On the agronomy and botany of Salak

(Salacca zalacca)

Sumeru Ashari

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Promotoren: Prof. dr. ir. P.C. Struik
Hoogleraar in de gewasfysiologie
Prof. dr. ir. M. Flach
Hoogleraar in de tropische plantenteelt

Samenstelling promotiecommissie:
Prof. dr. ir. M. Wessel (Wageningen Universiteit)
Dr. ir. E.W.M. Verheij (Wageningen Universiteit)
Prof. dr. ir. L.J.G. van der Maesen (Wageningen Universiteit)
Dr. ir. J.S. Siemonsma (Wageningen Universiteit)

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Proefschrift
ter verkrijging van de graad van doctor
op gezag van de rector magnificus
van Wageningen Universiteit,
Prof. dr. ir. L. Speelman
in het openbaar te verdedigen
op maandag 2 december 2002
des namiddags te half twee in de Aula

Sumeru Ashari (2002)
On the agronomy and botany of salak (*Salacca zalacca*)
PhD Thesis Wageningen University – With ref. –
With summaries in English, Dutch and Indonesian
ISBN: 90-5808-424-8
Subject heading: agronomy, botany, salak, *Salacca zalacca*

ABSTRACT

Sumeru Ashari, 2002. On the agronomy and botany of Salak (*Salacca zalacca*). PhD Thesis Wageningen University, 126 pp., English, Dutch and Indonesian Summaries.

Salak is a dioecious, suckering palm, grown for its fruit, mainly in Indonesia. Traditionally, plants are raised from seed and planted in market gardens under the shade of existing trees. Crop care is largely limited to roguing of most male plants, cutting excess suckers and ageing leaves, and hand pollination. Each production centre mainly grows its own favoured variety, but in the 1990s 'Pondoh', originally from Yogyakarta, became popular also elsewhere. Yield varies widely (say 5 - 13 kg per plant per year). A better understanding of the crop can presumably greatly increase yield levels. This fits in with Indonesia's strategy to develop fruit growing with a view to improving nutrition and increasing exports. Salak is one of the fruit crops selected under this strategy. This thesis reports explorative research on the agronomy and botany of the crop.

Agronomy

Intensive pollination of this dioecious species leads to heavy fruit and seed set. Seed shape is determined by the number of seeds per fruit. A correlation between seed shape and sex of the seed as assumed by salak growers in Indonesia is unlikely.

Pollination and pollen quality influence both quality and quantity of the fruits. Choice of pollen depends on the cultivar to be pollinated.

Salak seed is recalcitrant and endosperm plays an important role in germination. Without endosperm the embryo is unable to grow and develop. Storage of salak seed in charcoal can sustain its viability and enhance seedling growth compared to storage in ambient air or even in sawdust.

Germination of salak seeds was retarded when planted in heavy soils. Organic matter is needed to improve the physical properties of the soil, particularly of heavy soils. A higher organic matter content also increased N and P levels in the soil and nutrient levels in the leaves. In the nursery, salak seedlings need 50 - 75% shade and an adequate supply of nitrogen.

During later stages of growth inorganic fertilizer reduced the numbers of split and decaying fruits, thus increasing the numbers of good fruits per bunch.

Botany

In young seedlings, the leaf shape is simple but leaves emerging later are pinnate. The duration of leaf formation from emergence and spear growth until expansion and maturation varies considerably from one leaf to the next.

Leaf area assessment is cumbersome; simple leaf characteristics may be measured to estimate leaf area, but the relationships with leaf area vary, depending on growing conditions.

Suckers are produced from short horizontal stems radiating from the mother stem. Their number needs to be reduced in commercial growing.

In a variety trial, the first inflorescence emerged 23 - 34 months from sowing; after 42 months the percentage of flowering plants ranged from 50 - 84%. The inflorescence bud develops into a spear and splits the base of the subtending leaf to break into the open.

Female and male plants are similar in morphology. The sex should be known at planting, to allow optimal spacing of fruit-bearing plants in an orchard and to include enough pollinator plants from the start. This can be achieved through vegetative propagation, if necessary through tissue culture, or possibly by the genetic markers indicating the sex of seedlings.

Key words: Salak, *Salacca zalacca,* Palmae, dioecious, haustorium, simple leaf, compound leaf, sucker, phyllotaxis, seedling, inflorescence, fruit, hand pollination, farm yard manure, fertilizer, shading, walking palm.

ACKNOWLEDGEMENTS

This dissertation owes quite a bit to the contributions from a number of people. Without their support, assistance and guidance, the work would not have been finished.

First of all I would like to express my sincere thanks to my esteemed promotor Prof. Paul C. Struik, who guided me during the final write-up of the thesis. He has spent his precious time and energy to help me in finalizing the thesis. His encouragement and patience had a significant, positive effect on my work. Thus, working with him was fruitful and has added a lot to my experience and knowledge.

I extend my gratitude to the second promotor Prof. Em. Michiel Flach who encouraged me to undertake this study and who also provided guidance through the actual research and stimulated me by his critical reviews of the draft versions of the chapters. I obtained much benefit from his experience and the many discussions we had together.

I am also grateful to the Wageningen University, which provided financial support during my stay in the Netherlands and for printing of the thesis. I would like to thank all the people in the 'De Nuije, Haarweg 333' and especially the librarians who helped me in finding the information related to my work. I enjoyed the company of the people in the 'Attic' who were my roommates during the last 60 days of finishing the thesis.

My gratitude and appreciation are extended to Dr. E.W.M Verheij. At a time when this study was floundering, he came to Malang to work with me, showing the way to the completion of the thesis. Especially his contribution to the improvement of my English is gratefully acknowledged. He also enlisted the support of Dr. R. Verdooren, whose assistance led to a comprehensive statistical analysis of the leaf area measurements, for which I am greatly indebted. I thank Gon van Laar for excellent final editing and lay-out.

My sincere thanks also go to Prof. Bambang Guritno who as my local supervisor encouraged me and guided me during the work. I am much indebted to the Rector of Brawijaya University, the Dean of the Agricultural Faculty for giving me a study leave in order to finish the work. My gratitude and appreciation are extended to Prof. Tri Susanto (Food Technologist) for his criticism and comments especially on the seed germination aspect; to Prof. Syechfani (Soil Scientist) for his criticism and suggestions on the soil aspects; to Dr. Bernadetha Mitakda for her comments on the English language, the statistics and the biometry aspects; to Mr. Kasman Cadiwirjo MA for his help in the English language; to Mr. Agung Nugroho MS who took the photographs, prepared the diagrams and graphs for the manuscript, and to all students in horticulture who assisted in this study.

To my late father M. Ashari and my father in law Napsir Wirjoadmojo: I am deeply sorry that you do not have the opportunity to see the result of my work. However, I believe that both of you are happy and proud of its completion as a thesis of Wageningen University; you were often telling me stories about the Dutch period in Malang and in Indonesia. To both my mother and my mother in law: I express my appreciation for your patience and support during all these years.

Finally, last but not least, I would like to thank my wife, Endah Sri Handayani and my children, Dadang Meru Utomo, Astri Warih Anjarwi and Yordan Wicaksono Ashari for their patience and understanding during the preparation of this thesis.

CONTENTS

CHAPTER 1: GENERAL INTRODUCTION

Agriculture plays an important role in the Indonesian economy. Under the current economic crisis the agricultural sector has proved its value. Commodities such as coffee, clove, banana, mango and salak contribute substantially to the national income and earn foreign currency.

Unfortunately, Indonesian farmers have several handicaps. They farm only small pieces of land, often not large enough to nourish the family; their knowledge of agricultural technology also needs to be improved. For the national income selection of agricultural commodities, which offer more economic value and can be grown on large scale plantations, is also very important. Salak *(Salacca zalacca)* is a good example of a horticultural crop that has a potential of contributing more to the national product. However, little is known on the agronomy and botany of this crop. Therefore the objective of the thesis work was to gather basic information on the agronomy and botany of salak.

In the introduction to this thesis some basic background on the fruit production in Indonesia is given. This is followed by an introduction on the botany, ecology and production characteristics of Palmae in general and of the genus *Salacca*. This leads up to a description of salak cultivation in the country. Finally this general introduction provides details on the research questions and objectives, the outline of the thesis and the limitations and constraints to the experimental work.

For the terminology used in this introduction and in the remaining text of the thesis, the reader is referred to the glossary (Appendix 3).

1.1. Background information

Indonesia had a population of 180 million in 1990 (Anonymous, 1992). The rate of population growth has since then slowed down slowly and in the early nineties it was 1.97% per annum. With a growth rate of 1.9% per year the population is estimated to have reached 215 million in the year 2000.

A great variety of fruits and vegetables thrive in Indonesia. People greatly appreciate this diversity and generally know a lot about varieties, quality, and different food preparations using both green and ripe fruit, health benefits of various fruit, etc. However, statistical data regarding fruit production and consumption are scarce. The fruit production in 1994 was around 8 million tons (Anonymous, 1996). Assuming the same production and a population of 215 million people for the year 2000, this amounts to about 37 kg per person. Because of substantial post-harvest losses the average consumption may be about 30 kg per year. Verheij and Coronel (1991) arrived at the same figure for 1986/87.

Nutritionists recommend a daily intake of 50 - 100 g fresh fruit, that is 18 - 36 kg per year. Because the edible portion is somewhat more than 50% this means that 30 - 60 kg should be available per head. Given the fact that not all fruit is consumed fresh and that consumption is related to purchasing power, it is not surprising that Sunaryono (1990) concludes that most Indonesians consume less than two-thirds of the fruit that the body needs. Thus the indications are that production and consumption are too low to meet nutritional requirements. This situation affects the people's health. The prevalence of vitamin (A, C) and mineral (Fe) deficiencies is high, leading to serious diseases, particularly among children. The symposium on Food and Nutrition in 1989 in Indonesia reported that 1.64% of our youngsters are affected by Xerophthalmia or other eye diseases due to vitamin A deficiency (Wardoyo, 1992).

Most fruit – and especially the best quality fruit – is so expensive that common people are generally only able to buy low-priced fruits such as banana and papaya.

This national health condition became the reason for the Indonesian government to give more attention to the development of horticultural crops (Anonymous, 1990a). This was enhanced by the potential for export of fruit. In the current economic crisis in the country foreign currency earning commodities are very welcome.

Knowledge on most tropical fruits is still scarce. Whereas the yield level of tropical plantation crops such as oil palm, cocoa and coffee, and of leading fruit crops from the temperate zone, such as apple and grape has increased several-fold through sustained research efforts, the contribution of science to the development of tropical fruit crops has so far been very modest (Verheij and Coronel, 1991). Salak also has received little attention from scientists. Because the crop is virtually limited to South-East Asia and Indonesia is by far the largest producer, it is only fitting that research workers in this country do their best to promote development of the crop.

1.2. General characteristics of palms

Botany and ecology

Linnaeus named the palms **Principes**, which means: 'the princes among plants'. Because palms are at home in the tropics and not in Europe, they came late to the attention of taxonomists. In 1753, Linnaeus recognized only 10 species of true palms. However, in Heywood's book on flowering plants, Whitmore (1993) lists 212 palm genera, comprising 2,780 species, distributed over Africa, the Indian Ocean islands, South America and the South-East Asian tropics (the region with the largest diversity: 97 genera and 1,385 species). This large increase in number of species indicates that the work of taxonomists on palms is still far from complete.

Palms grow in a wide range of ecological conditions. Some palms grow in deserts, others in swamps; they are found on limestone (Hodel, 1993; Pritchard, 1993) and even on ultra basic soils (Merlo et al., 1993). More than 75% of the palms are rain forest species and they show a great diversity of habit in the forest understorey. Generally speaking (and as a result of long-term natural selection and evolution) palms with inflorescences in the leaf axils are found in congenial environments, because they have to continuously balance vegetative growth and flowering/fruiting. On the other hand palms in which the terminal bud converts into an inflorescence (ending the life of the palm), can more easily adapt to extreme environments, because adverse conditions just slow down growth, postponing flowering and fruiting. The palms whose growth culminates in a single flowering event are called **hapaxanthic**, the ones, which flower repeatedly while they continue to grow, are **pleonanthic** species.

Palms are economically important because they include major plantation crops (oil-palm, coconut, date-palm, etc.) as well as many lesser crop plants, sources of cane, oil, starch, wax, fibre, sugar and alcohol. Nowadays, the palms have also become increasingly important in ornamental horticulture because of their elegant and predictable shapes (Hodel, 1993).

In spite of the large number of species and the adaptation to a wide range of environments, the diversity of growth habits in palms is limited to 5 architectural models, as defined by Hallé et al (1978) and presented by Tomlinson (1990):

1. Holtum's model: trees with an unbranched axis and a terminal inflorescence, for example *Corypha* and most species of *Metroxylon*. These can be described as *single-stemmed hapaxanthic palms*.
2. Corner's model: trees with an unbranched axis and lateral inflorescences, represented for example by *Areca catechu, Cocos, Elaeis, Roystonea* and *Phoenix canariensis*, which can be described as *single-stemmed pleonanthic palms*.
3. Tomlinson's model: trees with the axis branched exclusively from the base, represented by all *multiple-stemmed palms*. Two subdivisions are recognized: *hapaxanthic* (*Metroxylon* spp., *Eugeissona minor*) and *pleonanthic* (*Bactris gasipaes; Calamus trachycoleus*) palms. The salak palm belongs to the pleonanthic form of this model.
4. Schoute's model: trees with an aerial axis branched exclusively by equal *dichotomy*, i.e. equal division of the shoot apical meristem, represented by non-suckering species of *Hyphaene* and *Vonitra*.
5. Mixed architecture model: combination of Schoute's and Tomlinson's models (*Nannorrhops ritchiana*); Corner's and Tomlinson's models (*Serenoa repens*).

Growth and development

The growth and development of palms can be divided into five stages (Tomlinson, 1990):

1. Embryonic phase: from zygote formation to the dormant embryo in the seed.
2. Seedling phase: from the start of germination until the seed reserves in the haustorium are finished.
3. Establishment phase: the extended period of early development until the terminal bud of the rosette attains its full size.
4. Mature vegetative phase: the period extension of the vegetative axis – the palm trunk – through the formation of leaves of a near-constant size.
5. Reproductive phase: from the appearance of (the) inflorescence(s) until the end of the palm's life.

The different phases are describes in more detail below.

Embryonic and seedling phase

The embryos of palms are very small in relation to the total size of the seed and endosperm and they have a single cotyledon. The cotyledon has two main regions: the distal portion or haustorium remains within the seed and the proximal portion extends to push the shoot and root axis of the seedling into the ground (DeMason, 1984). Tomlinson (1990) divides palms into two groups according to germination types, i.e. remote germination (young plant positioned at some distance from the seed through the extension of the cotyledonary sheath axis) and adjacent germination (cotyledonary sheath axis unextended). The cotyledonary sheath may or may not have a ligule, i.e. a protuberance through which the scale leaves and the first bladed leaf emerge. When a ligule is produced the germination is called ligular, but if not present germination is called non-ligular.

In seedlings of the palm family, the haustorium expands at the expense of the endosperm, absorbing the degradation products from the endosperm. These products may be modified and are eventually transported to the seedling axis. At the end of the germination period the spongy haustorium has completely absorbed the endosperm and fills the seed cavity; at that time the leaves are able to photosynthesize and sustain growth (Hartley, 1988).

Establishment phase

During the establishment phase the young seedling produces ever larger leaves from a growing point which expands till it reaches its ultimate size, reflecting the local growing conditions. At that stage the leaves attain their full size, the rosette of leaves expands no further and the formation of the palm trunk can begin. A suckering palm, such as the salak, also suckers freely during the establishment phase, forming a stool to extend its territorial claim.

Mature vegetative phase

During the mature vegetative phase palms grow in height, but do not spread further. The dimensions of the crown have become more or less constant, because leaf size and number have reached a steady state. The number of leaves is kept fairly constant because for each emerging leaf an old leaf withers. Likewise the root system has reached a steady state, new adventitious roots replacing decaying ones.

Reproductive phase

The main distinction here is that between hapaxanthic (once-flowering) and pleonanthic (continuously flowering) palms, already referred to above. In hapaxanthic palms the reproductive phase comes at the end of the mature vegetative phase; in fact it spells the end of the palm's life. In pleonanthic palms the reproductive phase tends to be reached on completion of the establishment phase and thus coincides with the mature vegetative phase. Whereas in hapaxanthic palms the distinction between a juvenile and an adult stage is not really relevant, pleonanthic palms conform to the notion that the young plant exhibits juvenile traits and that the more complex source-sink relationships in the adult plant may have consequences for crop husbandry.

Palms are either wind-pollinated (**anemophilous**) or animal-pollinated (**zoophilous**) crops. In zoophilous palms precisely timed relations between opening of female and male flowers and 'visiting hours' of successive swarms of pollinating insects have been reported, e.g. for the pejibaye (Mora-Urpi and Solis, 1982; Beach, 1984).

According to Tomlinson (1990) there are three types of sex distribution in palms: dioecy, monoecy, and palms with perfect flowers. Dioecy means a single palm produces one sexual type only; monoecy means that both sexual types are produced but in different flowers (either male or female), while in plants with perfect flowers both pistillate and staminate organs are present in a single flower.

Palms can be very fruitful. Ouvrier (1984) showed that in coconut almost half the energy fixed annually by the palm is going to the fruit; in oil-palm this fraction can even exceed 50% (Corley, 1983).

Leaves: form, number, and longevity

Foliation of palms is special because of the large size and limited number of leaves in a crown. During the seedling and establishment phases the shape and the size of the leaves change gradually, until the form and size of the mature vegetative phase are reached. Before the production of green-bladed leaves, the plumule produces one or more bladeless sheaths or scale leaves. The function of the scale leaves is to help the plumule to break the soil surface.

