Names given by Kraalingen are given in parentheses.

Kraalingen (1984) found a relationship between length of spines and trunk age, shown in Fig. 10. Not all his varieties are present in the graph.

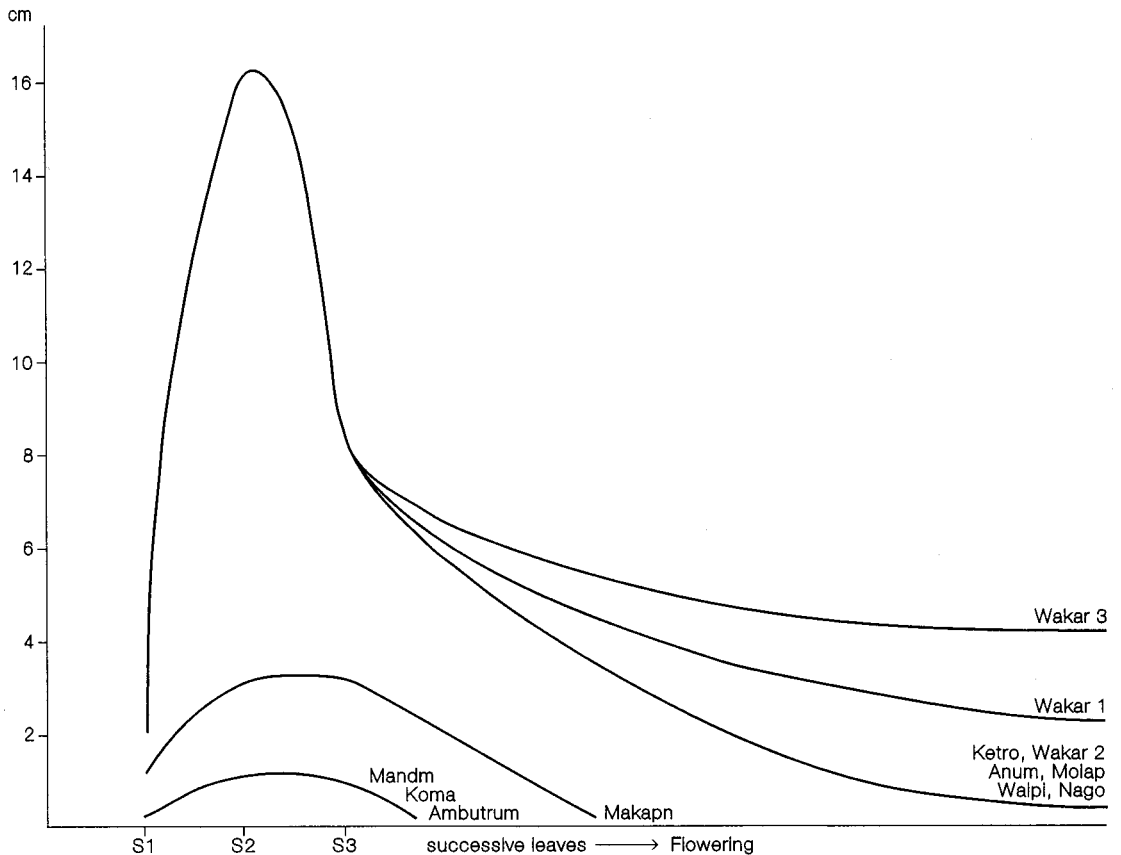


Fig. 10. Length of spines in relation to trunk age in the sago palms of the Imbando language group of the Sepik River Basin in Papua New Guinea. S1 is sucker no.1, etc (from Kraalingen 1984).

Kraalingen (1986) also established the correlations between starch content and some outwardly visible characters among the best wild variety (Wakar 1) in a sample of 19 trunks in the Sepik area. The correlations are presented in Table 6. In each row, the upper figures in the table represent the correlation coefficients, and the lower ones, their significance.

Table 6. Correlation matrix of a number of externally visible characteristics of sago palms, of the wild variety Wakar (1) (Kraalingen 1986).

CBH†	NFL‡	ENL§	AIL¶	LHI#	NIN††	SCP‡‡	
1.000	0.014	0.234	0.071	0.261	-0.332	0.186	CBH
	0.953	0.324	0.772	0.281	0.614	0.440	CBH
	1.000	0.788	-0.157	-0.001	0.302	0.312	NFL
		0.000	0.522	0.996	0.209	0.193	NFL
		1.000	-0.126	-0.036	0.0189	0.499	ENL
			0.607	0.884	0.438	0.030	ENL
			1.000	0.809	-0.868	-0.464	AIL
				0.000	0.000	0.046	AIL
				1.000	-0.796	0.529	LHI
					0.000	0.020	LHI
					1.000	0.421	NIN
						0.072	NIN
						1.000	SCP

† Circumference at breast height.

‡ Number of functional leaves.

¶ Average internode length.

‡‡ Pith starch content (g/cm³).

†† Number of internodes.

§ Expected minus real number of leaves.

Length of highest internodes.

Upper figures represent the correlation coefficients. Lower figures represent significance.

Kraalingen also established the best regression equation out of the correlations:

$$(SCP) = 0.2190 + 0.0242 (ENL) - 0.0108 (LHI)$$

where SCP = predicted dry starch content of pith in g/cm³; ENL = deviation between number of leaves found at flooding and expected number of leaves at the end of the dry period, and LHI = length of highest internodes on the bole.

The amount of starch in a bole can then be calculated by multiplying the predicted dry starch content by the volume of pith in the bole. The equation predicts 76% of the

yield. The average yield of the wild variety Wakar 1 amounted to 70 kg of dry starch. The correlation shows that the flooding regime has an important influence on yield: at flooding, the number of leaves decreases. After flooding, the number of leaves increases by 1.25 leaves/month on average, without flooding. In practice, the number of leaves per trunk increases from 13-14 to 20-21. Obviously, slowing down leaf production increases the age at which the trunk becomes fall-ripe.

Shimoda (1986) did research in the same region. He found that 'Anum' and 'Ketro' are the most favoured cultivars, owing to their high yields. They occupy 25.3 and 32.5% of his sample areas, respectively. Growers prefer spiny cultivars because they are protected against attack by wild boars; spineless cultivars occupy only 6.6% of the areas. A sample of boles, stored in the nearby loop of the river, contained seven 'Ketro' boles, with an average of 84 scars (bole age at inflorescence, 7 years). In addition, there were two 'Koma' boles with 74 leaf scars (bole age at inflorescence, 6.2 years) and five 'Ambutrunk' boles (of the same age at inflorescence). According to the author's estimation, the ages at flower initiation would be 5, 4 and 4 years, respectively. 'Koma' is considered by Shimoda (1986) to be spiny, but Rauwerdink puts it under his forma *tuberosum*, which means that knob-like structures are only present at the base of the plant. In an adjacent wild area, Shimoda found Wakar 1, Wakar 2 and Wakar 3 (covering 26, 42 and 32% of the sample area, respectively). Wakar 4 was not found in this area. Of these varieties, only Wakar 1 is occasionally used for starch extraction.

Shimoda and Power (1986) report on the same area, albeit for different purposes. Strikingly, they do not mention any of the earlier publications on the subject. They present data on leaf scars and living leaves of a number of varieties as also mentioned by Rauwerdink and Kraalingen (see Table 7).

Table 7. Number of years of bole growth until flower initiation, calculated from data presented by Shimoda (1986), Shimoda and Power (1986) and Rauwerdink (1984).

Name of cultivar	No. leaf scars	No. living leaves	No. years until inflorescence initiation		
			Shimoda (1986)	Shimoda and Power (1986)	Rauwerdink (1984)
Wakar	53	20	—†	4.5	4.1++
Wakar	57 (53)‡	15 (19)	—	4.5	3.2
Ketro	69	22	5	5.75	7++
Makapun	75 (70)	14 (19)	—	5.8	7.2
Kangrum	65	19	—	5.4	6.3
Ambutrunk	81	20	4	6.75	5.0
Awirkoma	93 (88)	15 (20)	—	7.33	—
Koma	—	—	4	—	4.0

† Data not available.

‡ Figures in brackets are the author's corrections.

5.3 Halmahera

On Halmahera, an island in the northern Moluccas, a number of surveys have been made. The first was in 1884 by Campen, an officer in the former KNIL, the Royal Dutch East Indian Army, who was stationed on the island. He gave a general description of its agriculture, in which the sago palm plays an important role, although he did not state on which part of this large island he made his observations.

A century later, a Japanese group did a survey on the northern part of the island, apparently in an area with a different language, Galela. In the group's combined report, Yoshida (1980) wrote an excellent chapter on the island's folk taxonomy. Schuiling *et al.* (1993) visited the island in 1992 to see the operation of INHUTANII, running a 6000-t dry starch factory. In their report a limited number of varieties were described.

Starting from the work of Yoshida (1980), the author has tried to place the varieties of both Campen (1884) and Schuiling *et al.* (1993) in the same key. Yoshida states: "Galela people divide the sago palm into eight varieties, which they can identify instantly. However, they have difficulty in explaining the differences between the varieties, and it appears that they do not clearly recognize the distinctive features of the different varieties, but that recognition is rather gestalt." Only after repetitive questioning and explanations could the differences be made clear to the foreign observer. There were two levels of classification, one at the sucker level and one at the level of a growing bole. Keys for both are presented in Figures 11a and b.

Campen (1884) presents seven varieties, as distinguished by the local population:

1. 'Toppo bohekka', with small spines, 5 cm long, and white starch.
2. 'Soang', with spines 1 cm long, and reddish starch.
3. 'Bawah', without spines, and often with reddish starch.
4. ('Toppo) Nau', a large bole with spines of at least 15 cm, and white starch.
5. 'Hangee bohekka', without spines and small, yellowish rachides
6. 'Hangee', without spines, and wider, darker green rachides than 'Hangee bohekka'.
7. 'Bawah namalau', with many rather tough fibres, and therefore hard to work with a low yield. Spininess and starch colour are not mentioned.

According to Yoshida, the 'Kuweso', 'Sika' and 'Yafa' varieties possess reddish starch, while for Campen, this holds for 'Soang' (2) and for 'Bawah' (3) only. But the classifications cannot be brought together; it is only possible in part to relate the varieties distinguished by Campen and Yoshida with those presented by Schuiling *et al.* (1993). The latter describe three palms, i.e. 'Sisika', a spined palm with 52 leaf scars, measured in the first bole until flower initiation, and 72 in the second. This palm is considered to be wild. Its name is rather close to Yoshida's 'Sika', and also to a palm with large spines. The other two are 'Béka' and 'Ratému', both with 72 leaf scars at flower initiation.

From Ternate, a small island close to Halmahera, Schuiling *et al.* collected two varieties, 'Hange' and 'Soang'. Both names can be found in the list made by Campen (1884), and, remarkably, have persisted unchanged for over 100 years. Unfortunately, Schuiling and coauthors only made fruit counts, and did not describe the varieties in detail.

With respect to comparison with East Sepik, Kraalingen (1984) describes both stages, which are also described by Yoshida (1980). Unfortunately, this was not known to Kraalingen when he did his research. The author tried to apply Yoshida's key to the work of Kraalingen, but this proved impossible without seeing the varieties directly. In both areas, however, the local sago palm experts use the same properties to classify varieties. Thus, it is still uncertain whether both areas have varieties in common.