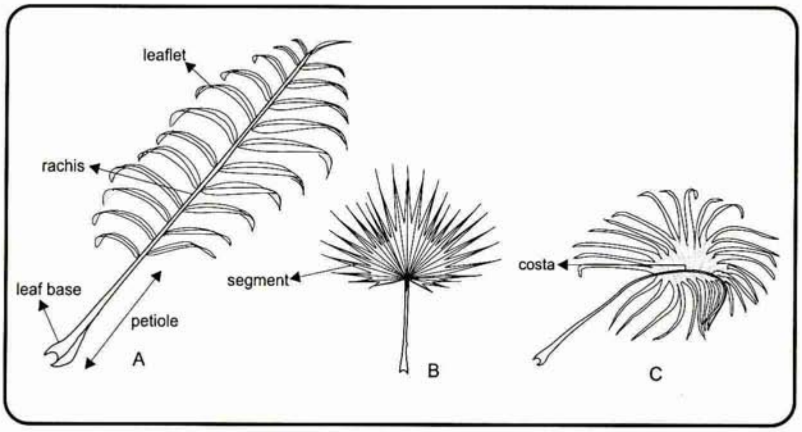

Figure 1.1. Leaf form in palms.
A: pinnate leaf; B: palmate leaf; C: costapalmate leaf.
Redrawn based on Tomlinson (1990); Hickey and King (2000) with modifications.

The first green-bladed leaf following germination is called **'eophyll'**, from the Greek 'eos': dawn or early and 'phyllon' meaning leaf (Tomlinson, 1990). There are two forms of eophyll, i.e. (i) linear or linear lanceolate such as *Phoenix pumila* and *Washingtonia filifera*; and (ii) emarginate or bifid as in *Chrysalidocarpus lutescens* and *Salacca zalacca*.

All palm leaves have a sheath, a petiole and a lamina. The lamina mostly has one of three general shapes: it can be palmate, lacking a rachis; it can be pinnate, where leaflets are borne on the rachis; or it can be costapalmate, an intermediate shape in which palmately arranged leaflets are born on a very short rachis or costa (Bell, 1991). For more details, see Figure 1.1.

The sheath of each leaf clasps the terminal bud, the sheaths of the younger leaves being enclosed in those of the older leaves. The leaf initials in the bud are dome shaped, the older ones completely enfolding the younger ones.

The leaf population in the crown consists of a series of unexposed leaves (Lu) and exposed leaves (Le), the total leaf population in the crown, (n), being:

$$n = Lu + Le$$

In the palm species in which these numbers have been counted, the numbers of unexposed leaves and exposed leaves are usually about equal. In the few instances where this was not the case, there were more unexposed than exposed leaves (Tomlinson, 1990). The production of unexposed leaves and the duration of their functional life are influenced by growing conditions. When growing conditions get worse so that the exposed leaves cannot sustain the terminal bud any more, the terminal meristem will form smaller leaf initials. If there are fewer unexposed than exposed leaves, it will take a relatively short time before the smaller leaves can be exposed to establish a new equilibrium with the poorer growing conditions. In a palm with many unexposed leaves this period to adapt to changed conditions would be excessively long; such a species would be at home only in a fairly constant environment. Hence the fact that Lu and Le tend to be equal, can be interpreted as an attempt to balance flexibility with continuity of growth, corresponding with the observation that 75% of the palm species are at home in the rain forest, where growing conditions tend to be rather steady.

Palm leaves are large and the period from initiation till full exposure is very long. So much is invested in each leaf that it must be able to function for a long time. Corner (1966) offers an equation of leaf-longevity (LL):

LL = np days

in which

- LL leaf longevity
- n number of unexposed and exposed leaves (Lu + Le)
- p the interval between emergence of successive leaves.

In a healthy coconut palm there may be 30 leaves present in the crown, in addition to a similar number in the bud (Child, 1974). On average, the coconut produces 12-14 leaves per year, thus, assuming the interval to be one month, the leaf longevity of a single leaf from primordium to leaf fall is (30 + 30) x 1 = 60 months. Of this 5-year period the leaf is in the making for 2.5 years and functions in the crown for a similar period. A true sago palm growing under optimum ecological conditions produces equal numbers of unexposed and exposed leaves, each 24. The interval between emergences of successive leaves in a healthy palm is around 30 days. Hence, the leaf longevity from primordial to senescence is 48 months (Flach and Schuiling, 1989), 2 years in the bud and 2 years exposed in the crown.

1.3. Classification of the family Palmae and of the genus *Salacca*

The palms are such a distinct group of plants that they have all been kept together in a single family. Uhl and Dransfield (1987) divide this large family in six sub-families and distinguish several tribes and sub-tribes within most sub-families. Their classification is based on several characters including morphology, anatomy, fossil records, geography, ecology and also describes the evolution and relationships among palms.

As a member of the palm family, the salak palm belongs to the subfamily Calamoideae Griffith, tribe Calameae Drude, subtribe Calaminae Meisner and genus *Salacca* Reinwardt. The closest relative of the genus *Salacca* is *Calamus* Linnaeus, another genus in the same subtribe, which includes nearly all the economically important rattans. Another subtribe, the Metroxylinae Blume, contains the true sago palm (*Metroxylon sago* Rottb.), which nowadays receives increasing attention as a starch crop.

The Calamoideae, which includes the salak palm, comprises 22 genera, the largest being *Calamus*. The subfamily occurs in areas of high rainfall and is especially frequent in swampy regions with the genera *Mauritia* in Latin America, *Metroxylon* in South-East Asia and *Raphia* in Africa. The subfamily can be distinguished by the closely overlapping scales, which cover the ovaries and fruits. The fruits commonly have a fleshy layer, sweet to exceedingly sour. Moreover, this subfamily shows spines, cirri and prickles. The chromosome number (n) is 14 (Whitmore, 1993).

The genera *Calamus* and *Salacca* are two of the eight genera of the subfamily Calamoideae, tribe Calameae and subtribe Calamineae. Calamineae are important in furniture making and as edible fruits. The two genera have some behavioural similarities: branching at the base, mostly dioecious, scaly fruits, 1 - 3 ovules within the ovary, the seed with an edible outer fleshy layer, adjacent-ligular germination (Dransfield, 1979; Manokaran, 1985). Rattan (*Calamus* spp.) is one of Indonesia's more important export commodities.

1.4. Description of the genus *Salacca*

The genus *Salacca* is dioecious, usually acaulescent, spiny and clustered. The stem is partly erect, procumbent and short. The internodes are very short, often with abundant adventitious roots. The suckers grow from a leaf base. The leaves are pinnate or palmate with pinnate venation. The inflorescence is borne at the leaf sheath base. The staminate flower is borne in dyads with two small prophyllar bracteoles; there are stamina, which appear at the mouth of the corolla tube. The pistillate flower is in a dyad with a sterile staminate flower; the form of the calyx is tubular at the base and it contains a trilocular ovary. Seed is basally attached. The sarcotesta or flesh of the fruit is thick, sour or sweet; the endosperm is firm (Dransfield and Mogea, 1986).

So far, about 19 species of *Salacca* have been identified (Mogea, 1986, 1990). They are distributed over southern Yunnan, lower Burma, Thailand, the Malay Peninsula, Sumatera, West-Java, Borneo (Kalimantan) and the southern part of the Philippines (Mogea, 1980). The largest number of species is found in Borneo (about 10 species), in the Malay Peninsula and Sumatera (7 species each) (Mogea, 1986). Out of 19 species, 13 have recently been identified in South-East Asia (see Table 1.1).

Of the species listed in Table 1.1, *S. sumatrana*, *S. zalacca* and *S. wallichiana* are cultivated, the first two mainly in Indonesia (Mogea, 1986; Schuiling and Mogea, 1991), the latter almost exclusively in Thailand (Polprasid, 1991). The leaves of these species are pinnate, but the top part of the leaf is palmate/flabellate. The most distinct character of this group is that the species are dioecious and therefore need pollinator plants to produce fruits. Only one taxon reveals a monoecious character, the Balinese salak from Karangasem, Bali, Indonesia (Moncur and Watson, 1987); it has been named *S. zalacca* var. amboinensis (Becc.) Mogea by Schuiling and Mogea (1991).

S. sumatrana is dioecious and grown in the highlands. The male inflorescence consists of 25 - 40 spadices. The mature palm is much bigger than *S. salacca*. The palm is cultivated in dense stands in the highlands. One in three or one in four are male flowering; artificial pollination is not practised. The colour of the fruit flesh is reddish.

1.5. The cultivated salak in Indonesia

Production centres, area and yield

Two different species of salak in Indonesia produce edible fruits. *S. sumatrana* Becc. is mostly cultivated by farmers in northern Sumatera and *S. zalacca* (Gaertner) Voss is grown elsewhere in Indonesia. The centres of salak production are Sumatera (around Toba lake, Padangsidempuan), West Java (Jakarta, Sumedang, Tasikmalaya), Central Java (Sleman, Yogyakarta), East Java (Bangkalan, Pasuruan, Malang, Bojonegoro, Jombang), North Sulawesi (Pangu, Tagulandang) and Bali (Karangasem) (Sudaryono et al., 1991; Mogea, 1978a); see Figure 1.2.

Data on area and production are scarce and vary, but they indicate rapid

Table 1.1. South-East Asian species of the genus *Salacca* (Haryani, 1994)*.

No	Species	Found in:
1.	*S. magnifica* Mogea	Sarawak (Malaysia) East Kalimantan (Indonesia)
2.	*S. multiflora* Mogea	Malaysia
3.	*S. affinis* Griff.	Sumatera (Indonesia); Malaysia
4.	*S. sumatrana* Becc.	North Sumatera (Indonesia) Tapanuli (Indonesia)
5.	*S. zalacca* (Gaertner) Voss	Sumatera, Java (Indonesia)
6.	*S. glabrescens* Griff.	Malaysia
7.	*S. sarawakensis* Mogea	Sarawak (Malaysia)
8.	*S. dubia* Becc.	South Sumatera (Indonesia)
9.	*S. flabellata* Furtado	Trengganu (Malaysia)
10.	*S. minuta* Mogea	Malaysia
11.	*S. dransfieldiana* Mogea	South Kalimantan (Indonesia)
12.	*S. vermicularis* Becc.	Kalimantan (Indonesia)
13.	*S. wallichiana* Wall. & Mart.	Thailand

*Scientific names according to Ferguson (1986) and Mogea (1986).

expansion of salak growing in Indonesia. Soerojo (1993) reports a doubling of the area, from 10,000 ha in 1986 to 20,000 ha in 1990, the yield level remaining steady at around 6.8 t/ha per annum. In 1992 the production was about 197,000 t, with Java coming first (148,000 t) while Sumatera produced only around 11,000 t (Anonymous, 1996). In East Java the population of salak has also increased sharply. The palm population in 1984 was 3.9 million plants with a production of 48,000 t. In 1987 the population had increased to 6.7 million plants with a production of 110,000 t (Anonymous, 1987).

The fruit production of the varieties per annum per ha varies. The average production of 'Pondoh', mainly grown in kabupaten Sleman of Yogyakarta, is 6.8 t per ha (Sudaryono et al., 1991), while for other varieties in the salak production centres in East Java it is 4.5 t per ha (Ashari, 1993). The difference in the yield level is probably mainly due to the agronomic practices of the gardeners, such as weeding, fertilizing and, the most important one, hand pollination.

Salak cultivation will very likely expand in Indonesia, especially around the large cities where fruit is constantly in high demand. The demand will increase in line with the increase in population, in income per capita, in awareness of need for better nutrition and the development of tourism.

Varieties and cultivars

Salak is an out-crossing crop and commonly propagated from seed. Hence the varieties are ill-defined; they are usually named after the locality where they have come to the fore. There is little information about the way in which growers select seeds for propagation and there are no authoritive descriptions of varieties. As said before, the salak of Bali, also grown in Ambon, is distinct because it is monoecious.

Among the dioecious varieties 'Pondoh' assumes true cultivar traits, because the current expansion originated from a single plant and it is increasingly propagated from suckers rather than seeds. The history of 'Pondoh' has not been clearly documented.

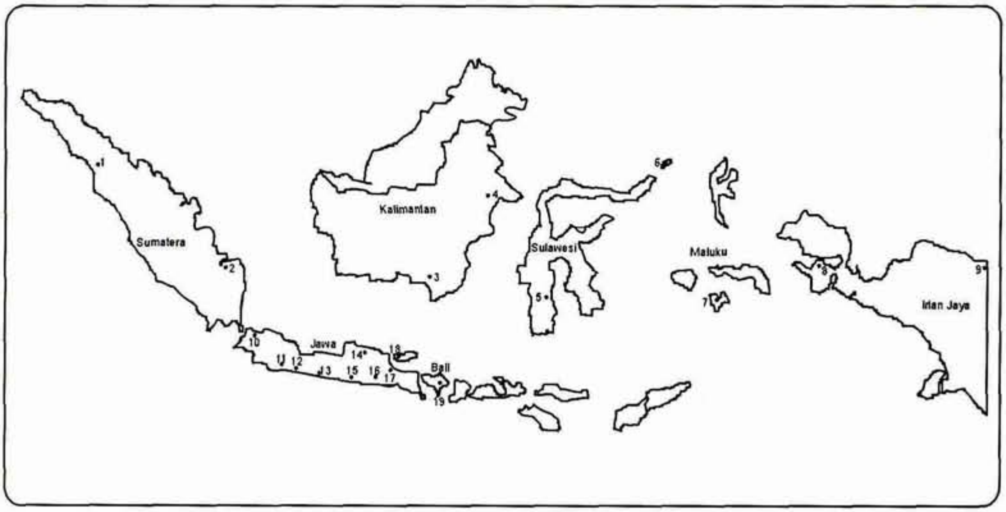

Figure 1.2. The production centres of salak in Indonesia.
1. Padangsidempuan; 2. Palembang; 3.Banjarmasin; 4. Samarinda; 5. Enrekang; 6. Tagulandang; 7. Ambon; 8. Fakfak; 9. Jayapura; 10. Jakarta; 11.Tasikmalaya; 12. Manonjaya; 13. Sleman; 14. Bojonegoro; 15. Jombang; 16. Malang; 17. Pasuruan; 18. Bangkalan; 19. Karangasem.

The delicious taste of the 'Pondoh' fruit was already reported by Ochse in 1931. According to Santoso (1990) a 'Pondoh' plant was given to a farmer by a Dutch tobacco planter before he left for the Netherlands. The farmer, Partomejo, and his son propagated it; in 1954 the son (Muhadiwinarto) had about 1000 plants.

Salak 'Pondoh' was first planted in the villages Soka, Merdikarejo, Candi and Mengunkerto of kecamatan Turi, kabupaten Sleman. Because of its excellent taste, the cultivar has been planted also in other parts of Yogyakarta area such as Tempel, Pakem, Mungkid. The average meteorological data for Sleman are presented in the Appendix 1. Recently the number of 'Pondoh' has increased sharply. The cultivar is not only grown within Yogyakarta area but also elsewhere on Java and on other islands (Purawinata, 1989). However, the number of 'Pondoh' plants in kabupaten Sleman of Yogyakarta is still lower than that of the other varieties combined (Table 1.2).

Most observations in this study refer to 'Pondoh'; where salak from different localities has been compared in the experiments below, the term 'varieties' has been used for the sake of convenience.

The production techniques and cropping system of salak

Salak is usually planted around the house in the home garden, but larger market gardens (one to several hectares) are not uncommon in some villages. Large orchards are found in Bali, because the monoecious variety on that island does not need hand pollination. In Java more than 30% of the production costs is for hand pollination (Ashari, 1993). This high share suggests that crop care is not very intensive and that is indeed the case. The growers usually do not irrigate, apply fertilizer, or control pests and diseases. Senescent leaves are cut and left as mulch. Growers believe that fertilizers affect the soil negatively, cause fruit drop and shorten shelf life of the fruit

Table 1.2. The population of salak palm in kabupaten Sleman in 1992.

Cultivar	Population (plants)	Production (kg/plant/year)
'Pondoh'	423,451	13.3
'Non-Pondoh'	1,418,551	11.8

Sources: Anonymous (1995, in Padmosudarso, 2000).

after harvest. Other cultural operations are weeding and desuckering in young salak gardens; old gardens tend to be so dense that few weeds and suckers grow out.

Salak is commonly intercropped with fruit trees such as rambutan, durian, langsat etc. These trees also provide shade for the salak. It is generally agreed that shade is essential for young salak plants to survive, and when salak is planted short-duration shade plants such as banana or *Sesbania grandiflora* ('turi') are usually interplanted to add to the shade of existing trees. A full-grown salak garden is very dense with extensive mutual shading by the palms. It is not clear whether in this situation shade trees are still important. They may just be a remnant of the mixed crops in the home garden, or their shade may still be welcome in areas with a pronounced dry season, as in East Java.

When a new salak garden is established, salak is still largely grown from seed. The crop is dioecious, thus about half the plants will be male-flowering. In case of direct seeding 4 - 5 seeds are sown in a hole (60 x 60 x 60 cm) dug to incorporate 5 kg of dry mature dung. In other cases, the seedlings are raised in the nursery and planted in the appropriate hole. The spacing is 2 x 2.5 m to 2.5 x 2.5 m; short-term shade trees (banana or turi) are interplanted at the same spacing.

The maintenance of the young plants consists of weeding, fertilizing and cutting of excess suckers and ageing leaves. When the plants are 3 - 4 year some are already flowering. The male plants are rogued leaving only 2 - 20 percent male-flowering plants to supply pollen for hand pollination. In the year after planting fertilization with urea (46% N), TSP (46% P_2O_5) and KCL (52% K_2O), at the rate of 60 - 90 g, 40 - 60 g and 20 - 30 g per plant position, respectively, is recommended; these quantities are to be increased slightly in the following years (Tjahjadi, 1989). However, fertilizer application is the exception rather than the rule.

Constraints for development of the crop

The yield of salak varies much more widely than the average figures of 4.5 ton (Ashari, 1993) to 6.8 ton per ha per annum (Sudaryono et al., 1991). This is also indicated by Padmosudarso (2000) who reports yields per plant ranging from 5 to 13 kg per year. The variation is not only due to differences in dry or wet monsoons, but also to limited crop care by the growers, associated with a poor understanding of the requirements of the crop, e.g. with respect to

- pollination,
- supply of water and nutrients,
- planting density, desuckering and intensity of shade,
- crop protection, etc.

Moreover, the quantity – and perhaps even more so: the quality – of the crop also differs for different varieties.

It is likely that higher and more stable yields could be achieved if research work can clarify crop requirements and if this can be translated into a better choice of varieties and improved growing conditions.