In Table 8, Yoshida presents interesting data on the quality of leaflets used in the production of thatch. The first two varieties — 'Sika' and 'Yafa' — are seldom used for thatch. 'Kuweso' leaflets are rather tough, and require a considerable amount of work. These are often used as roofing material for people's dwellings. 'Sirigi' leaflets are fairly strong and are sometimes also used by villagers. Thatch made from 'Seho ma tano' leaflets is also fairly strong and is easily made, as are 'Roku ma ano' leaflets. 'Roku ma amo pusa' thatch requires more leaflets, and also more time. 'Bobarai' thatch is easily made, but weak.

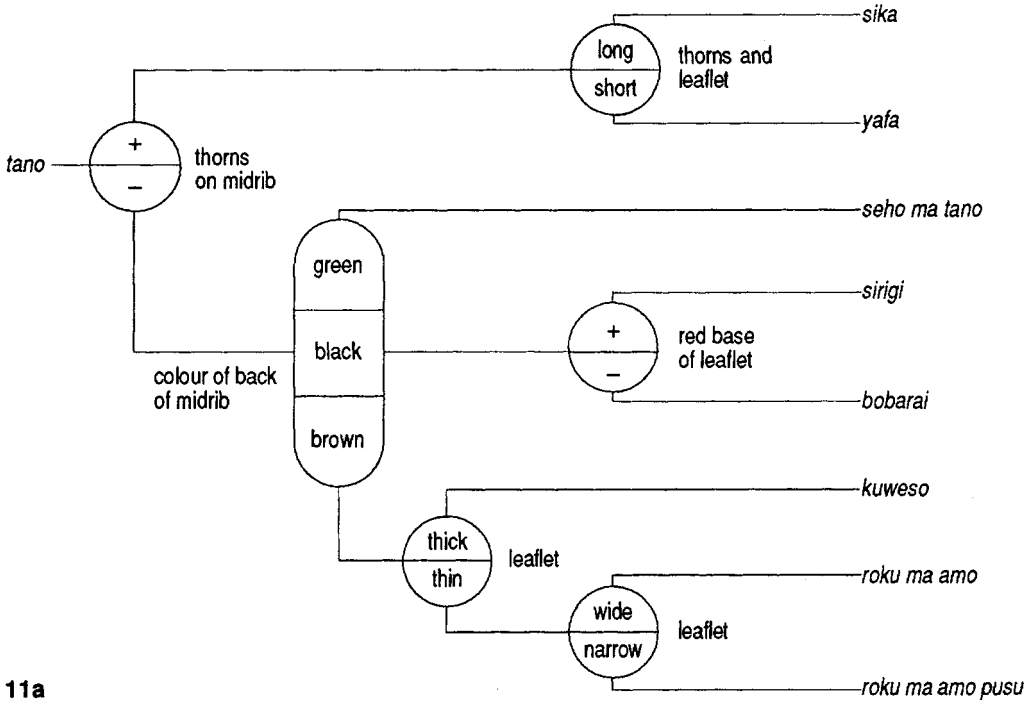
Table 8. Characteristics of sago palm leaflets on Halmahera, northern Moluccas (Yoshida 1980).

Variety	Degree of spininess	Thickness of leaflets	Width of leaflets	Length of leaflets
Sika	++			
Yafa	++			
Kuweso	+	++	+	+
Sirigi	+	+	++	—
Seho ma tano	+	+	+	—
Roku ma amo	±	+	++	—
Roku ma amo pusu	+	+	+	—
Bobarai	—	±	+	—

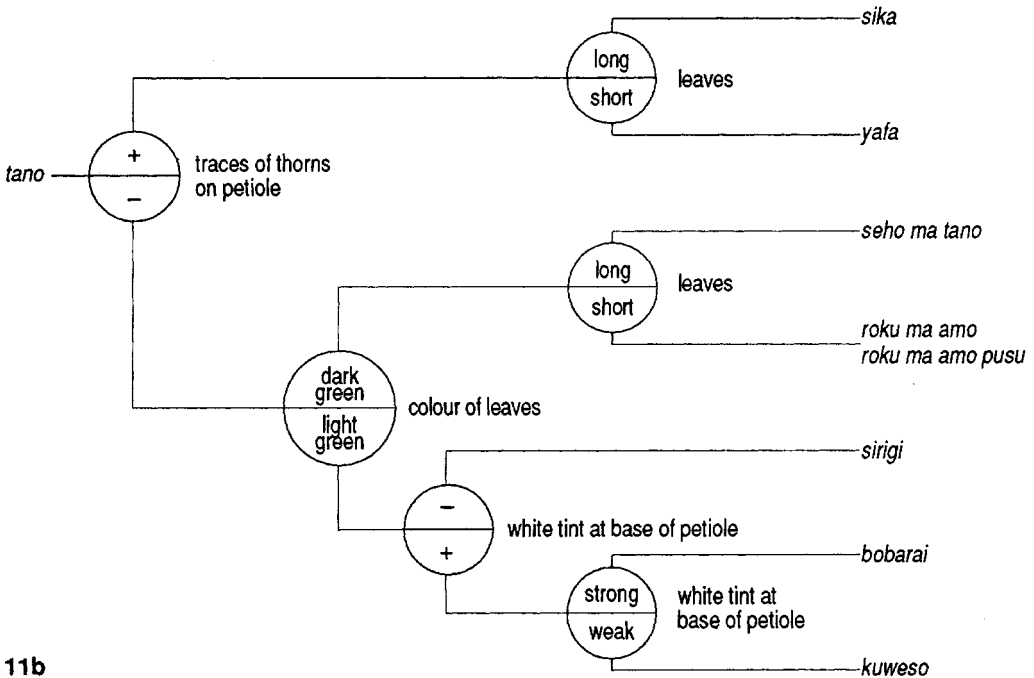
++ = very high; + = high; ± = moderate; — = low.

5.4 Northern Irian

In 1984, the author took part in a survey along the north coast of Irian, in Waropen, on the eastern side of the MacCluer Gulf. The soils in the area are continuously wet: rainfall exceeds evapotranspiration. Occasionally, flooding occurs. Part of the coastal population consists of people who migrated there from the mountains some 50 years ago. These groups now use the same names for sago as those used by the original inhabitants of the area. According to a local farmer, his people distinguish three spined varieties and one non-spined variety.



11a



11b

Fig. 11. Galela classification of sago palms at (a) the sucker level and (b) at the bole growth level (from Yoshida 1980, courtesy of the National Museum of Ethnology, Osaka).

- 'Mai', or 'Nduanda' (if planted). Of this variety, there are two different bole ages at flower initiation, i.e. 6-7 years ('Mai 2') and 9-10 years ('Mai 1' or 'Nduanda'). 'Nduanda' of 9-10 years is preferred. Bole age at flower initiation is not constant in the wild variety, and the grower may thus choose which one he wants to multiply vegetatively. The palm with the largest bole circumference and the tallest bole was most frequently grown.
- 'Ndosa', or 'Sakambai' (if planted). This variety has a constant bole age of 9-10 years at flower initiation.
- 'Faréi', a variety with short, soft spines. The variety has a bole age at flower initiation of 6-7 years.
- 'Umbéni', an unspined, small palm, with a lifespan of 6 years from planting as large sucker, to seed formation. The variety appears to be identical with Moluccan 'Molat' and Imbando 'Ambutrun'.

Palms belonging to the lower age group gave too little starch per bole. Local growers preferred the varieties, and both of these varieties ('Faréi' and 'Umbéni') were not seen. The bole age of 'Nduanda' and 'Sakambai' is thus 9-10 years. Large uniform tracts of 'Sakambai' were found in a vegetation that could be called sago palm forest. Table 9 presents estimates of starch density, size, leaf area and productivity of different sago palms, calculated from the measurements taken. The method of analysis used is that of Flach *et al.* (1986a). 'Sakambai' proved to be the best cultivar by far in the rather small sample. There may be considerable scope for selection of better palms in all groups, however, especially 'Mai 2'. For comparison, the situation under regular cultivation in Batu Pahat, Johore, West Malaysia is also given.

5.5 Western Irian

From 1950 to 1957, an experimental project was carried out on the island of Salawati, by a Dutch starch manufacturer (Holmes *et al.* 1984). The original data are no longer available, but the results after statistical analysis are. These are shown in Table 10. The wild stands were and still are found on clayish soils that are flooded for only part of the year.

From the data provided in the table, the average values for wild trunks from Salawati can be calculated. The average trunk weighs 1000 kg, has 250 kg of bark and 750 kg of fresh pith. The pith contains 150 kg of dry starch, 105 kg of other dry matter and 495 kg of moisture. At 1.2 m³/1000 kg of pith, an average pith starch density of 16.7 g/100 cm³ can be calculated.

On the same island, albeit at some distance from the site of the earlier project, Schuiling *et al.* (1993) collected data on the local folk taxonomy. The results are presented in Table 11. At the time of the visit, the area was completely dry. Groundwater level was 1 m below soil level. According to the information received, this happens fairly often, especially in the Australian summer, but the area was reported to be often flooded in the wet season. Excavating at the side of a dry waterhole at 1 m depth, it was possible to see the sago palm roots, their white tips indicating that they were alive and growing. The pneumatophores on top of the soil, however, had withered.

Table 9. Comparison of starch density, size, leaf area and productivity of different sago palms in Waropen, Irian.

	Starch density (g starch per 100 cm ³ pith)	CBH (cm)	Length (cm)	Leaf area (m ²)	Dry starch (kg)
'Ndosa' or 'Sakambi': bole age at flower initiation 9-10 years†					
1	15.1	155	1440	232	337
2	13.8	122	1530	208	169
3	3.7	172	2060	268	145
Mean	10.9	150	1677	236	217
'Mai 1' or 'Nduanda': bole age at flower initiation 9-10 years‡					
1	8.5	97	1350	120	53
2	3.7	139	1970	108	82
3	3.4	140	2040	64	85
Mean	5.2	125	1787	97	77
'Mai 2': bole age at flower initiation 6-7 years§					
1	11.8	119	1030	146	118
2	11.6	120	1040	114	104
3	10.1	149	1190	104	170
4	9.1	134	1200	106	107
5	3.4	144	1430	92	58
6	2.5	130	850	78	19
7	1.6	116	1060	78	11
8	1.2	114	1070	78	7
Mean	6.4	128	1109	100	74
Situation under cultivation in Batu Pahat, Johore, West Malaysia¶					
	30	120	700	90	180

† Average production per year of bole growth = 21.7 kg (217/10).

‡ Average production per year of bole growth = 7.7 kg (77/10).

§ Average production per year of bole growth = 10.6 kg (74/7).

¶ Average production per year of bole growth = 45 kg (180/4).

Source: unpublished data from field research of Flach and Gandri Simbardjo, 1984.

Table 10. Mean starch content of wild sago palm trunks harvested on the island Salawati, Irian, Indonesia (after Flach and Schuiling 1989).

Part of trunk	Mean	Low	High
Bark (%)	25		
Moisture in pith (%)	66	55	70
Starch in dry matter (%)	51	40	76
Starch in fresh pith (%)	20.5	15	30
Dry starch per trunk (kg)	150	90	325

Table 11. Sagopalm varieties on Salawati island, Irian, Indonesia (Schuilting *et al.* 1993).

Group/name†	Spines	Status	Life cycle (years)	Other properties
Group 1				
'Fok'	+	planted	15	seeds infrequent
'Fok surare'	+	planted	15	spinecombs closer and whiter than in 'Fok'
Group 2				
'Snang'	+	planted	15+	seeds infrequent
'Nesek lege'	+	planted	20	thin bark, leaf sheaths adhere
'Keta'	+	planted	20	as 'Nesek lege' with thicker bark
'Kla'	+	planted	20	soft bark and pith
'Kuf bra'	+	planted	20	leaf sheaths fall off, blue leaf base
'Snang kwi'	+	planted	20	tallest palm, grows dry, as rattan
Group 3				
'Katun'	—	planted	20	like nipa palm
Group 4				
'Mdah'	++	wild	20	largest trunk, seeds frequent, thickest bark, longest spines, leaflets most durable

† The variety names given here are all derived from 'Wah', generally the local name for sago palm.