1.6. Research issues and the research programme

From the foregoing description of salak cultivation in Indonesia it is clear that the crop is still grown in a traditional way, based on experience gained by the growers themselves. The contribution of science so far has been quite small.

Botanists have described the plant, but detailed studies are limited to a description of germination and the seedling by Mogea (1978b), the position of the inflorescence buds in *Salacca* by Fisher and Mogea (1980) and the floral biology of the monoecious salak by Machfoedi (1953) and Moncur and Watson (1987). Growth and development have not been studied in quantitative terms (e.g. the rate of leaf production, suckering, emergence of inflorescences and fruit set) and the seasonality of fruit production has not been explained.

The number of agronomic studies on salak in Indonesia is increasing rapidly. These studies describe salak cultivation in different regions with emphasis on the expanding areas (Lahiya, 1984; Sudaryono et al., 1991), on 'Pondoh' (Santoso, 1990; Siswandono, 1989), and on the suitability of soils (Padmosudarso, 2000). Several reports compare the fruit of different varieties (Haryani, 1994; Sarwono and Maryanti, 1990;) and the start of selection and hybridization work (Purnomo and Sudaryono, 1994; Purnomo and Dzanuri, 1996); in this context the report on vegetative propagation through air layering by Kasijadi et al. (1999) is also important. The tolerance of salak seed to drying, chilling and attack by fungi was investigated by Purwanto et al. (1988). Nutrient levels in the leaves have been determined by Kusumainderawati et al. (1992) and fertilizer recommendations are given by Tjahjadi (1989) and Sholeh et al. (1994). Baswarsiati et al. (1991) and Bawarsiati and Rosmahani (1992) have observed pollinating insects on salak. The economics of salak growing and export potential have also been subject of studies (Ashari, 1993; Kasijadi, 1996; Purawinata, 1989).

These studies are all recent and – in as far they are based on experimental work – the results are tentative, requiring continuation of the experiments or verification.

Thus topics for research work abound, both regarding the botany and the agronomy of the crop. For this thesis research objectives were chosen so that the experimental work fitted in the research programme of the Agricultural Faculty of Brawijaya University. For a perennial crop such as salak long-term experiments are needed to resolve most of the agronomic issues. One long-term experiment, a variety trial, could be accomodated at the research farm of the University. For most other experimental work the cultivar Pondoh was used, because it is gaining prominence. These other experiments were of short duration, mainly because thesis work of undergraduate students is limited to 6 months.

The variety trial led to a comparison of methods to measure or estimate leaf area, also in order to facilitate calculation of LAI in future experimental work.

The seed lends itself to short-duration trials. Salak seed is recalcitrant, and it was attempted to prolong seed viability by storage in different media. A trial in which germination was studied after removal of different portions of the endosperm is botanical in nature rather than agronomic, but in most of the experimental work aspects of botany and agronomy were combined.

Environmental factors – soils, nutrient supply, and shade level – were also included in the study, but these had to be limited to observing the growth of seedlings for a short period only.

To help resolve problems in existing salak gardens, two experiments were designed to study pollination, a crucial factor in determining yield; another experiment, putting the belief held by growers that fertilizers have adverse effects on yield to the test, was also conducted in an old salak garden.

Aspects of botany which were studied, mainly in 'Pondoh', include:

- the germination process in treatments where the endosperm was kept intact or partly removed;
- duration of growth stages of individual leaves, and the phyllochron and changing leaf shape and size in seedlings;
- numbers of unexposed leaves (in the terminal bud) and exposed leaves;
- phyllotaxis and position of leaf and flower buds;
- suckering;
- importance of pollination intensity and pollen source;
- fruit shape and size in relation to number of seeds per fruit.

1.7. Outline of the thesis

From November 1989 till January 1994 a series of field experiments was conducted to clarify agronomic aspects of salak growing. Most of the experiments were conducted with 'Pondoh'. These experiments are reported in Chapters 2 - 5.

Chapter 2 describes the only long-term experiment, a variety trial which was continued till the end of the juvenile phase. The problems encountered with leaf area measurements in this trial led to another experiment in which different ways to estimate leaf area are compared. This experiment is also reported in Chapter 2.

Chapter 3 is devoted to pollination experiments; the effects of more intensive pollination and the effectiveness of a range of pollinator varieties on two female-flowering varieties were studied in mature salak gardens.

Chapter 4 deals with the salak seed. Germination after removal of different portions of the endosperm was studied, as well as the effect of seed storage in different media and for different periods of time on germination.

In Chapter 5 experiments with potted plants are described. The seedlings were grown in soils collected from four salak centres. The soils were compared to Jatikerto soil where the salak cv. Pondoh is to be introduced.

Whereas the field experiments were designed to clarify aspects of the agronomy of the crop, they also yielded much information on growth and development of salak. Moreover, alongside some of the experiments, additional 'Pondoh' plants were raised for botanical observations. In Chapter 6 all this information is combined with published data in order to outline a model of the growth and development of salak.

The findings in the various experiments are further discussed in Chapter 7.

1.8. Limitations of and constraints to the experimental work

As the salak palm is a perennial, long-term agronomic research is needed. Treatments applied in one year may still have an effect on the plant in the following year(s). This study does comprise one long-term experiment, but it is limited to the juvenile phase and the onset of flowering. Nearly all other experiments covered periods of up to 6 months only, which in some cases – e.g. plant nutrition studies – is far too short to arrive at practical recommendations for growers. Nevertheless several experiments of this nature are reported in this thesis, because even within the short period of time the palms responded to the treatments. The 8-month duration of the pollination experiments reported here was about adequate, but ideally the experiments should have been repeated in successive years, which in this case was not possible.

The contribution of students to this study was substantial; several of them devoted their BSc thesis to salak research work; these theses are listed separately under References. However, student thesis work is limited to 6 months, and this is one reason for the short duration of experiments.

The spiny nature of salak also is a serious handicap for experimental work. Observations and records requiring close contact with the plants – e.g. determining phyllotaxis, bud positions in the axils, or leaf area measurements – are painful. Getting to grips with salak means getting hurt!

CHAPTER 2: VEGETATIVE AND GENERATIVE GROWTH

This chapter describes observational and methodological experiments in which the development over time of the number of leaves, the leaf area, the suckering, flowering and sex expression are quantified.

2.1. Variety trial: seedling and establishment phases

Introduction

The growth of plants in general consists of a vegetative and a generative stage. Vegetative growth is initiated by germination of the seed. Flower initiation marks the transition from vegetative to reproductive development in crop plants (Goldsworthy, 1984). Each crop, however, has a different timing with respect to onset and ending of these growth stages.

In palms, however, the vegetative phase is divided further into four phases, i.e. the embryonic phase, the seedling phase, the establishment phase and the mature vegetative phase (Tomlinson, 1990).

According to Mogea (1978b) the seedling phase – from germination till the moment that growth no longer depends on reserves in the seed, i.e. the heterotrophic growth phase – lasts 100 to 109 days in salak. However, the length of this period may range much wider if effects of genotype and growing conditions are taken into account.

During the establishment phase the palm seedling stakes out its territorial claim by forming a full complement of expanded leaves; salak also suckers freely during this phase.

The seedling and the establishment phases together make up the juvenile period, which is said to last 3 - 4 years in the salak palm (Santoso, 1990) and comes to an end when the first flowers are initiated. The length of this period may also depend on cultivar and growing conditions.

The mode of suckering of the sago palm, a plant which belongs to the same subtribe as salak, has been studied by Flach (1983). He concluded that suckers inhibited the growth of the mother trunk, and thus could delay the harvest.

Information on the early growth of salak is scanty. When a variety trial was planted at Jatikerto research farm this offered an opportunity to observe for a number of varieties such parameters as rate of leaf production, changes in shape and size of the leaves as the palms get established, the onset of suckering and the numbers and disposition of the suckers, etc., until the emergence of the first inflorescence, indicating the end of the establishment phase.

The early growth and suckering of salak have not yet been investigated. In the experiment described here, leaf growth and suckering of different seedling progenies were studied over a period of about 2½ years after sowing.

Materials and methods

The experiment was conducted at the Research Station of Brawijaya University at Jatikerto. Climatic data for Jatikerto are presented in Appendix 2.

Experimental design

Seven varieties grown from seed were used in the experiment, namely 'Kersikan' (black and yellow); 'Suwaru' (black and yellow); 'Kacuk' (black); 'Bali' (black); and 'Pondoh' (black). 'Black' and 'Yellow' refer to the colour of the fruit skin; growers use the terms 'Budeng' and 'Gading', respectively, and consider the colour a stable distinguishing trait. More than 200 seeds of each variety were sown in polythene pots on November 19, 1989, in order to obtain at least 100 seedlings per variety, except for 'Pondoh' which was sown on February 5, 1990. All references to age of the plants in this report are in relation to these dates of sowing. After the first simple leaf had matured, 90 good seedlings of each variety were planted in a complete randomized block design in three replicates, each plot consisting of a single row of 30 plants, spaced 50 cm apart. The inter-row spacing was 2 m. Surplus seedlings were planted as guard row plants around the experimental field. To provide shade *Sesbania grandiflora* was sown in the experimental field. At the time the salak varieties were planted out, the shade trees were about 1 m high, and spaced 2 x 1 m in rows alternating with the salak rows. When the salak rows became overcrowded, half the plants were grubbed to increase the spacing to 1 m. Further thinning to provide adequate space was effected by removing most male-flowering and some female-flowering plants after flowering set in, 30 months from sowing. As a consequence, at the end of the experiment the total number of plants in the experiment ranged from 22 to 25 for the different varieties.

Agronomy

Individual plants were fertilized with 500 g cattle manure, 20 g urea, 20 g TSP (triple super phosphate) and 20 g KCl. These quantities were provided every 6 months, in October and April, i.e. before the beginning and towards the end of the wet season.

Data collection and analysis

In the young seedlings the rate of growth of simple leaves was measured by recording the number of days from leaf emergence, that is when the new spear has a length of 1 cm, until:

- the spear attains its ultimate length,
- the spear begins to unfold,
- the leaf is mature (indicated by the colour change from pale to dark green).

Later, when compound leaves were formed, these were measured in the same way. The method of measurement of leaf development is illustrated in Figure 2.1; Figure 2.2 shows simple and compound leaves of the palm.

Sixteen months ('Black Pondoh': 13 months) after sowing the number of simple and compound leaves per plant and their leaf areas were measured. The leaf area was determined by multiplying the maximum leaflet length, the maximum leaflet width, number of leaflets on both sides of the rachis with a shape factor. The shape factor was derived by tracing the contour of all leaflets of the sampled leaves on a piece of paper and cutting the tracing out. The weight of the cuttings was divided by the weight of total paper and multiplied by the original paper area (Evans, 1972). The samples consisted of 4 simple leaves (the third oldest) and 4 compound leaves (the second mature leaf from the top) per plot.

When the plants were 19 and 33 months ('Black Pondoh': 16 and 30 months) the number of suckers per plant was recorded.

A complete random block design additive model was used to analyse the collected data according to Steel and Torrie (1980).

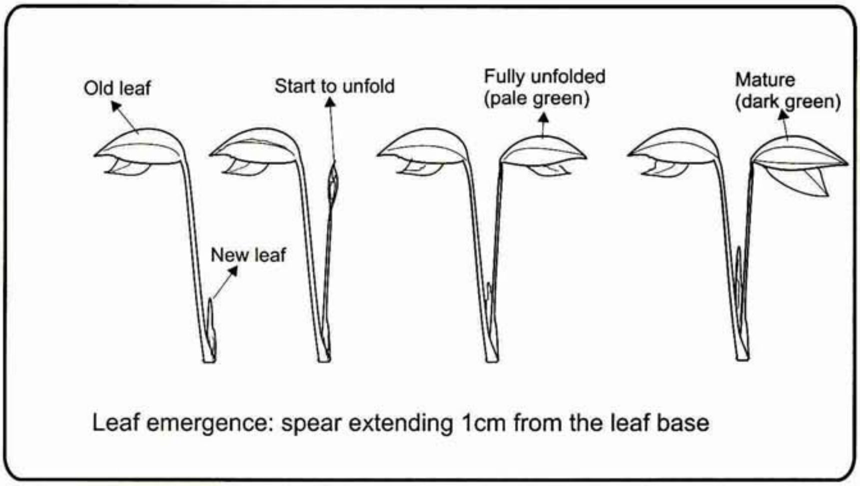

Figure 2.1. Method of measurement of leaf growth stages.

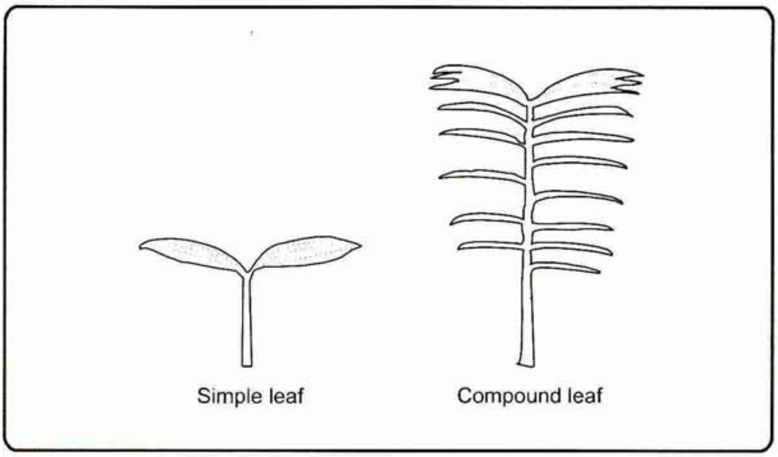

Figure 2.2. Simple and compound leaves of the salak palm.
Note the erratic positions of the leaflets along the rachis and the variation in leaflet size in the compound leaf.

Results

Leaf numbers per plant. Sixteen months after sowing the number of simple leaves varied from 4 to 7 and of compound leaves from 3 to 7 while total leaf numbers ranged from 8 to 12 as shown in Table 2.1. It is clear from Table 2.1 that small numbers of simple leaves tended to be compensated by larger numbers of compound leaves. One reason is that the definition of 'simple' and 'compound' leaf does not take into account the actual gradual change in leaf form: splitting-off of a single leaflet in the fifth leaf, for instance, shifts this leaf from the simple to the compound category. 'Yellow Kersikan' which had the largest number of simple leaves, had the smallest number of compound leaves. 'Black Pondoh' showed the largest number of compound leaves even though the plants were 3 months younger than the others. 'Black Pondoh' also had the largest total number of leaves.

With 12 leaves in 13 months, 'Black Pondoh' produced almost one leaf per month. In the other varieties the average interval between the emergence of successive leaves was approximately 45 - 50 days. The data on total number are calculated as the sum of the averages and thus not statistically analysed.

Leaf area. The shape factors of simple and compound leaves differed. The average value for the simple leaf was 0.6 while that for the compound leaf was 0.7. The shape factors for the simple leaves were not significantly different for the varieties, but those for the compound leaves were (see Table 2.2).

Table 2.3 shows large differences in leaf size between varieties, mainly because the leaves of 'Black Bali' and 'Black Pondoh' were so small. In fact 'Black Bali' grew very weakly; its compound leaves were even smaller than the simple leaves. Perhaps the seeds of this variety were too old; the results of Chapter 4.2 (see below) showed that with increasing duration of storage not only the germination percentage was reduced, but also the growth rate of the remaining seedlings. The small leaf size of 'Black Pondoh' is in agreement with its high rate of leaf production. For the remaining varieties the differences in leaf size were small in comparison with the differences in

Table 2.1. Mean numbers of simple and compound leaves per plant (for 'Black Pondoh' after 13 months, for the others after 16 months).

Variety	Simple leaf	Compound leaf	Total
1. 'Black Pondoh'	4.75 b	7.25 b	12.00
2. 'Black Suwaru'	6.00 c	5.00 ab	11.00
3. 'Yellow Suwaru'	6.50 de	3.75 a	10.25
4. 'Black Kersikan'	6.25 cd	4.75 ab	11.00
5. 'Yellow Kersikan'	6.75 e	3.00 a	9.75
6. 'Black Kacuk'	4.00 a	5.50 ab	9.50
7. 'Black Bali'	4.50 b	4.00 a	8.50

Means in the columns for simple and compound leaves followed by the same letter are not significantly different at P = 0.05.

Table 2.2. Leaf area measurements: shape factors for simple and compound leaves.

Variety	Shape factor	
	Simple leaf	Compound leaf
1. 'Black Pondoh'	0.60 a	0.65 a
2. 'Black Suwaru'	0.64 a	0.69 ab
3. 'Yellow Suwaru'	0.62 a	0.77 b
4. 'Black Kersikan'	0.67 a	0.72 ab
5. 'Yellow Kersikan'	0.64 a	0.73 ab
6. 'Black Kacuk'	0.60 a	0.65 a
7. 'Black Bali'	0.57 a	0.73 ab
Averages	0.62	0.71

Means in a column followed by the same letter are not significantly different at P =0.05.

Table 2.3. Average size of simple and compound leaves and estimated leaf area per plant 16 months ('Black Pondoh': 13 months) after sowing.

Variety	Area per leaf (cm^2)		Estimated leaf area per plant (m^2)
	Simple leaf	Compound leaf	
1. 'Black Pondoh'	155 a	813 b	0.66
2. 'Black Suwaru'	252 c	980 bc	0.64
3. 'Yellow Suwaru'	230 b	1112 bc	0.57
4. 'Black Kersikan'	241 bc	1144 c	0.69
5. 'Yellow Kersikan'	254 c	1079 bc	0.50
6. 'Black Kacuk'	273 d	992 bc	0.65
7. 'Black Bali'	167 a	156 a	0.14

Means in a column followed by the same letter are not significantly different at P= 0.05.

leaf number in Table 2.1. Consequently the variation in estimated leaf area per plant was substantial. Remarkably 'Black Kersikan' ranked highest, whereas 'Yellow Kersikan', at home in the same area, ranked lowest.

Data on estimated leaf area were calculated by multiplying the values on area per leaf with the values on leaf number in Table 2.1 and thus not statistically analysed.

Leaf growth. The duration of the sequence of growth stages of simple and compound leaves of the seven salak varieties examined was very much the same; there were no significant differences. The emerging leaf extended as a spear leaf during 32 - 35 days for both simple and compound leaves. The simple leaf started to unfold between day 40 and 43, and the compound leaves between 51 and 54 days after emergence. Hence, having attained its maximum length, the leaf does not unfold until after on average 8 days in simple leaves and nearly 20 days in compound leaves.

Leaf maturity of the simple leaf occurred at day 48 - 50 after emergence, while that of the compound leaves took place between day 65 and 67 (Table 2.4). Thus the simple leaves on average took about a week to unfold and mature, the compound leaves nearly 2 weeks.

The average interval between the emergence of successive leaves, calculated above at 45 - 50 days, is about equal to the period from emergence to maturation of simple leaves (48 - 50 days) and much shorter than the 65 - 67 days it takes a

Table 2.4. Number of days from emergence till attainment of successive leaf growth stages.

Variety	Max. spear length		Start to unfold		Leaf maturity	
	Simple leaf	Compound leaf	Simple leaf	Compound leaf	Simple leaf	Compound leaf
1. 'Black Pondoh'	33.6	33.4	41.7	52.5	48.7	65.5
2. 'Black Suwaru'	34.3	32.9	42.7	54.1	49.8	67.3
3. 'Yellow Suwaru'	32.6	35.3	40.7	53.1	47.7	66.0
4. 'Black Kersikan'	33.3	32.2	41.4	51.9	48.5	65.0
5. 'Yellow Kersikan'	33.6	32.3	41.5	52.4	48.6	65.2
6. 'Black Kacuk'	33.2	33.2	42.1	53.8	49.2	66.9
7. 'Black Bali'	35.2	34.4	43.3	54.1	50.4	67.1

Table 2.5. Mean number of suckers per plant 19 and 33 months ('Black Pondoh' 16 and 30 months) after sowing (transformed data based on $\sqrt{(x + \frac{1}{2})}$ according to Steel and Torrie (1980).

Variety	Number of suckers	
	19 months	33 months
1. 'Black Pondoh'	1.0 b	3.9 bc
2. 'Black Suwaru'	2.1 c	4.7 c
3. 'Yellow Suwaru'	1.3 bc	3.0 bc
4. 'Black Kersikan'	2.2 c	3.9 bc
4. 'Yellow Kersikan'	2.2 c	4.0 c
6. 'Black Kacuk'	2.1 c	4.0 c
7. 'Black Bali'	0.0 a	0.0 a

Means in a column followed by the same letter are not significantly different at P=0.05.

compound leaf to grow out. This implies that a new leaf emerges before the previous leaf has turned green, as was indeed the case in the field.

Suckering. At the age of 15 months, the palms started suckering, except 'Black Bali'; the stunted plants of this variety did not produce suckers at all. The average number of suckers per plant 19 and 33 months after sowing is presented in Table 2.5.

Discussion

The pattern of leaf growth of the seedlings was the same for all varieties: following the formation of 4 - 7 simple leaves, 3 - 7 compound leaves were formed with increasingly more leaflets. Every new leaf tended to be larger than its predecessor and after 16 months the average leaf area per plant ranged from 0.50 to 0.69 m² for the different varieties. The main exception was 'Black Bali' which grew very poorly. 'Black Pondoh' was also exceptional because of its small leaves, but this was compensated by an equally exceptional rate of leaf production.

The duration of the growth stages of individual leaves – spear extension, spear rest, unfolding and maturation – was very similar for all varieties, but differed for the two leaf forms: simple leaves took 48 - 50 days to grow out, compound leaves 65 - 67 days. Because leaf shape (and size) change in fact gradually, it is likely that the duration of the growth stages also increases gradually rather than abruptly as suggested by these figures.

'Black Pondoh' seedlings produced a total of 12 leaves in 13 months time, whereas seedlings of other varieties made 9.5 to 11 leaves in 16 months time. This works out to a 33 day interval between the appearance of successive 'Black Pondoh' leaves, against 45 - 50 days for the other varieties. These average figures may hide a gradual increase in the phyllochron, perhaps in keeping with the increasing time required for individual leaves to grow out. The calculated rate of leaf production of 'Black Pondoh' is similar to that of bearing coconut (1 leaf per month, Child, 1974), but much lower than in oil palm (2 leaves per month, Hartley, 1988). Since the phyllochron determines potential yield (each leaf axil holds a single inflorescence bud), it is important to verify the phyllochron in bearing palms of different salak varieties.

Nineteen months after sowing most plants had formed two suckers; only the 'Yellow Suwaru' plants lagged behind. After 33 months this variety still had the lowest number of suckers (3 per plant on average), the highest number being found in 'Black Suwaru' (4.7 suckers per plant). Thus suckering starts early, long before the end of the juvenile phase. The sago palm which belongs to the same tribe as salak, suckers in the first year after planting and second order suckers may also be formed (Flach, 1983). Unchecked suckering appears to slow down the growth of the main trunk; therefore farmers practise desuckering (Flach and Schuiling, 1989). In salak suckering causes problems in cultivation as well as in artificial pollination; there is a need to establish the optimum number of suckers per palm, also in relation to yield.

Conclusions

1. Salak seedlings show a gradual transition in leaf form. The first 4 - 7 leaves are simple. Later leaves are compound, near the leaf tip several leaflets remain united.
2. 'Black Bali' seedlings remained stunted; perhaps the seed was too old.
3. Sixteen months after sowing the mean leaf area per plant ranged from 0.50 to 0.69 m^2 for the different varieties. There was not much difference in mean leaf size of either the simple or the compound leaves, with the exception of the rather small leaves of 'Black Pondoh'. In all varieties the duration of the growth stages of an individual leaf was similar, the average period from emergence to maturity being 48 - 50 days for simple leaves and 65 - 67 days for compound leaves.
4. 'Black Pondoh' plants produced 12 leaves in 13 months, the other varieties 9.5 - 11 leaves in 16 months, leading to a calculated phyllochron of 33 days and 45 - 50 days, respectively. These average numbers of days, like the numbers of days in the previous conclusion, may hide a gradual increase in duration as the leaves become larger. Because of its importance for potential yield, the phyllochron should be measured in bearing salak varieties too.
5. Suckering starts early: most 19-month-old plants had 2 suckers, after 33 months the average was nearly 4 suckers. There may be scope to select for limited suckering, because 'Yellow Suwaru' had fewer suckers than other varieties, after 33 months as well as after 19 months.

2.2. Variety trial: onset of flowering and dioecy

Introduction

Vegetative and generative growth of plants should be balanced. The vegetative parts: leaves, stem and roots, should be adequate to support the generative parts, consisting of inflorescences, fruits and seeds. The age at which plants complete their juvenile phase, i.e. the period from germination until first initiation of flowers, differs between species and even within a species.

The kind of planting material also influences this period. If seeds are used, especially in perennial crops, the time needed by the plant to bear flowers is much longer than if asexual parts such as stems, rhizomes or leaves are used; in the latter case the propagule may already have progressed to flowering but it still has to complete its organs (branches, leaves, etc.) before it becomes capable of bearing flowers.

Salak is mostly propagated from seed. The plant requires 3 - 4 years from sowing till flowering (Tohir, 1983; Tjahjadi, 1989; Schuiling and Mogea, 1991). Well-sized suckers will flower after 2 - 3 years. Environmental factors such as temperature, humidity and nutrients also influence the start of the generative phase. Few aspects of the generative phase of the salak palm have been studied. This report concerns the onset of flowering in a variety trial, to determine the length of the juvenile phase and the ratio of female : male flowering plants.

Materials and methods

This experiment is a continuation of the one described in Chapter 2.1; hence the lay-out and the varieties are the same. Only 'Black Bali' had to be excluded because it grew so poorly that it could not be expected to flower. The first plant flowered in March 1992, 28 months after sowing. The number of plants, which had come into flowering, was recorded monthly from 34 to 42 months ('Black Pondoh': 31 - 39 months) after sowing, separately for male and female flowering plants. At the age of 33 months the salak stand became so crowded that getting into the row became problematic. Therefore, plants were desuckered after 33 months, leaving only the two smallest suckers and thereby facilitating observations.

Results

The number of flowering plants. The plant that flowered after 28 months was male, as were most of the plants which came into bloom in the following months. These male flowering plants were removed after recording their sex to relieve the congestion in the rows.

After 34 months, when monthly recording started, 2 or more plants had come into bloom in all varieties (except in the younger 'Black Pondoh' plants), 'Yellow Kersikan' having 7 plants with inflorescences (Table 2.6). The numbers increased gradually, in some varieties ('Yellow Suwaru', 'Black Kersikan') with a sudden leap in one month. When the experiment was terminated, after 3½ years, the percentage of adult plants ranged from 83 for 'Black Kacuk' to 50 for 'Black Suwaru', 'Black Pondoh' scoring 25%.

Looking at the monthly increase in number of plants which have issued inflorescences for the experiment as a whole, Table 2.6 suggests a strong seasonal influence. From October to January, i.e. from the end of the dry season till well into the wet season, many plants produce their first inflorescence, against hardly any during the next 2 wet months, February and March. There is an upsurge again in April, i.e. the transition from wet to dry season. In May, however, only 2 of the remaining 55 juvenile plants attained adulthood i.e one plant each for 'Yellow Kersikan' and 'Black Kacuk'.

For the individual varieties the period of little or no gain in numbers of plants with inflorescences ranged from 2 months (February - March) for 'Black Pondoh', 'Yellow Suwaru', Black Kersikan' and 'Black Kacuk' to 5 months (January - May) for 'Black Suwaru' and 'Yellow Kersikan'.

The proportion of female and male plants. In Table 2.7 the proportions of female and male flowering plants at the end of the experiment are presented. These figures, however, refer only to the 62% plants which had flowered, the rest did not flower yet. The data were therefore not analysed statistically.

According to the data presented in Table 2.7, the ratio of female and male plants varied widely, even in varieties where more than 60% of the plants had already flowered. Only 'Yellow Kersikan' and 'Black Kacuk' produced about equal numbers of female and male plants, but the number of female trees of 'Black Kersikan' was 3 times

Table 2.6. Monthly number of plants showing inflorescence(s), cumulative ('Black Pondoh': plants 3 months younger than indicated).

Variety		Month, age								
		Sep. 34	Oct. 35	Nov. 36	Dec. 37	Jan. 38	Feb. 39	Mar. 40	Apr. 41	May 42
1.'Black Pondoh'	(24) *	-	-	3	3	4	4	4	6	6
2.'Black Suwaru'	(22)	2	3	6	9	11	11	11	11	11
3.'Yellow Suwaru'	(25)	3	11	13	15	16	16	16	17	17
4.'Black Kersikan'	(22)	2	3	3	12	13	13	13	17	17
5.'Yellow Kersikan'	(23)	7	9	11	14	14	15	15	15	16
6.'Black Kacuk'	(23)	2	6	8	8	14	14	14	18	19
Total	(139)	16	32	44	61	72	73	73	84	86
Increase/month			+16	+ 12	+ 17	+11	+ 1	+ 0	+11	+ 2

*Figures between brackets are the number of plants observed.

Table 2.7. The number of female and male flowering plants and the sex ratio 42 months ('Black Pondoh': 39 months) after sowing.

Variety		Number of flowering plants		Sex ratio Female : male
		Female	Male	
1. 'Black Pondoh'	(24)*	1	5	0.2
2. 'Black Suwaru'	(22)	7	4	1.7
3. 'Yellow Suwaru'	(25)	10	7	1.4
4. 'Black Kersikan'	(22)	13	4	3.2
5. 'Yellow Kersikan'	(23)	8	8	1.0
6. 'Black Kacuk'	(23)	10	9	1.1
Total	(139)	49	37	1.4

* Figures between brackets are the number of plants observed.

that of the male ones. Taking all varieties together, however, the numbers of female and male plants did not differ much.

The number of plants involved in this study is too small to draw firm conclusions.

Discussion

Salak grown from seed started to flower at the age of 28 months; at 34 months some flowering plants were found in all varieties. The palms grown by farmers on Java island are pollinated by hand. When pollen is not readily available, the farmers get it from other gardens, even in other villages. This use of different pollen sources may cause variation in flowering time of the progeny as has been shown for pea seedlings by Khvostova (1983). Genetic control of precocious flowering has been demonstrated in *Pinus* (Smidtling, 1981).

The seasonality in the emergence of the first inflorescence is of much interest, but hard to interpret because the records do not cover a full year and the number of plants per variety is low. It takes about one month for the inflorescence to reach anthesis and a further 6 months for the fruit to ripen. Hence the inflorescences emerging from October to January should yield fruit in May - August, the April inflorescences in November. These periods fit fairly well with the main harvest season in East Java, which runs from December to January, and the second smaller crop which is harvested in June - July.

Thus it appears that flowering that makes an end to the juvenile phase is subject to the same seasonal influences as flowering in older palms.

The sex ratio in dioecious species is expected to be 1:1 at the zygote stage. Carrol and Mulcahy (1993) report that a deviating sex ratio is governed mostly by factors operating after fertilization, such as sex-linked mortality. Early identification of female and male plants is important for the growers. Female plants cannot be distinguished morphologically from male plants by vegetative markers. Genetic markers which find expression in young seedlings and which are linked to the sex chromosomes could possibly be used to reveal the sex while the seedlings are still in the nursery. This could include the mere presence of the Y chromosome.

A curious segregation of the sexes has been reported from Java island (Moncur, 1988). Seeds from fruits containing 2 or 3 seeds are always used for planting; it is assumed that they produce female plants. Those from single-seeded fruits allegedly produce male trees. Experimental verification of this unlikely notion is time-consuming, unless genetic markers or observations on Y chromosomes could be used.

Another possibility is vegetative propagation using suckers of known sex. Suckers are rarely used by Indonesian farmers, except for 'Pondoh' in Sleman. Recently, however, farmers in Gondanglegi have also started to propagate salak vegetatively, following advice of the local Agricultural Department and horticultural staff of Brawijaya University in Malang.

Conclusions

1. Seedlings of salak varieties, originated from seeds, came into bloom when they were 28 - 34 months old. Progress was slow: after 42 months the percentage of plants, which had flowered, ranged from 50 to 84.
2. The periods of the year during which many juvenile plants came into bloom

corresponded fairly well with the main flowering periods in older orchards.

3. The sex ratio of the flowering plants in the experiment was 1.4 female against 1 male; for some varieties the sex ratios were more extreme, but the numbers of flowering plants were quite small. Female and male plants can only be distinguished when they flower. In order to control the sex of planting material, vegetative propagation by suckers of known sex is recommended.

2.3. Estimating the leaf area

Introduction

The arrangement of the leaflets along the rachis of a salak leaf is unlike that in other palms. There is no apparent system in the positions: the leaflets are neither opposite nor alternating and over varying distances along the rachis there may be no leaflet or only a leaflet on one side. The impression is of some – often quite a few – missing leaflets, here and there along the rachis. Near the rachis basis there are some smaller leaflets, sometimes including very small ones. Normally at the leaf tip several leaflets remain united, but it is not obvious how many leaflets make up these two blades.

Leaf area measurements in palms are difficult because of the very large size of the leaves. The method used in the experiment described in Chapter 2.1 is not unusual for palms (Flach and Schuiling, 1989), but it is designed for mature palms where leaf shape and size are more or less constant. Its use in young seedlings, where leaf shape and size range widely, is of doubtful value. The irregular size and distribution of the leaflets on a salak leaf, so different from other palms, further complicates the matter. Therefore an experiment was conducted in which a number of leaf characteristics were measured in order to work out a suitable – preferably non-destructive – method to estimate leaf area in salak.

Materials and methods

The methods were compared on 30 'Pondoh' leaves from a 3-year-old salak garden in Junrejo, near Malang in January 2000. The shade trees had lost the competition with the salak and some of the older leaves suffered from sunburn; pests had damaged some others. Therefore the youngest mature leaf was chosen in 30 palms. To avoid complications through drying of the leaves, they were measured immediately after cutting. The leaflets were stripped from the rachis and the following data were collected:

- diameter of the petiole 1 cm below the lowest leaflet,
- rachis length,
- length and width of the largest leaflet (excluding the pair at the tip),
- number of leaflets (including the pair at the tip).

Corner (1966) suggested that the final length of the spear leaf might serve as an indicator of the area of the leaf in palms in general. Because it was difficult to reach the basis of the petiole in the spiny salak crown, rachis length was measured instead of leaf length. Verheij (1972) related the leaf area of 4-year-old apple trees to the square of the diameter of the tree trunk; he found that the estimate could be improved by seeking the optimal power to which the trunk diameter should be raised. Perhaps the area of a palm leaf can likewise be estimated on the basis of the diameter of the petiole.

Flach and Schuiling (1989) estimated leaf area of sago, closely related to salak, by multiplying length and width of the largest leaflet with the number of leaflets on the rachis. This method was used in Chapter 2.1, and hence it is included in the study.

To obtain a direct estimate of leaf area the stripped leaflets were placed on graph paper marked with a square centimeter grid. The number of grid points covered by the leaflets gives a mathematically correct estimate of area (Bleasdale,1973); the accuracy can be improved by shifting the leaflets somewhat and repeating the count. However, this method proved to be so time-consuming that only a single count was made per leaf. Before the grid count the leaflets were passed over a calibrated electric leaf area meter. On the supposition that it would give the best estimate of leaf area, this method served as control.

The analysis compares four methods (using a total of seven variables):

Method C1: Leaf area measured by the photo-electric meter (control);
Method C2: Leaf area estimated by counting grid points covered by the leaflets (alternative control);
Method A : Petiole diameter x rachis length x number of leaflets;
Method B : (length x width) largest leaflet x number of leaflets.

Multiple regressions were conducted to determine the correlations between the measured leaf attributes, followed by automatic stepwise selection of the most powerful predictors to obtain the regression equations which best relate each of the tested methods to the control. The analysis was repeated after transformation of the data into their natural logarithms.

Results

Mean values and their standard deviation. The mean values and standard deviations for the seven variables are listed in Table 2.8. The table shows that the average leaf area was about 0.75 m^2, the results of the two control methods agreeing fairly well. Methods A and B obviously require some adjustment to estimate leaf area; moreover the values of their standard deviations were about 2 to 3 times higher than those for the leaf area meter method. The average leaf consists of 50 leaflets and the rachis is nearly 2 m long. The petiole diameter is quite small and therefore must be measured accurately to serve as a meaningful estimator of leaf area.