All varieties give white starch. Good boles of 'Fok' and 'Snang' may yield 60 *tumang toko*, a basket made of sago palm leaflets as sold in a shop. Such a *tumang* is approximately 50 cm wide and 17 cm deep, containing approximately 8.5 L of wet starch. This would be equivalent to approximately 5 kg of dry starch. The boles mentioned would thus produce some 300 kg of dry starch. This is double the average starch yield found by Holmes *et al.* (1984) for the same area, and still below the maximum yield found by them of 325 kg.

Remarkably, the variety with red starch is not found in the area. The life cycle of the quickest variety is only 15 years, and of the others, 20, or even longer. It may well be that the succession of a rather low water level by quite prolonged flooding is responsible for an extension of the duration of growth, as shown by Kraalingen (1986) for the Imbanda area in Papua New Guinea (see **section 5.2**). This area has regular flooding during the wettest season, but no extremely dry period.

On Salawati, locals stated that the Bintuni area has the same varieties of sago palm. Zwollo (1950), who was working there, reported that Bintuni occasionally becomes so dry that the sago palms burn in forest fires. This was confirmed by personnel in Djajanti, now harvesting in the Bintuni area.

5.6 Critical evaluation

Relation between age and number of leaf scars

Most of the research reported here was done before the model used in Table 2 had been developed, and the probable relation between number of leaf scars and age was not yet known. Owing to this, too little attention has been paid to the estimated duration of growth. The criteria developed by Rauwerdink and those of Shimoda and Power differ, and it is not easy to determine when flower initiation occurs. This can only be done with certainty by opening the growing point.

Although both Rauwerdink and Kraalingen state that the local sago growers do not attach importance to high productivity, this is not the experience of the author. If asked, the sago growers immediately reply that you should use their 'Ambutrún', as it has a short growing period. The duration of bole growth is thus probably an important distinguishing character. Considerable variation in the data is apparent, however, and it could well be that only vegetatively propagated (clonal) material possesses a constant number of leaf scars on the bole at flower initiation. However, in a population derived from crosses, the number may vary around a mean, as was found in Sarawak (see **section 2.2**). This was also the opinion of the local farmer interviewed in Waropen, northern Irian (see **section 5.4**). Only under optimal conditions might the number of leaf scars be a reliable way of estimating the duration of growth. Both drought and flooding can extend the duration of growth, while keeping the number of leaf scars down. There may thus be a difference between the physiological age, as indicated by the number of leaf scars, and the real age, as indicated by the number of years. Further research needs to be done on this subject.

Spininess

Imbando people recognized the variety grown in Batu Pahat by means of a colour photograph as their cultivar 'Ambutrún'. 'Ambutrún' is said to be sterile; it apparently does not give seeds in the fruits. In Batu Pahat, however, if this palm is not cut at flower initiation, or just before, it produces seeds abundantly. The offspring produce spiny and non-spiny palms, with all sizes of spines. 'Ambutrún' may well be identical with Beccari's 'Molat', which he classified as spineless. Beccari (1918) already doubts that spininess is a distinguishing character. He writes "even the spinescence is probably a character of little diagnostic value, as it often happens in other palms, in *Calamus* for instance, that some specimens identical in all the reproductive organs, have the leaf sheaths sometimes densely covered with spines and at other times smooth". Barrau (1959) was of the same opinion.

The distinction was subsequently shown to be invalid by Kraalingen (1984) and Flach (1983). Often, a wide variation in spininess is found in the offspring of one mother palm, awareness of which can be elicited from sago growers. In the Moluccas, local people are aware that there are also spined 'Molat'. Schuiling (1991) also speaks of *molat berduri*, meaning 'spiny Molat'. Furthermore, Kraalingen (1984) established that spininess varies with age.

Rauwerdink points out that in his four forma, spininess could well be a character controlled by only two genes. His ideas are presented in Table 12. It is certainly a freely crossing character in 'Molat', but it is not known if spininess is a freely crossing character in all of the other varieties, however.

Table 12. The four forma of spininess, as controlled by two genes, according to Rauwerdink (1986).

	AB	Ab	aB	ab
AB	AABB <i>L</i>	AABb <i>L</i>	AaBB <i>L</i>	AaBb <i>M</i>
Ab	AABb <i>L</i>	AAbb <i>L</i>	AaBb <i>M</i>	Aabb <i>T</i>
aB	AaBB <i>L</i>	AaBb <i>M</i>	aaBB <i>L</i>	aaBB <i>T</i>
ab	AaBb <i>M</i>	Aabb <i>T</i>	aaBb <i>T</i>	aabb <i>S</i>

L = *longispinum*: 7 out of 16; *M* = *microcanthum*: 4 out of 16; *T* = *tuberatum*: 4 out of 16; *S* = *sagu*: 1 out of 16.

Trunk size

Sago palm trunks growing isolated on good soils may show a considerably larger circumference than those growing in groups. Circumference depends on the number of fronds present in the crown, with the diameter increasing with the number of fronds. It is not yet certain which factors influence growth pattern. For example, a sago palm trunk growing in isolation in the Sepik River Basin reached a circumference of over twice that of one of the same variety growing in a group. The leaf scars are then usually rather close to each other, which produces a short and sturdy palm. Furthermore, palms that are nurtured do considerably better than those that are not. Variation in trunk diameter along the length of a palm can also be seen in palms in a planting (as explained in section 2.3). In general, it can be concluded that circumference is more important for the amount of pith in the trunk than length.

Recognizing varieties

Sago growers usually recognize a variety from quite a distance, by its general appearance. This excludes spininess, which can only be judged from close range. During field trips, discussion of this characteristic tends to dominate interviews with local farmers, and to be of greater interest to researchers than the general appearance of the palm. There may still be other, possibly more important, distinguishing characters. For example, Jong (1995) reports that 'Sagu Ihur', classified by Beccari

(1918) as *Metroxylon rumphii* var. *sylvestre*, has pinkish starch. In the Sepik River Basin, Papua New Guinea, the author encountered a tall palm, growing in forest on dry land. This palm also had red pith, which resulted in pinkish starch. The variety 'Koma' showed over 160 leaf scars at flower initiation, making its bole age, as counted by one leaf scar per month, over 13 years (bole length, 11 m; girth, 135 cm). The name *sylvestre* would thus be appropriate.

Starch density

It is not yet known whether pith starch density is controlled by genetic or environmental factors. High starch density is of considerable importance, as proportionally less pith has to be transported to the processing plant. Pith moisture content is usually around 50%.

Sterility

The reported sterility may be caused by the small number of plants of a certain variety growing together. For successful pollination, at least two inflorescences need to flower at approximately the same moment, which is highly unlikely in small groups of plants. If 'Ambutrung' or 'Molat' is grown in larger groups of plants together, they usually produce some quite fertile seeds, and in the Sepik area, when grown in small plots, 'Ambutrung' occasionally produces some fertile seeds. Nicholson (1921) reports that 'Batu Pahat' produces seeds freely. This can also be seen at Wewak, on the north coast in Papua New Guinea, where a large plot of 'Ambutrung' can be found. In southern Sumatra, in the province of Bengkulu, large numbers of fertile seeds are often also found, always under decaying trunks near each other, which have been flowering at the same time.

It could well be that the reported sterility is caused by the plant being mainly an obligatory cross-pollinator. For successful pollination, different plants should not be vegetatively propagated identical plants from the same mother plant, and they should reach exactly the same flowering stage simultaneously. It is therefore possible that only a limited number of stable varieties exist, of which 'Molat-Ambutrung' is one, and Beccari's (1918) *Metroxylon rumphii* var. *sylvestre*, another. Under different natural conditions, other plants that are fit for competition with the surrounding vegetation and which are increased by natural vegetative propagation (suckering), may take over.

5.7 Conservation techniques and methods

As the seeds of sago palm are recalcitrant, collections are maintained as field genebanks. A considerable amount of preparatory work has been done on *in vitro* culture of the sago palm. Reports were given in the third and fourth sago symposia (Alang and Hisajima 1991; Alang *et al.* 1991a, 1991b; Hisajima *et al.* 1991; Krishnapillay and Alang 1986). Of the 1991 papers, only the summaries are given; just one paper (Hisajima *et al.* 1991) is presented in full. Growth of tissue and of embryos *in vitro* has been proved to be possible. Callus formation has not yet been achieved. At the time of the fifth sago palm

symposium, all work on *in vitro* culture in Malaysia had been handed over to the Sarawak Land Development Authority, responsible for sago palm planting in Sarawak.

For an assessment of the potential role of *in situ* conservation, more in-depth studies on the existing diversity of wild stands in the centre of origin and the danger of genetic erosion are required.

5.8 Collections

Only rather limited collections of sago palm have been made, and it is doubtful whether they are adequately maintained. If the collections are to be used for breeding or multiplication, observation is needed over a full growing cycle, from seed to seed. This would cover a period of at least 12 years for the quickest, and probably 20 years for the slower varieties.

Jong undertook collecting missions in Indonesia and Papua New Guinea. His collections were taken to the research station at Sungei Talau in Sarawak, where he had to hide his new accessions in the existing plantings, in order to forego theft by interested sago growers (Jong 1994, pers. comm.). The Land Custody and Development Authority in Sarawak, the agency responsible for the planting schemes, started collection of planting material. A trip was made on behalf of this organization to a number of Moluccan islands (Schuiling, pers. comm. 1995), and the material obtained was planted on the Sungei Talau experimental station. Responsibility for this station was shifted from the Sarawak Department of Agriculture, to the Sarawak Land Custody and Development Agency (LCDA).

Schuiling also collected 17 varieties in Indonesia, which were planted at Makariki on Seram, a substation of the 'Puslitbang Tanaman Industri' at Bogor, the Centre for Research and Development of Industrial Crops. A collection of local varieties of sago palm was made between 1980 and 1983, in the Sepik River Basin, Papua New Guinea, at the Saramandi experiment station, close to Angoram. Four plants of each variety collected were planted there in a square. The directors of the experiment station have changed repeatedly, however, and it is uncertain whether this collection is well documented and maintained.

6 Breeding

The palm can be classified as a nearly complete obligatory crossbreeder, with an easy vegetative multiplication. The minimum duration of growth, of at least 8 years until flower initiation, makes crossing a lengthy operation. A second difficulty is that it is unlikely that two trunks flower at exactly the same time in each other's neighbourhood, which is necessary for crosses. It is therefore of paramount importance to find methods to store pollen from desired male parents, for later pollination of palms selected as mother trees. The height of the inflorescence, which entails the building of scaffolds, represents an additional difficulty.

Small groups of the same cultivar of palms hardly produce seeds. This could be caused by incompatibility between the mother palm and its own pollen, and probably, also the pollen of its clonal offspring. Such palms occasionally produce some fruits with seeds, which may be caused by pollination from farther afield.

The other sago palms in the neighbourhood, which are sometimes numerous, as in Papua New Guinea, are also not able to pollinate them. But a second possibility is that pollination between different cultivars is mostly impossible. That groups of 'Molat-Ambutrun' form fertile seeds easily could point in this direction. It may well be that some types, e.g. 'Molat-Ambutrun', deserve species status. And the same may hold for the tall palm with red pith and red starch, named *sylvestre* by Beccari (1918). This palm type has also been encountered in most of the other areas.