The relationship between variables. Scatter diagrams were made relating the values obtained by control method C1 with those of each of the other three methods, in order to visualize the relationship (Figure 2.3). A linear regression function was fitted to each diagram, as shown in the figures and explained below.

Figure 2.3 shows the close correlation between both control methods; the relation between C1 and method A was less well defined and that between C1 and B was weakest.

Table 2.8. Mean value, standard deviation and coefficient of variation for the measured and derived variables.

Variables		Mean	Standard deviation	Unit	Coefficient of variation
Petiole diameter,	d	1.37	0.28	cm	0.204
Rachis length,	h	177.6	27.7	cm	0.156
Largest leaflet, width,	w	5.1	0.4	cm	0.078
Largest leaflet, length,	l	53.3	6.0	cm	0.113
Number of leaflets,	n	49.9	9.4		0.188
C1: Area meter		7236	1748	cm^2	0.242
C2: Grid count		7579	1579	cm^2	0.208
A: d x h x n		12982	2975	cm^2	0.229
B: w x l x n		13853	4145	cm^2	0.299

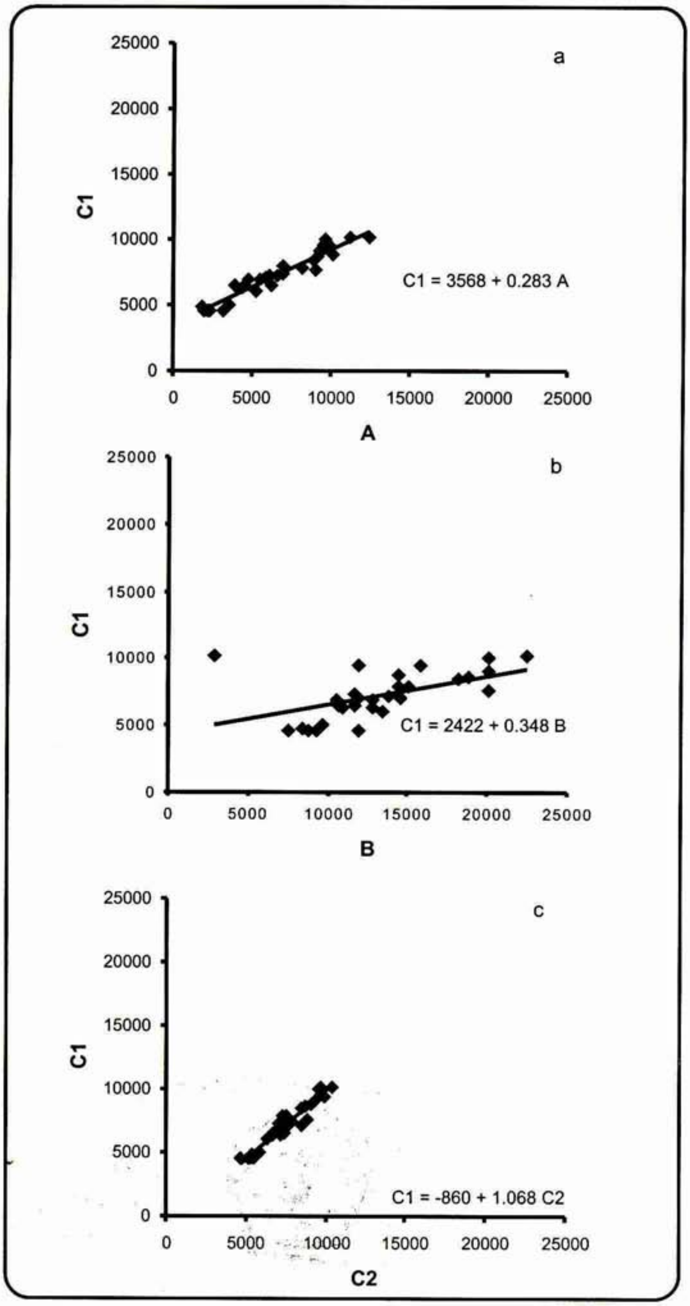

Figure 2.3. Scatter diagrams for the values for C1 against those for each of the other methods; in each diagram the fitted line represents the linear regression.
a is for C1 - A, b for C1 - B and c for C1 - C2; n = 30.

A multiple regression analysis with automatic stepwise selection of the most powerful predictors was carried out to relate method C1 to methods A and B, respectively. First, the matrix of single correlations between C1, the parameters used to calculate A and B, and A is presented in Table 2.9. Correlations between leaf attributes were generally close to one, as shown in Table 2.9; only correlations involving length and – in particular – width of the largest leaflet were below 0.7. In fact most correlations were highly significant, except those involving width of the largest leaflet. This parameter, therefore, should not be applied as predictor to estimate leaf area of salak.

Table 2.10 shows how stepwise removal of predictors affected the multiple regression of C1 - A. Including petiole diameter and number of leaflets in the multiple regression slightly improved the fraction of the variation in leaf area accounted for; including rachis length made virtually no difference (the standard error of the estimate even became slightly larger). Evidently, the straight regression of C1 on A was almost as good as the multiple regressions, 92.5% of the variation in leaf area being accounted for by method A on its own.

The same analyses as shown in Tables 2.9 and 2.10 for the regression of C1 on A were carried out for C1 on B and for C2 on A and C2 on B. It was found that the regressions with C2 were only slightly less well-defined than those with C1, but using method B to estimate leaf area was clearly inferior to using method A. This is shown by the regression equations and the goodness-of-fit in Table 2.11, which also includes these data for the regression of C1 on C2.

According to Table 2.11 agreement between the two control methods C1 and C2 was only marginally better than that between method A and C1. However, the relationship as indicated by the equations was very different; the small constant and a coefficient close to one suggest that C2 was almost equal C1. Therefore the ratio between C1 and C2 was also calculated; it is indeed close to unity. In Figure 2.3, lines have been fitted according to the regression equations in Table 2.11.

Analysis of transformed data. Leaf area may be better correlated with the cross sectional area of the petiole than with the diameter; this would mean a regression on the square of the petiole diameter. This brings up the question to what power the petiole diameter – and/or other variables – has to be raised to obtain the best possible estimate of leaf area. In other words: find the optimum values for p, q and r in the equation:

$$Y = s \cdot K^p \cdot L^q \cdot M^r,$$

where K, L and M stand for petiole diameter and any of the other leaf attributes measured.

The equation can be rewritten in a linear form by converting the data into their natural logarithms:

$$\mathit{ln}Y = \mathit{ln}s + p\,\mathit{ln}K + q\,\mathit{ln}L + r\,\mathit{ln}M,$$

after which regression can proceed as above.

The best results were obtained by regression of the logarithms of C1 on those of petiole diameter, rachis length and number of leaflets, i.e. the variables included in method A. Table 2.12 gives the outcome. Table 2.12 shows that the coefficients improved and the standard error became smaller when more predictors were included in the model. However, the highest value for R^2 (0.920) is not higher than in the corresponding model in Table 2.11 ($R^2 = 0.925$).

Table 2.9. Matrix of single correlations between leaf attributes, C1 and A; significances of the correlations.

	C1	d	h	l	w	n	A
Pearson correlation							
C1	1.000	0.899	0.875	0.617	0.171	0.867	0.962
petiole diameter, d	0.899	1.000	0.796	0.625	0.241	0.741	0.888
rachis height, h	0.875	0.796	1.000	0.657	0.077	0.821	0.913
leaflet length, l	0.617	0.625	0.657	1.000	0.594	0.489	0.634
leaflet width, w	0.171	0.241	0.077	0.594	1.000	0.009	0.128
leaflets, n	0.867	0.741	0.821	0.489	0.009	1.000	0.937
A	0.962	0.888	0.913	0.634	0.128	0.937	1.000
Significance(1-tailed)							
C1	1.000	0.000	0.000	0.000	0.184	0.000	0.000
petiole diameter, d	0.000	1.000	0.000	0.000	0.100	0.000	0.000
rachis height, h	0.000	0.000	1.000	0.000	0.343	0.000	0.000
leaflet length, l	0.000	0.000	0.000	1.000	0.000	0.003	0.000
leaflet width, w	0.184	0.100	0.343	0.000	1.000	0.481	0.251
leaflets, n	0.000	0.000	0.000	0.003	0.481	1.000	0.000
A	0.000	0.000	0.000	0.000	0.251	0.000	1.000

Table 2.10. Coefficients of determination (R^2), multiple correlation (R), and the estimate of the standard deviation (S) for a decreasing series of predictors of C1.

Predictors:	R^2	R	S
A + petiole d + rachis h + leaflets n	0.938	0.968	470.2
A + petiole d + leaflets n	0.937	0.968	462.4
A	0.925	0.962	487.0

Table 2.11. Regression equations, coefficients of determination and correlation, and estimates of the standard deviation for both C1 and C2 on A and B, as well as C1 on C2.

Regression equation	R^2	R	S
C1 = 3568 + 0.283 A	0.925	0.962	487.0
C2 = 4351 + 0.249 A	0.878	0.937	561.9
C1 = 2422 + 0.348 B	0.679	0.824	1007.5
C2 = 3450 + 0.298 B	0.612	0.782	1000.8
C1 = – 860 + 1.068 C2	0.931	0.965	466.0
C1 = 0.959 C2*			490.4

* linear regression through the origin, ratio C1/C2.

Table 2.12. Coefficients of determination (R^2) and correlation (R), and the estimate of the standard deviation (S) for 3 regression models.

Model	Predictor(s)	R^2	R	S
1	*ln*(petiole d)	0.829	0.911	0.1063
2	*ln*(petiole d), *ln*(leaflets,n)	0.903	0.950	0.0816
3	*ln*(petiole d), *ln*(leaflets,n), *ln*(rachis h)	0.920	0.959	0.0756

Table 2.13. Values of the coefficients in the regression equations for the three models presented in Table 2.12, their standard error, and the significance of their contribution to the correlation.

Model	Coefficients	Std error	Significance
1. (constant)	8.573	0.031	0.000
ln(petiole d)	0.989	0.085	0.000
2. (constant)	6.743	0.405	0.000
ln(petiole d)	0.701	0.091	0.000
ln(leaflets,n)	0.491	0.109	0.000
3. (constant)	5.205	0.759	0.000
ln(petiole d)	0.551	0.106	0.000
ln(leaflets,n)	0.320	0.125	0.016
ln(rachis h)	0.435	0.187	0.028

Table 2.13 lists the coefficients for the equations, that is the calculated optimum power to which each variable has to be raised, and statistical information.

In Model 1 in Table 2.13, the coefficient for *ln*(petiole d) is almost unity, which means that the optimum power for raising the petiole diameter is very close to one. Hence, the supposition that the optimum power would be close to 2, is not confirmed. In Model 3 the coefficients for both *ln*(petiole d) and *ln*(rachis h) are about one half, corresponding to the square root of petiole diameter and rachis length. Whereas the square of petiole diameter is proportional to cross sectional area and therefore should be linked with the mechanical strength and perhaps the transport capacity of the petiole, no biological explanations can be given for relationships based on the square root of either petiole diameter or rachis length.

Discussion

Leaf area measurements in palms are complicated by the large leaf size and in the case of salak also by the irregular leaf shape and the long spines. On the other hand the leaves of a mature palm adapted to its environment should all be about the same size, greatly facilitating the step from area of a leaf to leaf area of the crop.

It is generally accepted that the ultimate length of the spear leaf gives a prediction of the size of a palm leaf; after all the fully extended spear contains the folded leaflets which only have to unfold to expose the leaf area. It therefore comes as a surprise that rachis length is not such a good estimator of leaf area in salak; in most multiple regressions it does not augment the coefficient of determination as much as other predictors.

The petiole diameter is only a slightly better predictor of leaf area, although petiole dimensions must ensure adequate mechanical strength and transport capacity for the leaf. One would expect these functions to be correlated more closely with petiole cross sectional area than with petiole diameter, but in a model with petiole diameter as the sole predictor of leaf area, the best correlation was obtained by raising it to a power which was almost one.

Measuring the rachis instead of the spear, and the petiole diameter just below the leaflets instead of near the petiole base, may have made a difference, but it is hard to see how this could have affected the relationship with leaf area. In salak the petiole diameter is very small in relation to leaf size; perhaps the correlation with leaf area could have been improved by greater accuracy of measurement (use a nonius to read to 0.1 mm, duplicate measurement).

The number of leaflets proved an important predictor in multiple regressions, in spite of the extreme variations in leaflet size in salak.

The combination of rachis length, petiole diameter, and number of leaflets in method A gave an acceptable estimate of leaf area in comparison with both controls (methods C1 and C2). In fact Method A resulted in leaf area estimates which were almost as good as those obtained by Method C2, the grid count. However, the large value of the constants in the regression equations shows that A is not simply proportional to C1 or C2. It follows that the equations are only valid for the sampled leaves; they cannot be used for much smaller or larger leaves in younger or older gardens. Consequently in another garden – and also in the case of other varieties – the appropriate equation has to be established anew by sampling leaves according to Method A and a control method.

Method B gave the poorest estimates of leaf area and the regression equations on C1 and C2 show that like Method A its validity is limited to the plants from which the sample was taken. Length and particularly width of the largest leaflet were by far the poorest predictors of leaf area, so that the effectiveness of the method depends largely on the predictive value of the number of leaflets. The idea that the dimensions of the largest leaflet are indicative of the area of the other leaflets stems from palms with a much more rigid regulation of size and placement of leaflets along the rachis; it is not surprising that it is not really suited to salak, as salak has many missing leaflets.

Method B was used to estimate leaf area in the variety trial (Chapter 2.1). In the light of the present findings these estimates are of doubtful value, the more so since a simple ratio (the 'shape factor') was assumed between the values according to Method B and the control method. The plants were 16 months old, so leaf size ranged from the smallest simple leaf to a fair-sized compound leaf. Fortunately the shape factors were determined separately for each variety and for simple leaves as well as compound leaves. So there is no reason to discard the findings altogether; they may still be indicative of the leaf area per plant and the differences between varieties.

Both control methods, the photo-electric measurement and the grid count, are based on the same principle, so it is not surprising that the results are in close agreement. The grid count was very laborious and prone to counting errors, but with more practice the efficiency could probably be improved a lot. On the other hand, the homogeneous structure of the leaf blades suggests that another control method, based on the ratio between the weight of discs of known area punched out of the leaflets and the total weight of the leaflets, might be much simpler and quite accurate.

The control methods are destructive, whereas Methods A and B are meant to be non-destructive. This may indeed be the case in young salak stands, but mature plantations are so dense and prickly that measuring in-situ becomes impractical. However, growers occasionally cut ageing leaves in mature stands, and if these are still intact they can be used for sampling.

Conclusions

1. Four methods for measuring leaf area produced significantly different results. Estimates of the leaf area by counting the number of grid points covered by the

leaflets corresponded closely with those of the electric leaf area meter. However, this method is time consuming.

2. Method A, defined by the product of rachis length, petiole diameter and number of leaflets, produced acceptable results, not much inferior to the grid count, but it is only valid for the sampled population. The petiole diameter is small, requiring precision in measurement; the leaf area estimate could not be improved by using the cross sectional area instead of the diameter or by raising the petiole diameter to any other power.
3. Method B, based on the dimensions of the largest leaflet and the number of leaflets, was inferior to Method A because length and width of the largest leaflet were very poor predictors of leaf area.
4. Methods A and B were meant to be non-destructive, but it is virtually impossible to take the required measurements without cutting the leaves.
5. A full appraisal of the four methods requires a wider range of leaf sizes than was included in the sample.

CHAPTER 3: POLLEN

3.1. Yield per spadix as determined by intensity of pollination

Introduction

The productivity of the salak palm varies according to climatic conditions, soils and method of cultivation. Sarwono and Maryanti (1990) reported a production of 6 - 7 kg fruit per tree per year. The productivity per plant in East Java was reportedly higher, i.e. around 16 kg (Sudaryono et al., 1991). It is likely that the differences in production are also partly due to the genetic background of the varieties and the intensity of pollination (Purseglove, 1972).

Pollination usually precedes the production of fruit (Swamy and Krishnamurthy, 1980) as fruit growth is associated with seed set and production. In exceptional cases, however, formation of seeds is not needed for the fruit to grow out (parthenocarpy); in these cases pollination is not essential to harvest fruits. Parthenocarpic fruit growth has not been observed in salak. As the species is dioecious the fruits can only be produced through cross-pollination. This requires an adequate proportion of male-flowering plants, synchrony of anthesis of staminate and pistillate inflorescences and an effective vector – whether wind, insects, or man – for transmission of the pollen.

Pollination by wind or insects is inadequate for good fruit set in salak (Baswarsiati et al., 1991; Baswarsiati and Rosmahani, 1992). Growers pollinate by hand, which is very time consuming. Ashari (1993) estimated that hand pollination accounts for about 30% of the production cost. Only the Balinese salak does not require artificial pollination, as this type is monoecious.

The pistillate flower of salak consists of an ovary covered by hairs, containing three ovules, a short style and three lobed, almost sessile stigmata, one for each ovule (Moncur, 1988; Tomlinson, 1990). When all stigmata are successfully pollinated by hand, the developing fruits are triple-seeded.

Based on this information it is postulated that the number of pollinated stigmata of the pistillate flowers determines fruit development of salak. This was tested in an experiment in which one or two stigmata of a pistillate flower were excised and the treated spadices were bagged.

Materials and methods

The trial was conducted in a salak garden of Mr. Adi Pranowo in desa Suwaru, approximately 30 km southeast of Malang, from June to October 1991, that is during the dry season. The salak was grown rainfed in a garden around the house. The orchard was well maintained. According to the owner the age of the palm stools was over 100 years. The treatments were:

1. All three stigmata hand-pollinated.
2. Two stigmata hand-pollinated.
3. One stigma hand-pollinated.
4. Unpollinated.

The pistillate flower is a dyad (Uhl and Dransfield, 1987) (Figure 3.1). The sterile staminate flowers were removed before the stigmata became receptive. In the second and third treatment, stigmata were cut with a sharp razor using a magnifying glass (Figure 3.2), when the bracts enclosing the spadix had opened up, indicating that the stigmata were becoming receptive. In all treatments the pistillate flowers were covered with thin paper soon after being pollinated by hand and before natural pollination by wind or insects could take place (unpollinated control). Palms with 3 spadices in the inflorescence were selected at random and one spadix was allocated for each of the treatments 1, 2, and 3. On average there were 20 flowers in a spadix and all flowers were treated. Different palms were selected for the 4th treatment. The treatments were replicated on five palms/inflorescences. The pollen came from trees in the same garden. Mature pollen, sticky when touched, was used. The male flowers were tapped above the emasculated pistillate flowers.

Fruit set, diameter, length, fresh weight and seed numbers per fruit were measured. The collected data were analysed using a complete randomized block design additive model according to Steel and Torrie (1980).

Results

Fruit set and seed set. As expected, when all stigmata were intact, fruit set was much better than when 1 or 2 stigmata had been removed (Table 3.1). Differences in receptivity of the flowers – within and between spadices – may explain why intensive pollination resulted in no more than 75% fruit set and why removal of two stigmata led to a significantly higher fruit set than removal of a single stigma. Moreover, because of the sharp drop in fruit set – from 75 to about 30% – for flowers with excised stigmata, an adverse effect of the excision on pistils cannot be ruled out. Moreover, the physical damages during the excision work could be the cause of the drop of fruits.

Unpollinated flowers produced no fruit. The pollination treatments affected both the fruit set and the fruit number per bunch in a similar way. The number of seeds per fruit was close to the maximum for intact flowers and dropped to half as much for flowers with a single intact stigma.

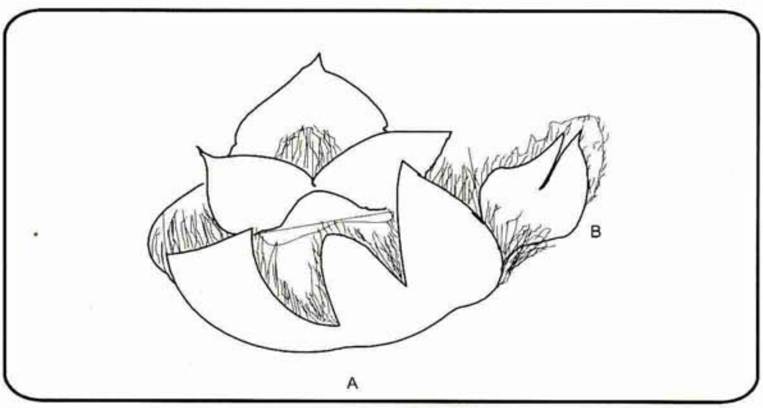

Figure 3.1. Dyad of pistillate flower and sterile staminate flower with bracteoles.
A: pistillate; B: staminate.
Redrawn based on Uhl and Dransfield (1987).

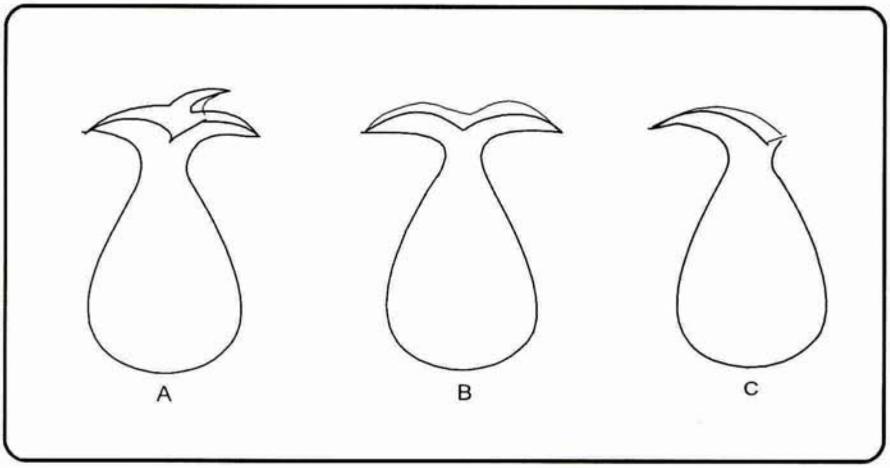

Figure 3.2. Florets of pistillate flowers showing the way the stigmata were cut. Pollinated stigmata: A: three; B: two; C: one.

Table 3.1. Percentage fruit set, and mean numbers of fruits per bunch and seeds per fruit.

Hand-pollinated stigmata	Fruit set (%)	Fruits/bunch	Seeds/fruit
3	74.9 c	14.9 c	2.85 c
2	27.3 a	5.5 b	2.22 b
1	31.9 b	6.4 b	1.41 a
0	-	0 a	-

Values followed by the same letter are not significantly different at LSD 5%.

Number of seeds per fruit. The fruits from flowers with three pollinated stigmata were mostly triple-seeded with a small number of double-seeded and single-seeded ones. Two pollinated stigmata produced 9.5% single-seeded fruits; 59.3% double-seeded fruits and 31.3% triple-seeded fruits. One pollinated stigma produced 70.1% single-seeded fruit; 18.5% double-seeded fruits and 11.5% triple-seeded fruits (see Figure 3.3).

Differences in the number of seeds per fruit were associated with differences in the shape of the fruit and, in particular, of the seed. When there were three seeds per fruit, the seed shape was trigonous (terminology after Mogea, 1978b), in fruits with two seeds the seeds were flattened on the side facing the other seed, and seeds of single-seeded fruit were round (see Plate 1A-C). The shape of triple-seeded fruits was nearly globular, double-seeded fruits were oblong/lanceolate and single-seeded fruits were globular but smaller than the triple-seeded ones (see also Plate 13).

Fruit size. Four weeks after pollination, the diameter of the fruit was more than 5 mm; after 20 weeks it was about 25 - 30 mm (Figure 3.4). Fruit diameter growth was apparently enhanced by the intensity of pollination. The growth rates of the fruit were 1.46, 1.33 and 1.21 mm per week for treatments 1, 2 and 3, respectively.

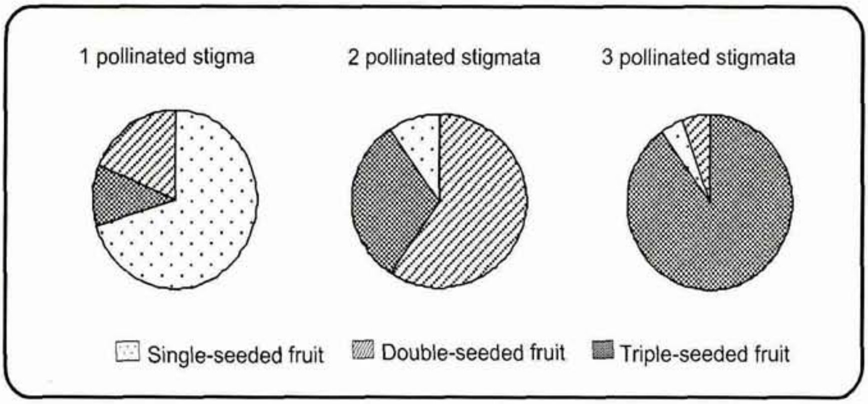

Figure 3.3. The proportions of fruit with 1, 2 or 3 seeds in each pollination treatment.

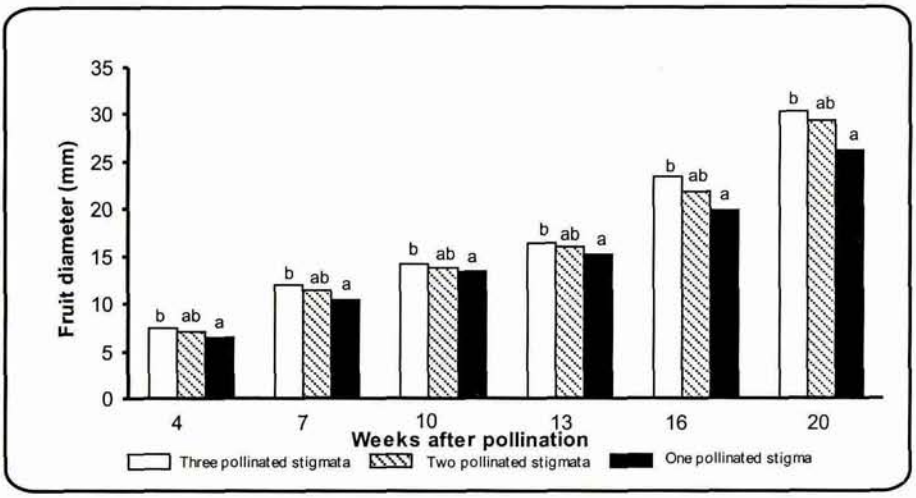

Figure 3.4. Increase in fruit diameter from 4 to 20 weeks after pollination.
* Bars topped by the same letter for a given week do not differ significantly at LSD 5%.

When all stigmata were pollinated, the fruits produced were longer than when only two or one were pollinated (Figure 3.5). Twenty weeks after hand-pollination the fruit length exceeded 30 mm. The rates of growth for fruitlets with 3, 2 and 1 pollinated stigma(ta) were 1.69, 1.51 and 1.38 mm per week, respectively.

As was the case with fruit diameter and length, the fresh weight of fruit with three pollinated stigmata was higher than that of fruits with either two or one pollinated stigma (Figure 3.6). In Plate 13 the shape and size of immature fruit is shown 20 weeks after pollination for the three pollination treatments.

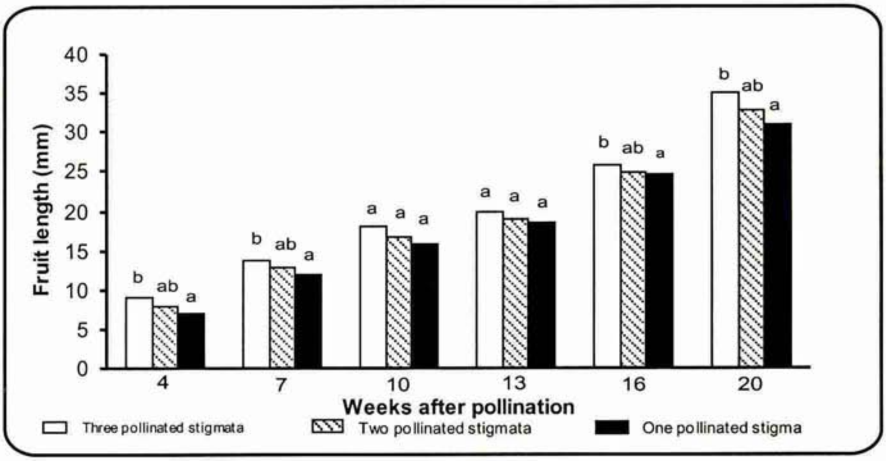

Figure 3.5. Increase in fruit length from 4 to 20 weeks after pollination.
* Bars topped by the same letter for a given week do not differ significantly at LSD 5%.

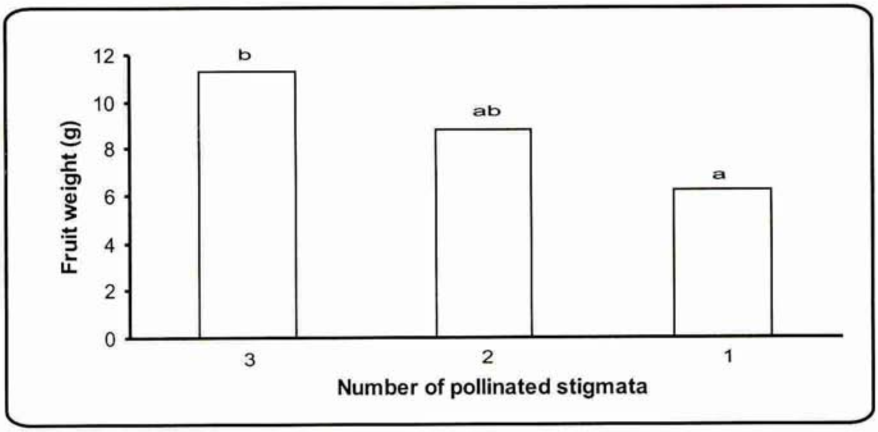

Figure 3.6. Fresh fruit weight, 20 weeks after pollination.
* Bars topped by the same letter are not significantly different at LSD 5%

Discussion

The results show that pollination is necessary for fruit set; there is no evidence of parthenocarpy. Intensive pollination leads to high fruit set (75% of flowers) and seed set (90% 3-seeded fruit). This indicates that:

- nearly all ovules are functional;
- the plants have enough energy to sustain fruit set of nearly all flowers in a spadix.

Moreover, there is no indication of competition between the fruits in a bunch: pollination of all stigmata resulted in much larger fruit, even though the number of fruit was more than twice as high as in the other pollination treatments; the experiment was conducted during the main cropping season, and – apart from the treated inflorescence – the plants were bearing normally.

It follows that intensive pollination is necessary to realize the fruit bearing capacity of the palm. The position of the spadices – close to the ground and sheltered by the dense canopy of large leaves – makes wind pollination less effective. The sticky pollen points to pollination by insects. It has been suggested that a *Nodocnemis* weevil is involved in pollination in Indonesia, and in Australia large numbers of curculionid beetles have been found on the flowers, carrying pollen from palm to palm.

In an observation on pollination of *Crysophila albida*, Henderson (1984) reported that this species is cantharophylous. During 36 hours prior to anthesis, a number of insects (curculionids, nitidulids, scarab beetles, *Trigona* bees and canopid flies) visited the flowers both during the day and at night. The inflorescence appeared to be a major food source for these natural pollinators. A study by Beach (1984) of pollination in the pejibaye palm (*Bactris gasipaes*) reveals precisely timed relations between flower opening and invasion of the spadices by successive swarms of insects (tiny weevils and scarab beetles, followed by drosophilid flies and *Trigona* bees). Megachilidae and Halictidae are pollen-gathering bees and *Sabal etonia* is predominantly bee-pollinated (Zona, 1987). Other palms which are reported to be insect pollinated are *Socrata exorrhiza* and *Iriartea ventricosa* (Henderson, 1985). However, natural pollination in salak is generally inadequate for a good crop and growers in Indonesia practice hand pollination.

The results show that the number of seeds is strongly correlated with the number of stigma lobes pollinated. Also the shape of the seeds is largely determined by the number of seeds per fruit. A correlation between seed shape and sex of the seedling as assumed by salak growers in Indonesia is, therefore, most unlikely.

The pollen tube grows down through the stylar canal to reach the ovule. The floral vascular system in palms is complex because it involves relatively large numbers of vascular bundles (Tomlinson, 1990). This may be the reason that some pollen tubes enter other ovules than the one associated with the stigma lobe on which they germinated. This may also be the reason that some flowers with a single stigma lobe produced triple-seeded fruits.

Conclusions

1. The experiment showed no evidence of parthenocarpy; unpollinated, pistillate flowers did not produce fruits.
2. Intensive pollination leads to heavy fruit set (75% of flowers) and seed set (90% 3-seeded fruit). Hence nearly all ovules appear to be functional and imperfect pollination can easily become yield-limiting. In a good orchard there needs be no competition between fruits in a bunch. The best treatment more than doubled the number of fruits per bunch and nevertheless the fruit grew to a larger size than in the other treatments.
3. The smaller fruit size resulting from flowers with excised stigmas can be attributed to the smaller number of seeds per fruit.
4. Pollinating 2 or 1 stigma lobes gave a large majority of respectively double- and single-seeded fruits, but both treatments also produced 3-seeded fruits.
5. The seed shape correlates with number of seeds per fruit. In fruits with three seeds, the seed shape is trigonous, when there are two seeds the seed is flattened on one side, and in case of a single seed the shape is globular.

3.2. Pollen sources in relation to fruit yield

Introduction

Artificial or hand pollination is required for salak in Indonesia. Natural pollination by wind or insects is inadequate (Baswarsiati et al., 1991; Baswarsiati and Rosmahani, 1992) to carry pollen from male-flowering to female-flowering plants.

Competition for pollination (CFP) has been reported to limit the production of avocado in Israel (Ish-am and Eisikowitch, 1998). When oranges, mustards and avocados flowered at the same time, the nectar-foraging bees were more attracted to visit flowers of orange and mustard rather than avocado flowers. Nectar-sugar content is supposed to be one of the parameters responsible for genetic variability in flower attractiveness to bees in the genus *Citrullus* (Wolf et al., 1999). The CFP is likely to occur in salak production, since most Indonesian salak gardens are surrounded by many plants of the same species and also fruit trees grown as shade plants, such as rambutan, durian, banana, or even coconut.

By roguing and replanting the proportion of male plants in orchards is reduced to 2 - 20% (Tjahjadi, 1989; Schuiling and Mogea, 1991). The farmers collect pollen from other orchards in case of shortage of pollen. Lack of male flowers is usually due to untimely anthesis of the male plants or too low a percentage of male plants. Cross-pollination using different pollen sources may affect plant productivity. Salak growers in kabupaten Sleman, Yogyakarta, believe that if 'Pondoh' flowers are pollinated by other varieties, e.g. 'Jawa', they will produce larger, better tasting fruits than when they are pollinated by the 'Pondoh'. Use of pollen of other varieties and indiscriminate propagation by seed could be the reason that several types of 'Pondoh' are distinguished: Black, Yellow and Red (Santoso, 1990). However, Siswandono (1989) did not find an effect of pollen types on the productivity of 'Pondoh'.

Pollinators had a significant effect on the inheritance of precocious flowering in beans (Khvostova, 1983) as well as in *Pinus* (Schmidtling, 1981). Where the previously described experiment (Chapter 3.1) showed the importance of intensive pollination, the current experiments were designed to study the effect of different pollen sources on productivity and fruit quality.

Materials and methods

The trials were conducted in orchards in two locations. The first experiment was done in desa Cepoko, kecamatan Berbek, kabupaten Nganjuk. The altitude is about 100 m above sea level, soil type latosol, average daily temperature about 28 °C, rainfall 2000 mm per year. The second was conducted in desa Kacuk near Malang (about 350 m a.s.l; the average temperature about 23 °C, rainfall 2017 mm per year). The trials were laid out in May 1993, that is early in the dry season; the fruit was harvested in December (early in the rainy season) and the observations were completed in January 1994.