There may therefore be two different factors that need to be considered: first, the obligatory and thus continuous crossing that results in a highly heterozygous population, and secondly, the easy natural vegetative propagation of these heterozygous populations may produce clones that are competitive in the natural vegetation. These may survive and multiply. Such palms could well have been helped by humans. This would explain on the one hand the high variability of the natural vegetation, and on the other, the large tracts of palms which could well be clones of the same palm.

Research on crop improvement should also aim at high starch content per trunk, produced in a short period. This, expressed as grams of dry pith starch/cm³, may vary considerably: in the samples taken on Salawati, in northern Irian, the average was 16.7, while in plants under regular cultivation in Batu Pahat, Johore, West Malaysia, the average was nearly 30.

Selection should therefore aim at:

- short duration of bole growth
- high pith starch density
- thin bark
- white starch.

Whether or not spininess is a desirable characteristic depends on the risk of attacks by wild boars and monkeys.

7 Production areas

7.1 Malaysia

West Malaysia. The oldest description of the intensive cultivation around Batu Pahat, Johor, is given in a translation into French of a paper written by Nicholson (1921). His original paper is no longer available. Half a century later, Flach *et al.* (1971) showed that cultivation of an exceptional high standard still existed. The method of cultivation was developed by local farmers, without any support from the research community. At the beginning of the 1970s, a government subsidy scheme was implemented to encourage planting.

At the beginning of the 1990s, production was still estimated to be at 11 000 t (Othman 1991). This well-developed cultivation may well be disappearing now, for two reasons: first, a rice irrigation scheme is being developed in the area; second, young people dislike the wet and dirty work involved, and are moving to towns and cities where they can make more money.

Sarawak. East Malaysian Sarawak has a long history of sago starch production, mainly on peat. Originally, it was purely a subsistence crop, but subsequently it also became of importance for export, especially for the population of coastal areas.

Jong (1995) gives an overview of the history of sago starch production for the international market. Sago palm starch has been exported since the early 19th century, when Singapore was founded. Currently, it ranks fourth among the agricultural export commodities of Sarawak, producing 50 000 t of air dry starch, worth RM4 31 000 000 (starch currently fetches RM 620/t). The Sarawak government is now developing it as a plantation crop, utilizing part of the 1 500 000 ha of peat swamps. In 1982, the Sarawak government established a specialized research station, also on peat (although by that date, research on the crop had already been carried out in Sarawak for some time). Near Mukah, the world's first large-scale commercial plantation of 7700 ha was developed by the Sarawak land development agency (Fig. 12). In 1993, a second plantation of 1600 ha was established near Oya.

While the author applauds the large-scale planting of sago palm, he is concerned that the overall lack of knowledge, especially on fertilizer application, of considerable importance on undrained deep peat, will become a serious impediment to profitable production.

Sabah. A considerable amount of sago palm is also cultivated in East Malaysian Sabah. Most of it is sold, and is used for home consumption by the local population. Small engine-driven factories with rotary rasps produce 200-500 kg wet starch/day.



Fig. 12. The LCDA planting in Sarawak on deep peat; in the centre the office for the operation. This is the first large scale planting scheme of sago palm in the world (photo: F.S. Jong).

7.2 Indonesia

On the island Benkalis, east of Sumatra, and around it, a considerable amount of sago palm is cultivated. Trunks are floated out to small factories. Geographically, the area is close to Batu Pahat in Johor, West Malaysia. Its starch was originally exported through Singapore, but now it is sold to Cirebon, on Java, where it is mainly used in noodle manufacture. Not all authors have been convinced of the usefulness of the sago palm. In 1921, an article appeared in a Dutch language agricultural weekly, entitled "The curse of the Molucca's: the sago palm" (Bandanees 1921). In the author's opinion, the ease of production of sago palm starch as a staple led to the incurable laziness of the Moluccan population, and the paper suggests how this 'curse' might be transformed into a blessing!

In 1947, efforts were made to mechanize starch extraction from stands on Seram in the Moluccas (Salverda 1947). Experiments were done with a cassava scraper to rasp sago palm pith. The experimental factory was mounted on an 80-t shallow draft boat. Labourers penetrated the forest on foot and selected, felled and split the palms. The pith was cut into blocks and carried to the boat.

Zwollo (1950) investigated the extensive wild groves in Bintuni in former Dutch New Guinea. Exploitation, albeit difficult, might be feasible. An aerial survey of the same area showed extensive natural stands (Stellingwerf 1957). From 1956 to 1963, a Dutch starch manufacturer systematically investigated the feasibility of

mechanized starch extraction from wild stands on the island of Salawati, close to Bintuni (Holmes *et al.* 1984). It resulted in a plan to establish a processing plant for 30 000 t of high-quality dry starch/annum.

More recently, surveys were carried out, with a view to tapping the natural resources on Seram (Team Proyek 1981).

A private company, P.T. Sagindo Sari Lestari, now runs a 36 000 t floating extraction plant in Bintuni, in Irian Jaya. A new plant is being established on dry land in the area, and the floating factory will be taken to the southern part of Irian. In both cases, wild stands are being exploited.

A semi-governmental forest exploitation company, INHUTANI I, runs a 6000-t dry starch plant on the island of Halmahera, harvesting from existing stands.

On Siberut, the main island of the Mentawai islands, west of Sumatra, a private investor is being encouraged to open a starch factory.

Close to the production centre of Benkalis, on the island of Tebing Tinggi, new plantings are being started on peat soils. A 3000-ha planting was started 9 years ago. A new 20 000-ha planting will be developed over the next decade. The sum of US\$2 million/year is expected to be invested in the new plantings.

In the province of South Sulawesi are some 25 000 ha of sago palm (Maamun and Sarasutha 1987), mainly in the Bone, Pare-pare and Luwu districts. Yields are said to average 14 t wet starch/ha per year, estimated by the author to be equal to 8.4 t dry starch. Most of the product is consumed locally.

7.3 Papua New Guinea

In Papua New Guinea, attention also has been paid to the possibilities for exploitation of the huge tracts of sago palm vegetation (Cavanaugh 1953, 1955). In the early 1970s, a survey was carried out in the Sepik River Basin by a Japanese group (Toyo Menka Kaisha 1972). Although the survey established the area's potential for exploitation, it was not followed by any project. At the time of the energy crisis, preparations were made for the production of power alcohol, based on sago palm, as a feedstock (Holmes and Newcombe 1980). This led to a survey in the northeastern part of the Sepik River Basin (Flach 1981). For this purpose, the 1956-63 pilot project on the island of Salawati in Indonesia was reviewed (Holmes *et al.* 1984). No action resulted when the energy crisis subsided.

8 Ecology

Sago palm grows well in humid tropical lowlands, up to an altitude of 700 m. Temperatures should be above 25°C on average, but the crop tolerates temperatures of around 17°C, provided these only last a few hours. Relative air humidity should on the average be above 70%, but a few hours below that level are not harmful. Incidental light should preferably be above 800 k/cm² per day, thus above the level under a half-clouded sky (Flach *et al.* 1986a). Salinity should not exceed 10 S/m, equivalent to one-eighth of the salt concentration of sea water. Flooding for a prolonged period has an adverse effect on yield. Stagnant water inhibits growth, but inundation for a few hours, even with saline water, does not appear to do so (Flach *et al.* 1977). These experiments were conducted in hothouses, with young seedlings, but the results are not contradicted in cultivation.

Water shortage is detrimental to growth. If dependent on rainfall, evapotranspiration should be exceeded most of the year. The area should have a well-distributed rainfall, above 2000 mm per year, without any pronounced dry periods. And, if there are short dry spells, the groundwater level should be at the most 40-50 cm below the soil surface (Flach and Schuiling 1989). On the notoriously poor and usually undrained peat soils, sago palm grows 25% more slowly than on mineral soils (Jong and Flach 1995). Clayey soils with a high organic matter content yield the best results.

Neither manure nor fertilizer is being used as yet. Nutrient needs are of the same order as those of the oil palm, but, owing to the high number of trunks per hectare, the amount of nutrients in the palm vegetation appears to be three times that of oil palm. Centralized processing on a somewhat larger scale will lead to nutritional problems, as will continuous harvesting of leaves for thatch, as in both cases the plant nutrients are removed. Application of fertilizer under occasionally flooded conditions does not as yet increase either growth or starch production (Kueh 1995).

With respect to photosynthesis, the crop appears to follow the C₃ pathway (Flach 1977). This was confirmed by Uchida *et al.* (1990). Hisajima *et al.* (1995) did not detect starch in the leaves. It thus is possible that photosynthetic products are temporarily stored as sugar.

9 Agronomy and technology

9.1 Crop husbandry

As can be seen in Johor, West Malaysia, the best farmers plant relatively small and quick-maturing varieties on clayish soils high in organic matter at 7 x 7 m. Good-sized suckers of at least 2 kg each are used. This results in 204 clusters/ha. Suckering is regulated by pruning, so that each cluster of palms produces one bole/18 months. After the first 8 years, which are unproductive, this leads to a production of 136 boles/ha per year. Each bole contains 175 kg dry starch, on average. Total annual production per hectare thus amounts to around 25 t of dry starch. There are also slightly different planting systems, all resulting in approximately the same amount of dry starch per hectare.

Trunks are cut up into logs, and floated out to privately owned small factories. At spring tide, the land is flooded by slightly brackish or even saline water. This water probably carries sufficient plant nutrients to replenish the soil.

The main impediment to this type of cultivation is that it takes 8 years until first production. As the age of the planting increases and it becomes semi-wild, production diminishes to about 15 t dry starch, owing to unchecked suckering and fruit trees that are allowed to grow in the planting.

9.2 Propagation

The palm propagates itself, both vegetatively and sexually. Vegetative propagation is by means of suckers, mostly growing from the lowest leaf axils. Suckers may start trunk formation close to the original trunk; they do so by means of a horizontal stem, the stolon. With full light in the surrounding area, e.g. in a paddy field, the stolon may become up to 6 m long. In wet and clayish soils, the stolon grows on top of the soil. In drier conditions, on lighter soils, it grows in the soil. In the long run, suckers are separated from the original trunk, thus forming new clusters. Occasionally, suckers may be formed higher up on the bole.

The palm propagates sexually at the end of its life cycle. After initiation of the inflorescence, the leaves become progressively smaller, grow to the same height and become table-like in appearance. Then the inflorescence with only bracts appears. A well-developed one may carry up to 850 000 fruits. Ripeness of the fruit is indicated by a browning of its scaly husk.

If the fruit contains a seed, germination only follows under wet circumstances. A rosette grows from the seed, out of which a new bole and new suckers may be formed.

9.3 Nutrients

Flach and Schuiling (1991) and Jong and Flach (1995) made it clear that a considerable amount of nutrients are required for sago palm to be cultivated to a high standard. Table 13 contains measurements from Sarawak, Malaysia and from Seram, Moluccas, Indonesia.

Table 13. Nutrient contents of a single bole and a single leaf, based on measurements taken in Sarawak, Malaysia, and Seram, Moluccas, Indonesia.

Nutrient	Nutrient contents (g)	
	In one bole	In one leaf
N	590	37
P	170	6
K	1700	20
Ca	860	90
Mg	350	7

Source: Flach and Schuiling (1991).

If boles are processed in the field, almost all nutrients will be returned to the soil. But in central processing, the nutrients will be removed and will disappear from the growth site. The same happens if leaves are used for thatch on a wide scale. Kueh (1995) summarized the results of fertilizer experiments on undrained deep peat in Sarawak over a period of 12 years. Growth was assessed by means of rate of frond production of the leading palm, trunk girth at 1 m height and rate of trunk elongation. These parameters did not show any results. Kueh suggests that the number and size of suckers should be taken into account. The present author also recommends that other parameters be used, such as leaf longevity and total area per leaf. Kueh (1995) also concludes that the foliar NPK level may be a better indicator, although the optimum level has not yet been established (Sim and Ahmed 1991). Other research on fertilizer application on mineral soils is not recorded in the literature.

It is clear that research into fertilizer use is necessary if sago palm cultivation is to be raised above the traditional levels. This is more important for sago palms grown on peats, where the continuously wet conditions pose an additional problem, as the fertilizer applied may be washed away.

9.4 Pests and diseases

Until now, the sago palm has not been seriously affected by pests and diseases. However, with increasing intensity of cultivation, the dangers posed by pests and diseases are likely to increase, as with all other crops. Gumbek and Jong (1991) present an overview of pests at Sungai Talau research station, in Sarawak where cultivation has been intensified. The main pests there were:

- Hispid beetles (*Botronyopa grandis*), whose larvae feed on young tissues of the unopened spear at the central base of the crown.
- Termites (*Coptotermes* spp.); these insects may become a pest on peat soils containing undecomposed vegetative matter. They may then tunnel through the palm.

- The red striped palm weevil (*Rhynchophorus* spp.); eggs may be deposited on young plants that have injured exposed tissue, e.g. the cut surface of a sucker, or damage by boars. The larvae burrow into the tissue. They are also prized as a delicacy.

Other pests include wild boars and monkeys, which may uproot newly planted suckers. If these cause damage to the crop, they can only be controlled by shooting.

There are no records of diseases in sago palm. Palms at the Sungei Talau experiment station in Sarawak have been affected by a physiological disease attributed to sudden drainage of the peat. The bole-forming palms lost quite a number of leaves and the older leaves showed yellow spots. The symptoms disappeared when drainage was blocked (Schuiling *et al.* 1993.)

9.5 Commercial starch production

Commercial production aims at a consistently high level of production per unit time and area. Therefore, complete boles, including the lowest part, are harvested around flower initiation.

The starch produced by small factories is usually of varying quality. It is often not completely white, contains remnants of fibre, and the starch grains may be corroded through microbial activity. This is a limitation in international markets, which will only shift to sago if there is a constant supply of clean, white non-corroded starch granules.

Efforts have been made to develop techniques for larger scale production. The main constraint is the transport of the boles to the factory. Each bole weighs at least 1 t, 50% of which is moisture. Two-thirds of the boles, which float in water, are submerged. The boles are usually cut into logs measuring 1.2 m in length, which are rolled out of the planting to the nearest waterway (Fig. 13a). They are then floated to the factory (Fig. 13b and c). The small factories (Fig. 13d) can easily be found by the pungent smell of lactic acid fermentation.

In the last 20 years, interest in the production of sago palm starch has increased considerably. Theoretical economic calculations by Hoogland (1986) showed that large-scale production can be quite profitable. A 30 000 t dry starch factory located near an existing producing stand could give a rate of return on investment of over 10%. Even new plantings were shown to be profitable, including the 8 years until the crop can first be harvested (Riezebos 1986). At 1984 prices, such a factory would need an investment of US\$ 6 000 000.

9.6 Starch extraction

Ten recommendations for the improvement of sago palm starch extraction are listed below. Seven of these were made by the starch technologist Cecil (1986), after working in Sarawak for a number of years. Those of the present author (after various authors), are footnoted.

1. **Harvesting time of trunks.** Harvesting of immature trunks should be avoided, as the starch grains then may be too small for easy settling. A trunk is considered



13a



13b



13c



13d

Fig. 13a. Rolling logs to nearby river, Kao, Halmahera, Indonesia. Two pins have been driven into the cut ends of the log.

Fig. 13b. Sago logs arriving at the starch factory at Kao, Halmahera, Indonesia.

Fig. 13c. Sago logs entering the log storage pond at Kao, Halmahera, Indonesia.

Fig. 13d. A small sago starch factory close to Mukah, Sarawak. Notice the logs waiting for processing in the river and the large amount of bark lying outside.

to be mature close to flower initiation, when the inflorescence first begins to form in its growing point⁵.

2. **Iron tools.** The use of iron tools should be avoided as much as possible. It stains the cut surface irreversibly⁶ (See also number 6 below.)
3. **Log storage.** Logs should not be stored for more than 2-3 days at the very most, and preferably in water; both longer and dry storage lead to deterioration of starch quality, through microbial activity, and to a diminishing quantity of starch (Fig. 14).
4. **Bark thickness.** Bark should be removed carefully, and as sparsely as possible, as the inner layers still contain a considerable amount of starch; the bark layer itself is usually less than 2.5 cm thick, but this also depends on the variety.
5. **Milling of pith.** Pith must be grated or milled finely, in order to wash out the starch grains; fibres still may contain starch. Colon and Anokkee (1986) advocate the use of the old-fashioned hammermill for this purpose, but Cecil (1986) fears that a hammermill may damage the starch granules.
6. **Heavy metal ions in the processing water.** These should be avoided, as they promote oxidation of polyphenols, present in boles, that dye the starch irreversibly⁷. (See also number 2 above.)



Fig. 14. Dry storage of sago palm logs. Deterioration is strong, leading to large losses of starch in both quantity and quality.

5 Recommended by the author, after Fujii *et al.* (1986)
 6 Recommended by the author, after Ito *et al.* (1979)
 7 Recommended by the author, after Ozawa and Arai (1986)

7. **Sieving out fibre.** Before sedimentation, the starch slurry should be passed through a screen no coarser than 120 mesh (125 μm). This removes the remaining fibre particles that may be instrumental in the microbial deterioration of the starch. This will also lead to some loss of large starch grains, but this amounts to less than 1%.
 8. **Settling.** Settling tanks should be extensive and shallow, rather than compact and deep. The same holds for settling tables; in this way, small starch grains can also be captured.
 9. **Storage of wet starch.** Starch should not be kept wet for more than 24 hours. Where there is no alternative for storing wet starch, it must be treated with SO_2 . If kept wet too long, the starch grains may erode. This results in gas pockets in the grains, which makes settling more difficult, and also diminishes starch quality.
 10. **Cleaning of factory equipment at stops.** Equipment should be cleaned thoroughly after each prolonged factory stop; if this is not done, the new start will be accompanied by increased microbial activity.
- Observing these ten recommendations may lead to an increase of 30-50% in the amount of starch extracted, and a considerable improvement in quality.

9.7 Pollution

The refuse from the pith starch extraction contains proteins, some sugars, most of the plant nutrients and a considerable amount of fibre. Proteins, sugars and some of the plant nutrients are soluble in water, and will be removed by the water the starch is washed in. The fibres remaining after starch extraction usually still contain some starch, with the quantity depending on the quality of extraction. There is also a considerable amount of hard bark.

Traditional starch production is on a small scale and is done in the field, where the refuse remains. Larger, more commercial production sites, however, are mostly built alongside rivers, where the refuse is washed away and is not recycled. The cortex is usually discarded close to the factory. As long as the factories are relatively small and well apart, depleting the soil of plant nutrients is the only danger they pose.

If really large-scale production is started, attention also should be paid to the amounts of refuse generated. Starch, cortex and fibre are produced in a ratio of approximately 10:16:7. If the chimney of the factory is especially adapted, the cortex can be used for firing (Flach 1995). The remaining rather wet fibre may be used to produce chipboard (Haryanto *et al.* 1991). Bintoro Djoefrie (1995) tried to use it as a substrate in nurseries for other crops, but it is too low in nitrogen for this. The remaining fibre could also be burnt, but would generate little heat because of its high water content.

At some future date, factories might be built in the middle of large plantings, with the cortex being used for firing and the remaining refuse being returned to the surrounding fields (as ideally it should be).

10 Limitations

Presently, three constraints exist for the cultivation of sago palm:

- If planted from seed, the crop needs 8 years before a first harvest can be done. This could be shortened to 6 years, by planting seeds in bags in a nursery for 2 years. If planted from suckers, the unproductive period could be shortened to 5 years, by starting off with very large suckers, or by cultivating suckers for an extended period, in polybags in a nursery.
 - The unproductive period could be avoided by developing existing natural stands. But such stands are likely to give a lower yield than new plantings. Moreover, natural stands of sago palm are to be found in remote and relatively undeveloped areas. Factories need to be established there, because otherwise, transport of the heavy feedstock (containing 50% water) is necessary. A shortage of skilled labour, and the logistical problems involved in transportation, present practical obstacles to the opening of such factories. Accessibility will also be a problem, as most natural stands are located in wetlands. Flach (1986) proposed a method for making natural stands exploitable by means of a canal system.
 - Without a solution for the problem of how to apply fertilizer on undrained deep peat, the new plantings, intended for an intensive production system on deep peat, in both Sarawak and the Riau islands in Indonesia, will fail. The sago palm will only give its traditional annual yields of 5-6 t dry starch/ha.
 - For transportation of the feedstock to a factory, a system of waterways should be laid out in each stand, be it a planting or a natural stand. This is probably the largest investment required for a successful operation of the factory.
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11 Prospects

11.1 The market

Sago palm has potential for development as a commercial crop, chiefly for high-quality starch for use as an industrial feedstock. In the author's opinion, its use as a fresh food will decline continuously. The largest market for the crop is Japan, which each year already imports some 20 000 t of starch produced in Sarawak, and is willing to increase its imports, provided a good-quality clean, odourless and uncorroded starch is available.

Indonesia has a fast-growing internal market, and all the starch the country produces will probably be used for domestic consumption. The starch produced by the pilot factory run by INHUTANI I at Kao, on Halmahera, in the northern Moluccas, is presently sold on the local market as food. Traditionally, the starch produced around Benkalis, west of Sumatra, is used in Cirebon, for the production of noodles. The production in the Bintuni area, in Irian, is mainly sold as an extender in the production of adhesives for the local plywood industry. Sago starch is used as an ingredient in the production of white bread, consumption of which is rising rapidly in Indonesia. Provided that it is colourless and tasteless (Clarke *et al.* 1980), sago starch can be used to make up to 40% of the content of white bread. It can also be used in the production of high-fructose syrup, particularly for the growing market of non-alcoholic beverages. In addition, sago starch has traditional uses in the manufacture of medicines and paper, and in the finishing of textiles. All the industries mentioned are growing in Indonesia, and at present, a considerable amount of starch is imported. At some time in the future, starch is expected to be used as a biodegradable filler in plastics.

Should these markets be saturated, the animal feed market offers further potential for development. Amylopectin is less suitable for animal feed than amylose, but the two components of sago starch can be readily separated (Higginbotham and Morrison 1934, cited by Radley 1976). Amylose is especially suitable for use as an extender of adhesives, and also has a market for conversion into ethanol as a renewable fuel. The refuse from the fermentation process can be used as a high-protein animal feed. As the bark can be used for firing in the factory, the crop gives a positive energy balance (Ham *et al.* 1985).