The pistillate flower used in the first experiment was 'Nganjuk' pollinated with 5 different pollen types, i.e. 'Nganjuk' (Nga), 'Suwaru' (Su), 'Kacuk' (Ka), 'Pasuruan' (Pas) and 'Pondoh' (Pon). The second experiment used 'Kacuk' as pistillate flower, pollinated with the same varieties and in addition with 'Bangkalan' (Ba). The treatments thus were (Table 3.2):

Table 3.2. Treatments and lay-out of experiments.

Nganjuk	Malang
1. Nga x Nga 2. Nga x Su 3. Nga x Ka 4. Nga x Pas 5. Nga x Pon	1. Ka x Ka 2. Ka x Su 3. Ka x Pas 4. Ka x Nga 5. Ka x Pon 6. Ka x Ba
Each treatment consisted of 4 inflorescences (one spadix per plant) and was replicated 5 times, resulting in a total of 100 pollinated spadices	Each treatment consisted of 5 inflorescences (one spadix per plant), replicated 5 times, resulting in a total of 150 pollinated spadices

Both experiments were arranged in a randomized block design. The variables observed were number of fruits per bunch, fruit weight per bunch, fruit size (length and diameter), fresh weight per fruit, ratio between edible and non-edible part (based on weight), fruit longevity and chemical fruit composition (sugars, total acid and tannin).

For each treatment samples of 10 fruits were measured and put into open paper boxes which were stored at room temperature (20 - 25 °C). Fruit longevity was defined as the number of days from picking until 50% of the fruit showed symptoms of decay.

The analysis of reducing sugars was done on other fruit samples, using Soxhlet solution reagent (Lane-Eynon volumetric method). The procedures of total acid and tannin followed those of Sudarmadji et al. (1984) and Ranganna (1977). Each analysis was replicated three times.

The data were analysed using a complete random design model, and regression and correlation analysis according to Steel and Torrie (1980).

Results

The differences in number of fruits per bunch were extreme, the best pollinator, 'Pondoh', setting 4x as many fruits as the poorest pollinator, 'Kacuk'. Self-pollination gave intermediate fruit set. The weight per bunch also varied greatly, but larger weight per fruit compensated to some extent for low fruit number per bunch, so that the differences were less extreme in weight per bunch (Table 3.3).

Table 3.3. Mean number of fruit and weight of fruit per bunch.

Treatments: Female Male	Number of fruits per bunch	Fruit weight per bunch (g)
Nga x Nga	17.5 b	490.6 b
Nga x Su	14.0 b	670.0 c
Nga x Ka	5.8 a	331.3 a
Nga x Pas	18.3 b	868.8 e
Nga x Pon	24.0 c	793.8 d
Average	15.9	630.9

Values in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

Table 3.4. Mean weight per fruit, size and longevity of fruit samples from different crosses.

Treatments Female Male	Fresh weight (g)	Length (cm)	Diameter (cm)	Longevity (days)
Nga x Nga	35.5 a	4.8 a	4.2 a	16.2 b
Nga x Su	59.4 bc	7.2 d	4.9 bc	11.8 a
Nga x Ka	57.9 b	6.2 bc	4.7 b	15.6 b
Nga x Pas	62.1 c	6.6 c	5.2 c	9.6 a
Nga x Pon	37.9 a	6.0 b	4.0 a	27.4 c
Average	50.6	6.2	4.6	16.1

Values in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

Table 3.5. Edible : non-edible ratio, reducing sugar, total acid and tannin content of fruit samples from different crosses.

Treatments Female Male	Edible: non-edible ratio	Reducing sugar (%)	Total acid (%)	Tannin (%)
Nga x Nga	1.3 : 1	2.72 ± 0.38	0.42 ± 0.06	0.82 ± 0.09
Nga x Su	2.1 : 1	2.60 ± 0.41	0.43 ± 0.06	0.41 ± 0.04
Nga x Ka	1.7 : 1	2.96 ± 0.58	0.25 ± 0.03	1.23 ± 0.21
Nga x Pas	1.8 : 1	3.96 ± 0.39	0.82 ± 0.11	0.82 ± 0.12
Nga x Pon	1.4 : 1	4.94 ± 0.84	0.52 ± 0.06	0.65 ± 0.07
Average:	1.7 : 1	3.43	0.48	0.78

±: Standard deviation

Differences in weight are of course strongly reflected in fruit length and diameter, but the figures (Table 3.4) show that shape was also affected by pollinator. Fruit length varied much more than diameter; whereas selfed 'Nganjuk' fruit was squat, fruit from crosses with 'Suwaru' was slender, the length exceeding the diameter by about 50%. Fruit longevity appeared to depend on fruit size rather than on pollinator; as a rule, the smaller the weight or diameter the longer the fruit could be kept.

Fruit quality as shown by edible : non-edible ratio, reducing sugar, acid and tannin content was also affected by pollen types (Table 3.5). The pollen of 'Suwaru', 'Kacuk' and 'Pasuruan' increased the edible portion on average by about 15% compared with self-pollination. The pollen of 'Pondoh' increased sugar content by 81% compared with self-pollination. 'Pasuruan' also scored well for reducing sugar and both varieties also were high in total acids. 'Kacuk' pollen gave fruit with low acid and high tannin content.

With 'Kacuk' as the female parent, the pollinators again gave significantly different numbers of fruits per bunch, but in this experiment the extreme effects were found in weight per bunch rather than in number of fruit (Table 3.6). 'Bangkalan' pollen gave the best yield, almost 4x as much as 'Nganjuk', the least effective pollinator.

Fruit fresh weight, fruit length, fruit diameter and fruit longevity were affected by pollen sources (Table 3.7). Being less numerous, the fruit was generally much bigger than in the first experiment. Average weight of fruit from the cross with 'Nganjuk' was only 37.3 g, but in the other treatments it ranged from 74 to 95 g, about twice as much as in the first experiment. Fruit length again varied more than diameter, the pollinators 'Suwaru' and 'Bangkalan' producing relatively slender fruits. Longevity was between 12 and 15 days, except for the small fruit of the 'Nganjuk' cross which lasted 24 days.

Table 3.6. Mean number of fruits and weight of fruit per bunch from different crosses.

Treatments: Female Male	Number of fruits per bunch	Fruit weight per bunch (g)
Ka x Ka	8.8 b	803.8 c
Ka x Su	7.8 b	761.4 c
Ka x Pas	6.0 a	504.0 b
Ka x Nga	7.0 ab	231.6 a
Ka x Pon	7.0 ab	525.0 b
Ka x Ba	8.8 b	838.0 c
Average	7.6	610.6

Values in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

Table 3.7. Mean weight, size and longevity of sampled fruit from different crosses.

Treatments Female Male	Fruit fresh weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit longevity (days)
Ka x Ka	82.2 c	6.2 b	5.3 c	12.1 a
Ka x Su	94.7 d	7.1 c	4.9 b	15.0 b
Ka x Pas	83.1 c	6.1 b	5.3 c	15.0 b
Ka x Nga	37.3 a	4.5 a	3.8 a	24.3 c
Ka x Pon	74.1 b	6.5 b	5.2 c	12.2 a
Ka x Ba	86.3 c	8.1 d	5.8 d	15.0 b
Average	76.3	6.4	5.1	15.6

Values in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

The pollinators affected the edible portion as a fraction of total fruit weight (Table 3.8) but to a smaller extent than in the previous experiment; in all treatments the edible portion amounted to about two-thirds.

Pollen types also affected the contents of sugar, total acid and tannin (Table 3.8). The pollen of 'Pondoh', 'Pasuruan' and 'Bangkalan' increased the sugar content by 4 to 29% as compared to self-pollinated 'Kacuk' and for these three crosses the tannin content was almost twice as high.

Comparison of selfing and the reciprocal crosses. For 'Nganjuk' and 'Kacuk' self-pollination and the reciprocal crosses can be compared by combining the results of the two experiments. Unfortunately, judged by the fruit weight per bunch, 'Kacuk' was the worst pollinator for 'Nganjuk' and 'Nganjuk' for 'Kacuk'. So in Table 3.9 the yield is better when the varieties were selfed than when they were crossed. The yield of 'Nganjuk' x 'Nganjuk' is based on good fruit set, that of 'Kacuk' x 'Kacuk' on high weight per fruit. In the crosses 'Kacuk' pollen indeed failed because of poor fruit set, but 'Nganjuk' pollen failed both with respect to fruit set and weight per fruit, resulting in the lowest yield.

Interior fruit quality in Table 3.9 appeared to depend on the female parent rather than the pollen source. Fruit on 'Kacuk' plants had a higher sugar content, that on

'Nganjuk' plants a higher tannin content. The main indication of a positive effect of crossing is the enhanced edible portion. The highest edible portion was found in the fruit of 'Kacuk' x 'Nganjuk' (69%), while that of 'Nganjuk' x 'Nganjuk' fruits was lowest (57%).

Résumé of results of both experiments. In Table 3.10 the results in the two localities are compared. Yield (fruit weight per bunch) was similar in both localities, but in Nganjuk fruit set was much better, whereas in Malang the fruit grew much larger and became sweeter.

Table 3.8. Edible : non-edible ratio, reducing sugar, total acid and tannin in fruit samples from different crosses.

Treatments Female Male	Edible : non-edible ratio	Reducing sugar (%)	Total acid (%)	Tannin (%)
Ka x Ka	1.7 : 1	4.8 ± 0.51	0.35 ± 0.05	0.39 ± 0.05
Ka x Su	1.6 : 1	3.3 ± 0.38	0.31 ± 0.04	0.39 ± 0.04
Ka x Pas	2.0 : 1	6.2 ± 0.91	0.53 ± 0.09	0.79 ± 0.11
Ka x Nga	2.2 : 1	4.7 ± 0.49	0.35 ± 0.05	0.39 ± 0.07
Ka x Pon	1.6 : 1	5.0 ± 0.52	0.35 ± 0.07	0.83 ± 0.12
Ka x Ba	2.0 : 1	5.5 ± 0.61	0.48 ± 0.08	0.79 ± 0.08
Average	1.9 : 1	4.9	0.39	0.59

±: Standard deviation.

Table 3.9. Comparison of findings for self-pollination of 'Nganjuk' and 'Kacuk' and the reciprocal crosses.

Treatments Female Male	Weight per bunch (g)	Fruits per bunch	Weight per fruit (g)	Edible weight (g)	Sugar (%)	Acid (%)	Tannin (%)
Nga x Nga	491	17	35.5	20.1	2.72	0.42	0.82
Nga x Ka	331	6	57.9	36.5	2.96	0.25	1.23
Ka x Nga	232	7	37.3	25.6	4.70	0.35	0.39
Ka x Ka	804	9	82.2	53.8	4.80	0.35	0.39

Table 3.10. Comparison of yield and of fruit characters in the two locations; means for all crosses.

Variables	Nganjuk	Malang
Fruit weight per bunch (g)	631	611
Fruit numbers per bunch	15.9	7.6
Fruit length (cm)	6.2	6.4
Fruit diameter (cm)	4.6	5.1
Fruit longevity (days)	16.1	15.6
Edible : non-edible portion	1.7 : 1	1.9 : 1
Reducing sugar (%)	3.43	4.90
Acid (%)	0.48	0.39
Tannin (%)	0.78	0.59

Discussion

In both locations the pollen source strongly influenced fruit production, qualitatively as well as quantitatively. Pollinators 'Pondoh' and 'Pasuruan' gave the highest yield of 'Nganjuk' plants, pollinator 'Bangkalan' was best for 'Kacuk'. Pollinator 'Suwaru' gave higher than average yields in both experiments.

The effects of pollinators on yield have been tested in many fruit crops. Cross-pollination tends to improve yield and is necessary for cultivars which are self-incompatible. The results show that both 'Nganjuk' and 'Kacuk' are self-compatible, but these two varieties happened to show a high degree of cross-incompatibility: both 'Nganjuk' x 'Kacuk' and 'Kacuk' x 'Nganjuk' yielded very little in comparison with the other crosses, selfing of both varieties included. Salak is dioecious and usually propagated from seed, so that the genotype of pollen of a 'variety' must be extremely variable. Hence it is not surprising that varieties are self-compatible; however, the poor yield of the reciprocal crosses of 'Nganjuk' and 'Kacuk' indicates that incompatibility factors do occur in salak.

The effect of pollinators on yield can best be measured by recording the percentage of flowers which set fruit and the number of seeds per fruit. Percentage fruit set shows to what extent the potential number of fruit is achieved; the number of seed per fruit has a strong bearing on fruit size, as was shown for salak in Section 3.1. Unfortunately these data were not recorded in these experiments. This makes it difficult to offer an explanation for the striking differences in yield of different crosses. However, it was noticed that 'Nganjuk' spadices usually contained 20 - 25 female flowers, whereas in 'Kacuk' the number was generally lower than 20. This implies that the differences in percentage fruit set were smaller than the recorded differences in number of fruit per bunch.

Where many fruit quality attributes are affected by fruit size, a proper comparison of pollinators involves:

- recording percentage fruit set, the main factor determining yield, and
- grading of the fruit in 2 or more size classes and recording number of seeds per fruit and other quality attributes in samples of each class, to clarify pollinator effects on fruit quality.

Such an experimental procedure would allow a more comprehensive comparison of the effects of pollinators on yield and quality. The influence of pollen on maternal tissue (i.e. outside embryo and endosperm) is called metaxenia (Abercrombie et al., 1961).

The results in Malang agree with those of the experiment reported in Section 3.2 in that fruit size was not affected by the number of fruits per bunch. In the trial in Nganjuk, however, the tendency towards smaller fruit size at larger numbers of fruits (up to 24) indicates that competition between fruits in a bunch does occur.

Shelf life of the fruit appeared to depend on fruit size rather than on the pollinator. This is fairly common; for several fruit crops it has been shown that small fruit can be stored longer. The edible portion did vary with the pollen source, but not much nor consistently in both locations. In the first experiment the edible portion tended to be higher for larger fruits, as might be expected, but in the second experiment the treatment with small fruit had the greatest edible portion. The non-edible portion consists mainly of the seeds, the only other component being the scaly fruit skin. Thus records of seed numbers per fruit could also have assisted in the interpretation of these findings.

The sugar, acid and tannin contents of the fruit also varied considerably for different treatments. Pollinator 'Suwaru' gave lower than average concentrations of all three constituents in both experiments, whereas pollinator 'Pasuruan' consistently gave higher than average levels, sugar in particular. Comparison of all four combinations of 'Nganjuk' and 'Kacuk', however, pointed to a much larger role for the female parent than the pollinator in determining chemical composition. No relations could be discerned between chemical composition and other attributes of the fruit, such as fruit size, edible portion and shelf life.

The results show clearly that choosing the right pollinator can substantially improve yield, as expressed by numbers and weight of fruit per bunch. There are indications that metaxenia plays a role as well, because pollinators also appear to influence other fruit attributes, such as size, shape, and chemical constituents of the flesh.

Fruit longevity seemed indeed to be correlated with fruit size, but there was no evidence in the data of correlation of either edible portion, or chemical constituents with fruit size. So metaxenia cannot be ruled out. Moreover, botanically the edible flesh of salak is a sarcotesta, i.e. a part of the seed, not of the fruit. The flesh grows from the integument(s) of the ovule and thus consists of maternal tissue, but as part of the seed it may be more prone to paternal influences than fruit tissues.

Conclusions

1. Pollen source strongly influenced yield, qualitatively (longevity, chemical constituents of the flesh) as well as quantitatively (numbers and weight of fruit per bunch, edible:non-edible ratio).
2. Two varieties were selfed and the pollen proved compatible, but the poor yield of the reciprocal crosses is evidence that incompatibility factors play a role in salak.
3. Metaxenia cannot be ruled out, but it is more likely that good pollinators simply increase the numbers of seeds per fruit, resulting in larger fruit size. The effects of pollinators on fruit shape, edible portion, shelf-life and chemical composition may therefore be just indirect, i.e. a consequence of better seed set making the fruit grow larger.

CHAPTER 4: SEED

4.1. Seed germination

Introduction

Germination is a process of growth of the embryo by utilizing reserves in the seed. The process involves a drastic reversal of the metabolism in storage tissues. Seeds of angiosperms store reserves either in the embryo, in the endosperm, or more likely, in the aleuron layer, the perisperm, which lies in between the embryo and the seed coat. However, in seeds of monocotyledonous plants the endosperm is important as storage tissue.

Apart from providing nutrients for the embryo, the endosperm also provides nutrients for tissues surrounding the embryo. During germination and before leaves are capable of photosynthesis, growth and development of the embryo depend entirely on the metabolites from this storage organ. In palm seeds stored reserves are present in the cotyledon of the small embryo and in the massive, hard endosperm. During germination, the distal part of the cotyledon enlarges to form an haustorium, digesting the endosperm (Copeland, 1976). The major functions of the haustorium are absorption and storage of the nutrients during germination (De Mason, 1985). Most plants within the Palmae family have haustoria.

Studies on the development of the embryo of coconut and other palms have been reported (Child, 1974; Tomlinson, 1990). In *Phoenix dactylifera* exhaustion of the endosperm takes 10 weeks (De Mason, 1985). Little is known about germination in the salak palm. Mogea (1978b) reported that 105 days after sowing the cotyledon had decayed and the first bladed leaf had matured, the second leaf being in the spear stage. The aim of the work reported here is to investigate the growth and development of the embryo during germination and to clarify the function of the endosperm and haustorium in supporting the embryo's growth and development.

Materials and methods

The seeds used in the experiment came from a grower in kabupaten Sleman, Yogyakarta. Fully mature fruits of 'Pondoh' were picked. After the seed kernels (or "stones") were extracted they were washed thoroughly in tap water. Four treatments were applied by excising parts of the endosperm (Figure 4.1):

1. All endosperm excised, leaving only the embryo,
2. Half of the endosperm excised by a longitudinal cut glancing the embryo,
3. Half of the endosperm excised by a transverse cut,
4. Control, endosperm left intact.

There were 25 seeds per treatment per replication, of which some were used for the destructive measurements for the chemical analysis. The embryos with and without endosperm were then sown in sand. The sand was washed, air-dried and sieved to <2 mm. It was put into boiling water for 30 minutes, and then spread on trays, 60 x 40 x 15 cm. The trays were placed in a growth chamber to study germination under constant, controlled conditions.

The following records were collected:

- percentage germination;
- fresh weight gain of the embryos over a period of 12 days.