11.2 Production

The sago palm has a number of definite advantages over all other commercially produced starch crops:

- It has an exceptionally high yield level. Under good conditions, the yield varies from at least 15 t to possibly 25 t of dry starch/ha. This is higher than that of any other starch crop (Flach 1977), but can only be obtained after the initial 8 unproductive years.
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- It is a perennial crop, which means that once planted, it can produce for many years. All other starch crops have to be replanted regularly. If a sago palm planting is not regularly cleaned and pruned, however, it becomes semi-wild, with a far lower yield level.
 - It has an extended harvesting period. Each trunk remains fall-ripe from the time of flower initiation in the growing point until the seeds are formed, i.e. for a period of 2 years. This makes spreading of the harvesting period possible. Late harvesting removes the light for the follower trunk, however, and thus leads to a diminished yield over a given period of time.
 - The palm grows well on soils that are liable to occasional flooding, even with somewhat saline water. Expensive water-control mechanisms are therefore unnecessary. Continuous flooding is detrimental to yield, nonetheless.
 - Cut boles can be kept under water for 2 days at most, at the factory site. This makes it possible to run factory operations smoothly. Keeping the cut boles for longer, however, results in loss of starch, and can also produce moulds, which corrode the starch grains.
 - Harvesting is easy. A chain saw and an axe are sufficient. Boles divided into logs can be rolled out to the nearest waterway and floated to the factory.
 - With continuous harvesting, processing plants can operate continuously. Moreover, less energy is needed for the extraction of starch from sago palms than from other crops.
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12 Research needs

12.1 Agronomy

In Sarawak, until 1983, part of the research effort of the Ministry of Agriculture and Community Development was directed at the sago palm, but at a low level. This is reflected in the Annual Reports of the Research Branch, where until 1983, the research results can be found under the heading 'Chemistry'. From 1983 onwards, they are given under a separate heading: 'Sago palm'. In 1982, the research effort was intensified. In that year, a sago research station was established on deep peat soils in Sungei Talau, and a supporting laboratory was established in Mukah. Around 1993, all research on sago palm was transferred from the Department of Agriculture to the Land Custody and Development Agency.

In Indonesia, the 'Badan Pengkajian dan Penerapan Teknologi' (B.P.P. Teknologi), the Agency for the Assessment and Application of Technology, an institute belonging to the Indonesian Ministry of Research and Technology, runs an 8000 m² trial planting of sago palm at Balumbang Jaya, close to Bogor. The palms were planted as suckers in 1984. Some accessions, collected in the Moluccas, are also available there. The Agency also operates a pilot processing plant at Ciampea, near Bogor. Research on the sago palm is only carried out occasionally in some universities, and not on experiment stations.

In the author's opinion, the principal problem that agronomic research needs to tackle is the use of fertilizers. All the research done until now has been on undrained peat soils, and does not indicate the effects of the use of fertilizers. Results are badly needed for the new plantings on peats, in both Sarawak and Indonesia, and also to improve production from natural stands on peat soils in the Bintuni area, in Irian Jaya. Experiments on mineral soils also need to be carried out, not only for comparison but also to support the harvesting from natural stands on Halmahera. The results of experiments on fertilizer application may also influence production in traditional stands. It may well be possible to grow sago palm on potentially acid sulphate soils, as it appears to be growing in Johor, West Malaysia (Othman 1991).

Below are listed the traits needed for estate cultivation, as described by Schuiling and Jong (1996), with a number of comments by the present author:

- Brief rosette stage. This can be shortened by planting either large suckers, healthy suckers or seedlings in an excellent nursery, under good care, with watering and fertilizer. Farmers often state that the rosette stage can be shortened from 4.5 years to 2 years, by planting large suckers instead of seedlings.
 - Quick bole maturation, to allow an early first harvest. Bole growth may possibly be speeded up by fertilizer application, and by a good regime of irradiation, i.e. by correct planting density.
 - High starch accumulation rate.
 - High planting density. A high starch accumulation rate can be obtained by high irradiation of the leaves. At the young stage, palms could be planted in a system of permanent ones and fillers, the fillers being harvested and eradicated after
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the first, or perhaps the second harvest. In this way, the ineffective use of irradiation during the first 6 years may be improved considerably. After 8 years, denser planting appears to be inappropriate. The Leaf Area Index then reaches the rather high value of more than 7, and an appropriate system of pruning of excessive suckers is necessary to obtain well-spread placement of palms on the field.

- Responsiveness to fertilizers. It is not yet known whether this is a problem. It may well be that the lack of response to fertilizer application is caused by flooding, or by defective methods of measurement, but further research on this subject is necessary. Other than on the deep peats in Sarawak and on the small trial planting run by B.P.P. Teknologi in West Java, no fertilizer has been applied yet.
- Pest and disease resistance or tolerance. Pest and diseases are not yet a real problem, but with more intensive cultivation they may become important.
- Ability to grow well on peat soils. This last characteristic is not of general interest, but is rather important for Sarawak.

12.2 Collecting and breeding

Making collections of palm types would appear to be the first priority. These palms should be observed carefully, as our knowledge of sago palm and its growth pattern is still imperfect. Such collections should consist of at least four plants each, derived vegetatively from the same mother palm. These clones should be observed carefully, over at least one complete life cycle. Selections could then be made in the collection. Only when the characteristics of the clones are known can breeding goals be formulated and a start be made with crosses.

Information also needs to be gathered with respect to storage of pollen, in order to make crosses between the palm types eventually selected.

12.3 *In vitro* culture

Although the present work on *in vitro* culture appears to be more advanced than other research items, it needs to be continued until a method of rapid multiplication has been developed.

12.4 Taxonomy

Taxonomic research should be done, using all observations with respect to the duration of the life cycle of the trunks (see **section 2.2**). Zymographic studies may be particularly useful. Such observations can only be made in well-organized collections, however. The present collections in Sarawak, Papua New Guinea and Indonesia are probably inadequate for this purpose.

12.5 Technology

Research on starch technology was started by the government of Sarawak (Cecil *et al.* 1982). The combination of measures presented in **section 9.6** may lead to a 30-50% improvement in starch recovery in the factory. If a good starch technologist,

well versed in sago palm cultivation and harvesting, continues the research started by Cecil and his group, this work will be of considerable interest. The user side of technology research is mainly done in Japan, the principal importer of sago starch.

12.6 Cooperation in research

At present, the Sarawakian Land Custody and Development Agency (LCDA), responsible for development of the new sago palm plantings in Sarawak, appears either to be afraid of its competitors, or to want to make money out of the research done by them. This conclusion may be drawn from the fact that as long ago as the symposium of 1990 (Ng *et al.* 1991), only summaries of the papers connected with *in vitro* culture were published. LCDA took over responsibility for the sago palm research in Sarawak in 1993, and did not produce any publications for the fifth international sago symposium, which took place in Hat Yai, Thailand, in 1994. Furthermore, two presentations given at the symposium⁸ were not published in the Proceedings (Subhadrabandhu and Sdoodee 1995).

Although the research in Sarawak is ahead of that being done in other countries, such an attitude usually does not encourage other researchers to make their results freely available to the international community. Furthermore, the starch market is large enough to allow competition. Sago research should be stimulated through international cooperation in South-East Asia. The main producers — Malaysian Sarawak, Indonesia and Papua New Guinea — should, if possible, combine their research efforts, preferably in one research station, where the international collection of sago palms should also be located.

⁸ Azuddin, M.N., K. Lim and Z.C. Alang: 'Comparative study on palm growth and starch yield of *Metroxylon sagu* at five stages of maturity, grown on gleyed mineral and organic soils', and a paper presented by R. Manurung on *in vitro* culture of sago palm.

References

Since 1970, five international symposia, and an FAO Expert Consultation have considerably increased interest in the sago palm. The first symposium was held in Kuching, Sarawak, East Malaysia (Tan 1977), and contained a section on prehistory and ethnobotany. The symposium was attended by 76 participants.

The second, held in 1979, in Kuala Lumpur, Malaysia (Stanton and Flach 1980) was only attended by 26 participants. By the time of this symposium, the ethnobotanic contribution had disappeared, and it had become a purely technical event. This trend continued in the symposia that followed.

The third was held in 1985, in Tokyo, Japan (Yamada and Kainuma 1986), and had 54 participants. It was supported by the Japanese Sago Palm Fund.

The fourth took place in 1990, in Kuching, Sarawak (Ng *et al.* 1991), and was attended by 112 participants.

The fifth was held 1994, in Hat Yai, Thailand (Subhadrabandhu and Sdoodee 1995). This had 75 participants.

The sixth symposium will be held in December 1996, in Pekanbaru, Indonesia.

The Expert Consultation was organized by FAO, and the Indonesian B.P.P. Teknologi in Jakarta, Indonesia, in 1984 (FAO 1986). This consultation played quite a role in awakening Indonesia to the possibilities of the sago palm.

In 1993, the Japanese Society of Sago Palm Studies was started. The society publishes the journal Sago Palm, which appears irregularly. The Tsukuba Sago Fund issues a regular publication, Sago Palm Communication, edited by S. Hisajima.

Schuiling (pers. comm., 1996) is preparing a comprehensive bibliography of sago palm, in which all journal articles, reports and other grey literature, including Indonesian publications, will be brought together and summarized. The bibliography ends in the year 1990. All material is available for consultation in the Sago Archives in Wageningen Agricultural University, Department of Agronomy, Section Tropical Crop Science.

Alang, Z.C. and S. Hisajima. 1991. Some observations on stress tolerance in sago palm (*Metroxylon* spp.) and oil palm (*Elaeis guineensis*), using *in-vitro* cultured embryos (summary only). P. 64 *in* Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.

Alang, Z.C., Y.-Y. Gan, F.C. Low and E. Paulose. 1991a. *In-vitro* propagation and biochemical characterization of sago palm germplasm relevance to the sago starch industry (summary only). P. 66 *in* Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.

Alang, Z.C., B. Krishnapillay, S.F. Pilus and S. Hisajima. 1991b. Embryo culture and nursery establishment in sago palm (*Metroxylon* spp.) plantlets (summary only). P. 65 *in* Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.

- Avé, J.B. 1977. Sago in insular South-East Asia: historical aspects and contemporary use. Pp. 21-30 in *Sago-76*. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July, 1976. (K. Tan ed.).
- Bandanees. 1921. De vloek der Molukken: de sagopalm [The curse of the Moluccas: the sago palm]. *Algemeen Landbouwweekblad voor Nederlandsch Indië*, 30 Sept. 1921. 6(14):613-616.
- Barrau, J. 1959. The sago palm and other food plants of marsh dwellers on the South Pacific islands. *Econ. Bot.* 13:151-162.
- Beccari, O. 1918. Asiatic palms - Lepidocarpaceae. *Annals Royal Botanical Garden, Calcutta* 12:156-195.
- Bintoro Djoefrie, H.M.H. 1995. To accelerate sago pith residue decomposition into a green manure. Pp. 261-268 in *Fifth International Sago Symposium*. Hat Yai, Songkhla, Thailand, 27-29 January 1994. (S. Subhadrabandhu and S. Sdoodee, eds.). *Acta Hort.* 38(9).
- Boonsermsuk, S., S. Hisajima and K. Ishuzuka. 1996. Isozymatic variations of sago palm (*Metroxylon sagu* Rottb.) in Thailand. *Jpn J. Trop. Agric* 39:229-235.
- Campen, C.F.H. 1884. Pp. 1-17 in *De landbouw op Halémahéra [Agriculture on Halmahera]*. *Tijdschrift voor Nijverheid en Landbouw in Nederlandsch Indië*, Deel XXIX, aflevering, Vol. 1.
- Cavanaugh, L.G. 1953. Report on *Metroxylon* species the Sepik river area. Memorandum for the Director of the Department of Forestry, Port Moresby, Papua New Guinea.
- Cavanaugh, L.G. 1955. Sago Flour Production in the Sepik River. Forest Products Research Centre, Boroko, Papua New Guinea.
- Cecil, J.E. 1986. Increasing profits from sago processing. Pp. 112-120 in *The development of the sago palm and its products*. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Cecil, J.E., G. Lau, S.H. Heng and C.K. Ku. 1982. The sago starch industry; a technical profile, based on a preliminary study made in Sarawak. *Trop. Res. and Dev. Inst.* L58.
- Clarke, P.A., E.S. Sim and D. Tan. 1980. The use of sago flour in bread making. *Trop. Sci.* 22(2):189-195.
- Colon, F.J. 1958. Het winnen van sago in de moerassen van Nederlands Nieuw Guinea [Production of sago starch from the swamps in the Netherlands New Guinea]. TNO-Report no. 58-0705 available in the archives of the former Directorate of the Netherlands. New Guinea, the Hague.
- Colon, F.J. and G.J. Anokkee. 1986. Survey of some processing routes of sago. Pp. 121-140 in *The development of the sago palm and its products*. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Corner, E.J.H. 1966. *The Natural History of Palms*. Weidenfeld & Nicolson, London.
- CSIRO. 1968. *Lands of the Wewak-Lower Sepik Area, Papua New Guinea*. CSIRO-Land Res. Ser. 22.
- FAO. 1986. *The development of the sago palm and its products*. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Flach, M. 1977. Yield potential of the sago palm and its realization. Pp. 157-177 in *Sago-76*. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July 1976 (K. Tan, ed.).
- Flach, M. 1981. Sago palm resources in the northeastern part of the Sepik river flood basin: report of a survey. Dept. Minerals and Energy (DME) Rep. no. 3. Konedobu, Papua New Guinea.
- Flach, M. 1983. *The Sago Palm*. FAO Plant Production and Protection Paper 47, AGPC/MISC/80. FAO, Rome.
- Flach, M. 1986. Agronomy of sago based cropping systems: a preliminary approach. Pp. 94-101 in *The development of the sago palm and its products*. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.

- Flach, M. 1995. Research priorities for sago palm development in Indonesia and Sarawak: an agenda for research. Pp. 19-39 in Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994. (S. Subhadrabandhu and S. Sdoodee, eds.). Acta Hort. 38(9).
- Flach, M. and D.L. Schuilting. 1989. Revival of an ancient starch crop: a review of the agronomy of the sago palm. *Agrofor. Syst.* 7:259-281.
- Flach, M. and D.L. Schuilting. 1991. Growth and yield of sago palms, in relation to their nutritional needs. Pp. 103-110 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Flach, M., F.J.G. Cnops and G.Chr. van Roekel-Jansen. 1977. Tolerance to salinity and flooding of sago palm seedlings. Preliminary investigations. Pp. 190-195 in Sago-76. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July, 1976. (K. Tan, ed.).
- Flach, M., K. den Braber, M.J.J. Fredrix, E.M. Monster and G.A.M. Van Hasselt. 1986a. Temperature and relative humidity requirements of young sago palm seedlings. Pp. 193-143 in Sago-85. Proc. 3rd Int. Sago Symposium (N. Yamada and K. Kainuma, eds.). Tokyo.
- Flach, M., A.H.J. Kroon and J.S. Baker. 1971. Sago production in Pahang Tenggara. Pahang Tenggara Regional Masterplanning Study Paper no. 16.
- Flach, M., D.W.G. van Kraalingen and G. Simbardjo. 1986b. Evaluation of present and potential production of natural sago palm stands. Pp. 86-93 in Sago-85. Proc. 3rd Int. Sago Symposium. (N. Yamada and K. Kainuma, eds.). Tokyo.
- Fujii, S., S. Kishibara, H. Tamaki and M. Komoto. 1986. Studies on the improvement of sago starch quality: 2. Effect of the manufacturing condition on the quality of sago starch. Pp. 97-106 in Science Reports of the Faculty of Agriculture Kobe University, Japan.
- Gumbek, M. and F.S. Jong. 1991. Pests of sago palms in Sarawak. Pp. 142-145 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Ham, J. van der, J.B.P. de Loor and M. Flach. 1985. Energy from tropical crops: energetic evaluation of the agricultural and industrial production of ethanol and vegetable oil. *Trop. Crops Comm.*, No. 8. Wageningen Agricultural University, the Netherlands. 37pp.
- Haryanto, B., S. Royangsih and S. Ali. 1991. The use of fibrous residue and the bark for making particle boards. Pp. 203-206 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, August 6-9, 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Haska, N. 1995. Study of productivity and starch yield of sago palm in West Java. Pp. 217-222 in Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994 (S. Subhadrabandhu and S. Sdoodee, eds.). Acta Hort. 38(9).
- Heyne, K. 1950. De nuttige planten van Indonesië. [The useful plants of Indonesia], 3rd impression. Van Hoeve, 's Gravenhage/ Bandoeng.
- Hisajima, S., E.S. Sim, F.S. Jong and Y. Arai. 1991. Propagation and breeding of sago palm (*Metroxylon* spp.) *in vitro*: stimulation of embryo growth and multiple shoots from sago embryos. Pp. 53-63 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, 6-9 August 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
-

- Hisajima, S., M. Yato, S. Boonsermsuk, S. Ramchatgoen, S. Kachonpadungkitti and K. Ishizuka. 1995. Preliminary observation on sugar metabolism and biochemical classification in sago palm. Pp. 147-161 in Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994 (S. Subhadrabandhu and S. Sdoodee, eds.). Acta Hort. 38(9).
- Holmes, E.B. and K. Newcombe. 1980. Potential and proposed development of sago (*Metroxylon* spp.) as a source of power alcohol in Papua New Guinea. Pp. 164-175 in Sago: the Equatorial Swamp as a Natural Resource. Proc. 2nd International Sago Symposium, Kuala Lumpur, Malaysia, 15-17 September 1979 (W.R. Stanton and M. Flach, eds.). M. Nijhoff, the Hague.
- Holmes, E.B., H.J. Vegter and O.L. Moll. 1984. Starch production from Irian. Report no. 3. Dept. Minerals and Energy, Energy Planning Unit, Konedobu, Papua New Guinea.
- Hoogland, J.D. 1986. Economics of large scale sago exploitation. Pp. 218-224 in The development of the sago palm and its products. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Ito, T., Y. Arai and S. Hisajima. 1979. Utilization of sago starch. Japan. J. Trop. Agric. 23:48-56.
- Jong, F.S. 1995. Research for the development of sago palm (*Metroxylon sagu* Rottb.) cultivation in Sarawak, Malaysia. PhD thesis, Wageningen Agricultural University, the Netherlands. Jong Foh-Shoon, Dept. Agriculture, Kuching, Sarawak, Malaysia.
- Jong, F.S. and M. Flach. 1995. The sustainability of sago palm (*Metroxylon sagu*) cultivation on deep peat in Sarawak. Sago Palm (J. Jpn. Soc. Sago Palm Studies) 3:13-20.
- Kawabata, A., S. Sawayama, N. Nagashima and R.R. del Rosario. 1984. Physico-chemical properties of starches from cassava, arrowroot and sago. Pp. 259-271 in Tropical Root Crops: Post Harvest Physiology and Processing (I. Uritani and E.D. Reyes, eds.). Japan Sci. Soc. Press, Tokyo.
- Kiew, R. 1977. Taxonomy, ecology and biology of sago palms in Malaysia and Sarawak. Pp. 147-154 in Sago-76. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July 1976 (K. Tan, ed.).
- Kraalingen, D.W.G. van. 1984. Some observations on sago palm growth in East Sepik district of Papua New Guinea. Report no. 1. Dept. Minerals and Energy (DME) and the Economic Planning Unit (EPU), Konedobu, Papua New Guinea.
- Kraalingen, D.W.G. van. 1986. Starch contents of sago palm trunks in relation to morphological characters and ecological conditions. Pp. 105-111 in The development of the sago palm and its products. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Krishnapillay, B. and Z.C. Alang. 1986. *In vitro* propagation of the sago palm (*Metroxylon* spp.): some preliminary findings. Pp. 131-138 in Sago-85. Proc. 3rd Int. Sago Symposium. (N. Yamada and K. Kainuma, eds.). Tokyo.
- Kueh, H.S. 1995. The effects of soil-applied NPK fertilizers on the growth of the sago palm (*Metroxylon sagu* Rottb.) on undrained deep peat. Pp. 67-76 in Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994 (S. Subhadrabandhu and S. Sdoodee, eds.). Acta Hort. 38(9).
- Maamun, Y. and I.G.P. Sarasutha. 1987. Prospects for sago palm in Indonesia: South Sulawesi case study. Indonesian Agric. Res. and Dev. J. 9:52-56.
- Mitsubishi, J. and K. Sato. 1994. Investigations on the edible sago weevils in Papua New Guinea. Sago Palm (J. Jpn. Soc. Sago Palm Studies) 2:13-20.
- Ng, T.S., Y.L. Tie and H.S. Kueh (eds.). 1991. Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, 6-9 August 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.

- Nicholson, G.P. 1921. Le sagoutier en terrains marécageux Malacca [The sago palm in marshy lands]. Bull. Économique Indochine 24:195-200.
- Ohtsuka, R. 1983. Oriomo Papuans: Ecology of Sago-Eaters in Lowland Papua. University of Tokyo Press.
- Othman, A.R. 1991. Sago: a minor crop in peninsular Malaysia. Pp. 17-21 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, 6-9 August 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Ozawa, T. and Y. Arai. 1986. Phenolic substances from sago palm pith. Pp. 197-200 in Sago-85. Proc. 3rd Int. Sago Symposium (N. Yamada and K. Kainuma, eds.). Tokyo.
- Paijmans, K. 1980. Sagopalm Ecology in New Guinea. Pp. 9-12 in Sago: the Equatorial Swamp as a Natural Resource. Proc. 2nd International Sago Symposium, Kuala Lumpur, Malaysia, September 15-17, 1979. (W.R. Stanton and M. Flach, eds.). M. Nijhoff, the Hague.
- Radley, J.A. (ed.). 1976. The minor starches of commerce: the manufacture of rice, arrowroot and sago starch. Pp. 229-245 in Starch Production Technology, Applied Science (J. A Radley ed.). London.
- Rauwerdink, J.B. 1984. On the taxonomy of *Metroxylon*: the status of the sago palm in Papua New Guinea. Dept. Plant Taxonomy, Agricultural University, Wageningen, the Netherlands. 42 pp.
- Rauwerdink, J. B. 1986. An essay on *Metroxylon*, the sago palm. Principes, the J. Palm Society 30(4):165-180.
- Research Branch of the Sarawak Department of Agriculture. 1975-1994. Annual Reports Government Printer, Kuching, Sarawak.
- Riezebos, E.P. 1986. The economics of two sago-based cropping systems. Pp. 179-217 in The development of the sago palm and its products. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Rumphius, G.E. 1750. Het Amboinsch Kruidboek. 2nd ed., J. Burmannus bij M. Uytwerf, Amsterdam.
- Salverda, Z. 1947. Groot-exploitatie van sago [Large-scale exploitation of sago]. Tectona 37:116-126.
- Sarkar, S.K. 1970. *Palmales*. Res. Bull. Univ. Calcutta 2:22-23.
- Schuling, D.L. 1991. Development of the inflorescence of the sago palm (*Metroxylon sagu* Rottb.). Pp. 74-87 in Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, 6-9 August 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Schuling, D.L. 1995. The variability of the sago palm, and the need and possibilities for its conservation. Pp. 41-66 in Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994 (S. Subhadrabandhu and S. Sdoodee, eds.). Acta Hort. 38(9).
- Schuling D.L. 1996. *Metroxylon* Rottb. Pp. 116-120 in Plants Yielding Non-Seed Carbohydrates. Plant Resources of South-East Asia, Vol. 9. (M. Flach and F. Rumawas, eds.). Backhuys Publishers, Leiden.
- Schuling, D.L. and M. Flach. 1985. Guidelines for the cultivation of sago palm. FAO, Rome, and Wageningen Agricultural University, the Netherlands.
- Schuling, D.L. and F.S. Jong. 1996. *Metroxylon sagu* Rottb. Pp. 121-126 in Plants Yielding Non-Seed Carbohydrates. Plant Resources of South-East Asia, Vol. 9. (M. Flach and F. Rumawas, eds.). Backhuys Publishers, Leiden.
- Schuling, D.L., Jong, F.-S. and M. Flach. 1993. Exploitation and natural variability of the sago palm. Report of a Sarawak and all-Indonesia study tour, January-February 1992.

- Dept. Agronomy, Section Tropical Crop Science, Wageningen Agricultural University, the Netherlands. 82 pp.
- Shimoda, H. 1986. Some agronomic and ecological investigations on Sagopalm forests in the East Sepik river basin, Papua New Guinea. Pp. 85-90 *in* The development of the sago palm and its products. Report of the FAO/BPPT consultation, Jakarta, Indonesia, 16-21 January 1984. FAO, Rome.
- Shimoda, H. and A.P. Power. 1986. Investigations into development and utilization of sago palm forest in the East Sepik region, Papua New Guinea. Pp. 94-104 *in* Sago-85. Proc. 3rd Int. Sago Symposium (N. Yamada and K. Kainuma, eds.). Tokyo.
- Sim, E.S. and M.I. Ahmed. 1991. Leaf nutrient variations in sago palms. Pp. 94-102 *in* Towards Greater Advancement of the Sago Industry in the 1990s. Proc. 4th International Sago Symposium, 6-9 August 1990, Kuching, Sarawak, Malaysia. Ministry of Agriculture and Community Development, Sarawak, and Dept. Agriculture, Sarawak, Malaysia.
- Stanton, W.R. 1993. Perspectives on, and future prospects for, the sago palm. Sago Palm 1:2-7.
- Stanton, W.R. and M. Flach (eds.). 1980. Sago: the Equatorial Swamp as a Natural Resource. Proc. 2nd International Sago Symposium, Kuala Lumpur, Malaysia, September 15-17 1979. M. Nijhoff, the Hague.
- Stellingwerf, D.A. 1957. Rapport bij de vegetatieschetskaart van Amaroë-zuid, Inanwatan, Wasian en Sebjar Babo, gelegen in de Vogelkop Nieuw Guinea [Report and provisional vegetation map of Amaroë-South, Inanwatan, Wasian and Sebjar Babo, in the Bird's Head, Netherlands, New Guinea]. I.T.C. report, Delft. Report available in the archives of the former Directorate. Netherlands, New Guinea, The Hague.
- Subhadrabandhu, S. and S. Sdoodee (eds.). 1995. Fifth International Sago Symposium. Hat Yai, Songkhla, Thailand, 27-29 January 1994. Acta Hort. 38(9).
- Tan, K. (ed.). 1977. Sago-76. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July, 1976.
- Team Proyek. 1981. B.P.P. Teknologi and Universitas Pattimura. Bagian 2: Hasil survey agronomi di kepulauan Maluku Proyek Penelitian pemanfaatan dan Pendayagunaan Sagu sebagai Bahan Pangan dan Energi (P3SBPE) [Part 2: Results of an agronomic survey of sago in the Moluccas etc.]. Jakarta, Badan Pengkajian dan Penerapan Teknologi.
- Tomlinson, P.B. 1971. Flowering in *Metroxylon*. Principes 15:49-62.
- Tomlinson, P.B. 1990. The Structural Biology of Palms. Clarendon Press, Oxford.
- Toyo Menka Kaisha Ltd. 1972. Feasibility study for the establishment of a sago flour plant in the Territory of Papua New Guinea. Forest Products Research Centre, Boroko.
- Tuwan, M.A. 1991. Studi biologi bunga pada tiga jenis sagu (*Metroxylon* spp.) dan efeknya terhadap prosedur permuliaanya. [Study of the flower biology of three sago palm species and its effect on breeding procedure]. S1 thesis under guidance of L. Anema. Ambon-Maluku, Indonesia. Pattimura University, Faculty of Agriculture.
- Uchida, N., S. Kobayashi, T. Yasuda and T. Yamaguchi. 1990. Photosynthetic characteristics of sago palm *Metroxylon rumphius* Martius. Jpn. J. Trop. Agric. 34:176-180.
- Uhl, N.W. and J. Dransfield. 1987. Genera *Palmarum*: a Classification of Palms, Based on the Work of Harold E. Moore, Jr. L.H. Bailey Hortorium and International Palm Society. Allen Press, Lawrence, Kansas, USA.
- Utami, N. 1986. Penyerbukan pada sagu [Pollination of sago] (*M. sagu* Rottb.). Berita Biologi 3(5):229-231.
- Verhaar, H. M. 1976. Chromosome pattern of the sago palm (*M. sagu* Rottb.). Pp. 155-156 *in* Sago-76. Proc. 1st International Sago Symposium, Kuching, Malaysia 5-7 July, 1976. (K. Tan, ed.).
- Yamada, N. and K. Kainuma (eds.). 1986. Sago-85. Proc. 3rd Int. Sago Symposium. Tokyo.

- Yoshida, S. 1980. Folk classification of the sago palm (*Metroxylon* spp.) among the Galela. Pp. 109-117 in *The Galela of Halmahera. A Preliminary Survey* (N. Ishige ed.). National Museum of Ethnology, Osaka, Japan.
- Zwollo, M. 1950. Rapport sago onderzoek Inanwatan. [Report of investigations on sago in Inanwatan]. Report available in the archives of the former Directorate. Netherlands New Guinea, The Hague.
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Appendix I. Collections

Collections of plant material of the true sago palm (*Metroxylon sagu* Rottb.) are rather rudimentary and badly documented. A description of the existing collections is given below (addresses and contacts are provided in Appendix II).

- Sarawak, East Malaysia, in the Sungei Talau Research Station. The collection probably contains some 40 entries, collected in Papua New Guinea and Indonesia. The research station now falls under the supervision of the Director, Land Custody and Development Authority, to whom all enquiries should be addressed. The collection contains material from Indonesia, notably from Halmahera, Ternate, Sorong, Saparua and Mentawai. Material also was collected in Papua New Guinea, especially from the Sepik area. Later on, collections were made on Buru. No further information is available.
 - Seram, Moluccas, Indonesia, at Makariki Experiment Station; a small collection of 17 varieties was started in 1992. Information on the collection is given in Schuiling *et al.* (1993).
 - East Sepik Province, Papua New Guinea, at Saramandi Agricultural Research Station, close to Angoram. During the period 1980-83, a small collection was started, containing 13 entries from the area along the Sepik river.
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Appendix II. Crop research (scientists and institutions)

Indonesia

The starch factory in Bintuni, Irian Jaya, harvesting from natural stands on peat soils:

The site manager of Sagindo Sari Lestari

Jalan Merdeka 61

Manokwari, Irian Jaya

Tel.: +62-962-21020

Fax: +62-962-21937

The starch factory in Kao, Halmahera, Moluccas, harvesting from natural stands on mineral soils:

The President Director of PT INHUTANI 1

Gedung Manggala Wanabakti

Blok VII Floor 12

Jalan Gatot Subroto, Senayan

Jakarta 10270

Tel.: +62-21-573-1765

Fax: +62-21-573-4335

E-mail: inhutdir@cbn.net.id

The experimental planting and experimental factory, both close to Bogor:

The Sago Palm Group of B.P.P. Teknologi

c/o Ms Sarawati

Director for the Assessment and Application of Technical Sciences

17th floor BPPT Bld II

Jalan M.H. Thamrin 8

Jakarta-Pusat 10340

Tel.: +62-21-316-9605 or 9600

Fax: +62-21-316-9614

The 3000 ha 9-year-old planting on Tebing Tinggi island in the Riau archipelago in Indonesia, partly on mineral and partly on peat soils:

Mr Sumadi, SE Akt

Jalan Pulau Karam 96 F

Padang 25119, Sumatera Barat

Tel: +62-751-33200 or 32968

E-mail: sumadi@pdg.mega.net.id

The 20 000 ha new plantings on Tebing Tinggi island in the Riau archipelago in Indonesia on peat soils:

Dr Jong Foh-Shoon
General Manager KEA-holdings
P.T. National Timber and Forest Products
Jalan Jenderal Shmed Yani 105
Selat Panjang, Riau

The sago palm research group of the Research Institute for Coconut and Palms (RIC):

Dr Novariant Hengky
Mapanget
PO Box 1004
Manado 95001, Sulawesi Utara
Tel: +62-431-51430
Fax: +62-431-51587

The Indonesian Sago Palm Society:

Dr H.M.H. Bintoro, secretary
c/o Institut Pertanian Bogor
Jalan Raya Pajajaran
Bogor 16143

Italy

Dr John E. Cecil
FAO - AGSI
Via delle Terme di Caracalla
00100 Rome
Tel: +39-6-5225 5604
Fax: +39-6-52254960
E-mail: John.Cecil@fao.org

Japan

Tsukuba Sago Fund and Sago Palm Communication
c/o Dr Shigeru Hisajima
Plant Biochemistry & Engineering
Inst. Applied Biochemistry
Tsukuba University
Tsukuba 305
Fax: +81-298-53-6631
E-mail: Hisajima@sakura.cc.tsukuba.cac.jp.

Japanese Society of Sago Palm Studies/ Journal 'Sago Palm'
c/o Dr Keiji Kainuma, Director General
The Japan International Research Centre for Agricultural Sciences
Ministry of Agriculture, Forestry and Fisheries
1-2, Ohwashi
Tsukuba, Ibaraki
Tel.: +81-298-38-6330
Fax: +81-298-38-6316
E-mail: Head@jircas.affrc.go.jp

Malaysia

Agricultural Research in Sarawak:

The Senior Assistant Director (Research) of the Department of Agriculture
Mr Kueh Hong-Shiong, MSc
Agricultural Research Centre Semongok
PO Box 977
93720 Kuching, Sarawak
Tel: +60-82-611171
Fax: +60-82-611178

The 7700 ha plantings close to Mukah and 1600 ha plantings close to Oya on deep peat, both in Sarawak:

Contact for development:

The Director Land Custody and Development Authority
10th floor Bangunan Tunku Abdul Rahman
Petra Jaya
93502 Kuching, Sarawak
Tel.: +60-82-440007/440008
Fax: +60-82-442844/445759

Contact for research:

The Crops Research and Applications Unit
at the same address

Papua New Guinea

The Director
Agricultural Experiment Station
Saramandi
Angoram, East Sepik Province
PO Box 433
Wewak, ESP

Mr Miri Setae
Agricultural Advisor of the Ministry of Finance
Dept. of Agriculture and Livestock
PO Box 7973
Boroko, National Capital District
Tel: +675-323-0269

Mr Anthony P. Power
c/o Ivin Enterprises Pty Ltd.
PO Box 772
Wewak
Tel: +675-320-0300
Fax: +675-321-1399

The Netherlands

Dr Michiel Flach
Prof. Em. Tropical Crop Science
c/o Dept. of Agronomy, Section Tropical Crop Science
Wageningen Agricultural University
Postal address: PO Box 341
Visiting address: Haarweg 333
6500 AH Wageningen
Tel. secretary: +31-317-483040 or 483072
Fax: +31-317-484575
E-mail secretary: secretariaat@sec.agro.wau.nl

Mr Dirk L. Schuiling MSc
Dept. of Agronomy, Section Tropical Crop Science
Wageningen Agricultural University
Postal address: PO Box 341
Visiting address: Haarweg 333
6500 AH Wageningen
Tel: +31-317-482514
Fax: +31-317-484575
Email: rik.schuiling@trop.agro.wau.nl

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