In the treatment with complete endosperm additional observations and analyses were made 0, 2, 4, 8, 11 and 18 weeks after sowing, in order to:

- measure the growth in diameter of the haustorium in transverse and longitudinal directions (corresponding to the planes used for halving the endosperm in treatments 2 and 3);
- measure the losses and gains in dry weight of endosperm, haustorium and root plus shoot;
- analyse the starch, sugar, lipid and N-total content in the dry matter of endosperm, haustorium, and root plus shoot.

About 0.2 g of dry matter was used to analyse starch content, 1 g for reducing sugars, 2 g for fat and 1 g for protein. Each analysis was replicated three times. These procedures for the analyses followed those of Sudarmadji et al. (1984) and Ranganna (1977). The starch content was analysed by direct acid hydrolysis, reducing sugars were determined using Soxhlet solution reagent (Lane-Eynon volumetric method), lipids by Soxhlet extraction using petroleum as a solvent, N-total was measured by using the Kjeldahl method.

The data were analysed using a complete random design model and regression analysis according to Steel and Torrie (1980).

Results

Germination. As expected, germination was influenced by the presence of endosperm. The embryos without endosperm did not germinate but those with full endosperm all did. Cutting half of the endosperm transversely did not reduce germination substantially, but longitudinal excision lowered germination to 87% of the embryos (Table 4.1).

Embryo growth and development. The embryos without endosperm showed activity on the 6th day after sowing, fresh weight increasing from 72 to 87 mg, but this weight decreased on the 9th day and the embryos had died on the 12th day (Table 4.2). The weights of embryos with half of the endosperm cut transversely and with intact endosperm were similar and increased progressively, but the rate of weight gain of the embryos in which the endosperm had been cut longitudinally lagged behind and

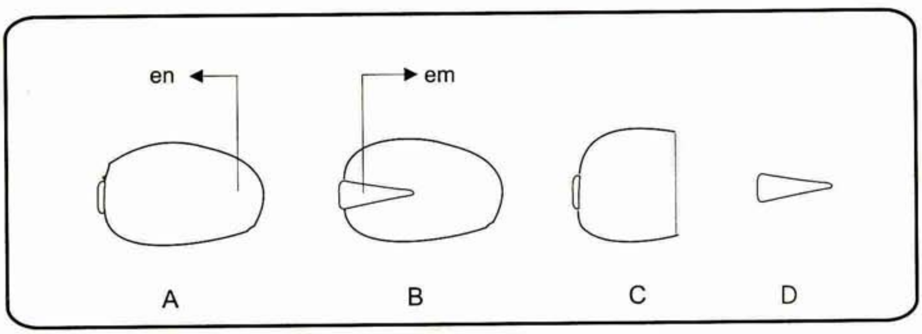

Figure 4.1. The treatments of seed kernels.
Embryo with A: full endosperm; B: 50% endosperm (longitudinal cut glancing the embryo); C: 50% endosperm (transverse cut); D: without endosperm; em: embryo; en: endosperm.

Table 4.1. Germination percentage of the salak seed, with and without its endosperm, analysis of data transformed to √% (Steel and Torrie, 1980).

Treatments	Germination (%)
No endosperm	0.0 a
Endosperm halved longitudinally	87.2 b
Endosperm halved transversely	97.5 c
Endosperm intact	100.0 c

Means in a column followed by the same letter are not significantly different at P= 0.05.

Table 4.2. Fresh weight of embryos (mg).

Treatments	Days after sowing			
	3	6	9	12
No endosperm	72 a	87 a	67 a	-*
Endosperm halved longitudinally	65 a	73 a	110 ab	126 a
Endosperm halved transversely	62 a	73 a	130 b	358 b
Endosperm intact	58 a	64 a	120 b	343 b

Means within a column followed by the same letter are not significantly different at P = 0.05.

* On the 12th day the embryos without endosperm had died.

became very small towards day 12. Eventually the transversely cut endosperm also reduced the growth rate; as shown in Plate 5 this resulted in large differences in size of seedlings 77 days after sowing. The embryos with full endosperm produced normal seedlings, but those with half the endosperm produced weak seedlings.

The cotyledon embedded in the endosperm grew steadily and became a haustorium. Approximately 12 days after sowing, the embryo started to develop. At approximately 19 days it showed shoot growth as well as root growth. After 40 days, the first bladed leaf appeared. It started to unfold at day 77 (Plate 5) and reached maturity about 126 days after sowing.

Dry weight losses and gains

The dry weight of root and shoot increased gradually as shown by a quadratic regression in Figure 4.2 (R^2 = 0.991**). Also the haustorium showed a quadratic function up to 18 weeks after sowing (R^2 = 0.966**). Meanwhile, the endosperm dry weight decreased rapidly, especially in the phase before the root, shoot and haustorium started to grow (R^2 = 0.820*), following a quadratic function. The seedling as a whole lost weight up to 11 weeks after sowing; by that time nearly 2/3 of the initial weight had been lost. The turning point – photosynthesis of the new leaf compensating respiration losses of the seedling – must have occurred shortly thereafter, because at 18 weeks the weight loss had been more than compensated by large gains in dry weight of haustorium and root plus shoot.

Chemical composition of endosperm. Owing to the limited number of embryos with intact endosperm for sampling, the chemical contents of haustorium and root and shoot were only measured 8, 11 and 18 weeks after sowing. At the time of sowing, the main

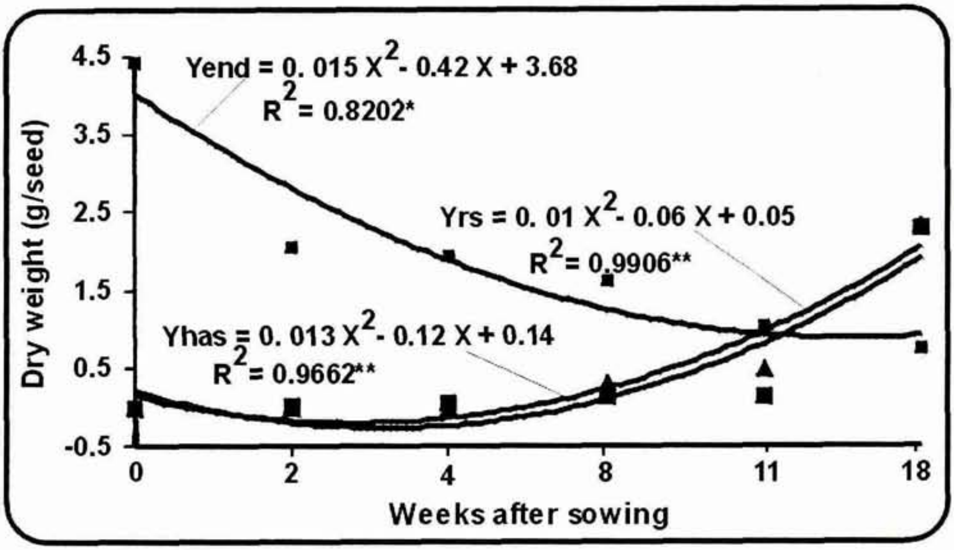

Figure 4.2. Dry weight losses and gains of endosperm, haustorium, root and shoot.

constituent of the endosperm was starch (95% of dry weight) followed by N-total, fat and sugar, respectively (Table 4.3). During germination the starch is converted into sugars and translocated to the haustorium and root and shoot, where it provides both energy and building material for the biosynthesis of the other constituents. The sugar content in the endosperm was relatively constant, whereas lipids and N-total initially increased sharply, but levelled off (lipids) or declined (N-total) towards week 18. After 18 weeks the starch in the endosperm was almost depleted.

The quantity of starch, fats and N-total in haustorium and root and shoot increased sharply towards week 18, contrasting with the changes in the endosperm. The weight of reducing sugars in haustorium and root and shoot rose less spectacularly, presumably because the sugars were metabolized as they became available. Until some time between weeks 11 and 18 the gain in weight of the constituents in haustorium and root and shoot did not compensate for the losses in the endosperm; this was due to the loss of dry matter by respiration, providing the energy for biosynthesis.

The growth of the haustorium. The growth of the haustorium made up for the decline of the endosperm. By week 18 the haustorium almost completely occupied the space where the endosperm had been (Table 4.4). When the first bladed leaf was fully mature, the haustorium was crisp and already depleted.

Discussion

The endosperm is essential for germination of the seed; without endosperm, the embryo is unable to grow out. However the excised embryos did show enlargement a few days after sowing. This suggests potential for raising embryos in-vitro for collection and conservation in breeding programmes. Embryos of palms such as coconut and palmyra have also been raised in artificial media to induce germination and to make long distance transport easier (Child, 1974; Kovoor, 1983). Rillo and Paloma (1991) cultured coconut embryos in artificial media under aseptic conditions; after long distance transport the germination percentage was between 42.7% and 72.6%.

The process of haustorium growth in salak seed is not fully understood. Tomlinson (1960) suggested that the surface of the cotyledon in germinating palm seeds secretes enzymes which convert the inert materials of the endosperm into soluble substances which pass through the haustorium and nourish the seedling. The question of the origin of the enzymes in palm seeds is somewhat controversial. Some believe that the enzymes originate from the endosperm while others hold the view that they come from the cotyledon or the haustorium and diffuse into the endosperm.

The development of the salak embryo is similar to that reported by Child (1974) in the coconut. In coconut, the embryo enlarges and differentiates, the apex into the plumule and the cotyledon into the haustorium. The globular form of the enlarging haustorium in this study suggests that the digestion of the endosperm proceeds at the same pace in all directions.

Identification of the enzymes which attack the endosperm is also very difficult. However, since the main constituent of the endosperm was starch, it is likely that amylase enzymes are predominant, followed by other enzymes such as saccharase,

Table 4.3. The changing quantities (in mg) of chemical constituents in the main organs during germination.

Organ	Weeks after sowing					
	0	2	4	8	11	18
Endosperm:						
- starch	4162	1279	1083	678	425	303
- sugars	0.05	0.15	0.16	0.15	0.14	0.14
- lipid	0.09	0.17	0.33	0.67	1.13	1.27
- N-total	0.31	1.38	1.61	2.69	2.63	1.70
Haustorium:						
- starch	-	-	-	56	54	869
- sugars	-	-	-	0.01	0.01	0.43
- lipid	-	-	-	0.02	0.11	2.25
- N-total	-	-	-	0.05	0.13	3.79
Root and Shoot:						
- starch	-	-	-	72	166	1033
- sugars	-	-	-	0.01	0.04	0.21
- lipid	-	-	-	0.02	0.11	1.82
- N-total	-	-	-	0.11	0.22	2.26

Table 4.4. The growth of the haustorium in two directions (% of the corresponding endosperm diameters).

Growth directions	Weeks after sowing					
	0	2	4	8	11	18
Transverse	0	14.7	22.2	60.8	70.6	96.0
Longitudinal	0	13.4	28.9	67.2	73.9	97.7

lipase and proteinase. In coconuts these enzymes are also active in the haustorium (Nagarajan and Pandalai, 1963).

Increasing nutrient contents within the root and shoot at week 11 and 18 indicated that there was a deposition of substances in these organs, resulting in seedling growth. The consecutive stages of germination consist of water absorption, embryo growth, haustorium development, initiation and growth of root and leaves and depletion of the endosperm. Germination is completed when the first leaf matures; by that time dry weight of the seedling surpasses the initial dry weight of the seed kernel, showing that photosynthesis sustains growth.

The leaf became mature at the same time that the haustorium, having reached its maximum size, became depleted, indicating that the seedling had consumed all the endosperm. When transferring seedlings to the field, the seed must remain attached to it if the first leaf has not yet matured; at a later stage the seed can be taken away.

Mogea (1978b) reported that 105 days after sowing the cotyledon had decayed and the first bladed leaf had matured, followed by the appearance of the second folded leaf. In this study leaf maturation as well as the exhaustion of the cotyledon occurred after 126 days. The difference may be due to the fact that the seeds in this study were placed in a growth chamber; lack of natural light resulted in etiolated seedlings.

Conclusions

1. The endosperm is essential for the germination of the embryo and the further development of the seedling.
2. Before being used by the embryo, the endosperm was digested by the developing haustorium. The growth of the haustorium is initiated in the cotyledon or at its surface. It is assumed that certain enzymes are secreted to hydrolyse the endosperm which consists largely of starch. The haustorium grew in all directions, assuming a globular form.
3. The haustorium starts decaying when the first bladed leaf matures. This marks the end of the germination phase, because at this stage the dry weight lost in respiration during germination, is compensated by photosynthesis.

4.2. Seed storage

Introduction

Seeds are commonly divided into two groups according to their viability after storage, related to water status. The first group, orthodox seed, is able to germinate after being stored with low water content, and at low temperatures. Seed of the second group called recalcitrant, is killed when the moisture content drops below some relatively high critical value (12 - 31%) (Chin and Pritchard, 1988). Most recalcitrant seeds are sensitive to chilling, have a tiny embryo compared to total seed size and are short-lived (King and Roberts, 1980).

In Indonesia salak is commonly propagated from seed. A large number of seeds have been sent to other places, sometimes far away. This long distance transport is reported to have reduced the seed viability sharply; the germination percentage became very low.

Schuiling and Mogea (1991) reported that salak seeds lose their viability quickly in storage. Fifty percent of the seeds did not germinate after one week in storage, and germination was zero when stored for 2 weeks. This seems to be caused by a loss of moisture, which results in the death of the embryo. Purwanto et al. (1988) reported that if the water content decreases to 24.9% the seeds no longer germinate. The aim of the work reported here was to find a method for storing seeds over longer periods, minimizing the adverse effects on germination percentage.

Materials and methods

The trial was done in the laboratory of the Agronomy Department, Brawijaya University Malang, from May to August 1991. The seeds used in the experiment were from 'Pondoh' of the black type. The fruits were obtained from a farmer in kabupaten Sleman, Yogyakarta. Fully mature fruits as shown by the easy shedding of hair from the base of the fruit, and of equal size, were chosen. The fruits were kept in the refrigerator at about 15 °C.

The treatments consisted of two factors, i.e. storage medium and duration of storage. The seed kernels were stored in (1) ambient air, (2) sawdust and (3) charcoal. Both sawdust and charcoal media were air-dried, crushed and sieved to 2 mm. They were then sprayed with fungicide ('Benlate' 2 ml/l water) and insecticide ('Furadan 2G': 2 g/l water). Storage trays were made of cardboard, dimensions 9 x 14 x 9 cm. The trays were left in ambient air for three days to allow the media to attain equilibrium humidity with that in the storage room. The moisture content of the media before storing the seeds was 7% for sawdust and 13% for charcoal. The seeds were extracted, washed thoroughly, dipped into a fungicide solution of 'Benlate' 2 ml/l water for 2 minutes, and put in the media.

The trays with seed were stored at room temperature (1) for 28 days; (2) for 21 days; (3) for 14 days; (4) for 7 days. The control treatment (0 days) was sown immediately. For germination measurement each treatment combination consisted of 6 seeds and 3 replications, while 3 seeds and 3 replications were used for fresh and dry weight observation of seeds after storage.

After storage the seeds were planted in a mixture of soil and sand in equal parts. The mixture was prepared by putting it into an oven at 80 °C for three days. It was then put into polybags of 10 cm in diameter and 15 cm in height. In each polybag a single seed was planted, buried at 1 cm depth. The bags were kept in a glasshouse. Natural light was used with a temperature ranging from 23 - 29 °C and a relative humidity between 75 - 85%. The seeds were watered daily during the first week and once every three days thereafter. After planting the variables observed were germination rate, germination percentage, time of emergence of rudimentary root and of the scale leaf and number of leaves and leaf area per plant. Germination rate was calculated according to the formula by Copeland (1976):

$$GS = \frac{A_1T_1 + A_2T_2 + \ldots\ldots A_xT_x}{(100)\,(A_1 + A_2 + \ldots\ldots A_x)}$$

in which

GS	germination rate (in days)
A	number of seeds germinating
T	time corresponding to A
X	number of days to final count.

Germination percentage was determined by dividing the number of germinating seeds by the number of seed sown. Germination was defined to occur when the cotyledonary sheath grew up to about two mm length from the seed (see Plate 4).

The collected data were analysed using a complete randomized design model according to Steel and Torrie (1980).

Results

Seed water content. There was no interaction between medium and storage period on seed moisture; therefore the effects of both factors are presented separately in Table 4.5. Averaged over the range of storage periods, the water content of seeds differred significantly for the media, although the differences were small in absolute terms. Seed stored in ambient air lost most moisture; seed in charcoal retained more moisture than that in sawdust. The initial moisture content of the seed was high, about 60%. Averaged over the storage media, nearly half the moisture was lost within 28 days, by far the greatest loss occurring during the first 7 days of storage.

Germination rate. The effects of storage duration were highly significant for all three media (Table 4.6). In general, storage in air retarded germination more as the storage period was extended. The seeds stored in air for 28 days did not germinate at all. The seeds stored in charcoal germinated faster than seeds stored in sawdust.

Germination. Germination was best when the seeds were sown directly after extraction from the fruit (Figure 4.3). Whereas the viability of seed stored in sawdust and charcoal only dropped after 3 and 4 weeks of storage, only about 60% of seeds stored for one week in ambient air germinated and seed stored for 4 weeks did not germinate at all. Charcoal proved a better medium than sawdust for storage during 3 and 4 weeks, although for seed stored 4 weeks the difference was not significant.

Table 4.5. Mean water content of seed stored in different media for 0 - 4 weeks, analysis of data after transformation to the arc.sin √% (Steel and Torrie, 1980).

Treatments	Water content (%)
Media :	
Ambient air	39.0 a
Sawdust	43.3 b
Charcoal	45.3 c
Period of storage (days) :	
0	60.4 e
7	43.5 d
14	39.6 c
21	35.9 b
28	33.3 a

Means in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

Table 4.6. The germination rate of the seeds after storage in different media and for different periods of time, in days.

Storage period (days)	Ambient air	Sawdust	Charcoal
0	11.5 a	11.5 a	11.5 a
7	16.9 b	15.0 b	13.5 b
14	18.4 bc	16.5 bc	16.0 c
21	20.4 c	18.0 c	16.4 c
28	-	19.2 c	17.5 c

Means in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

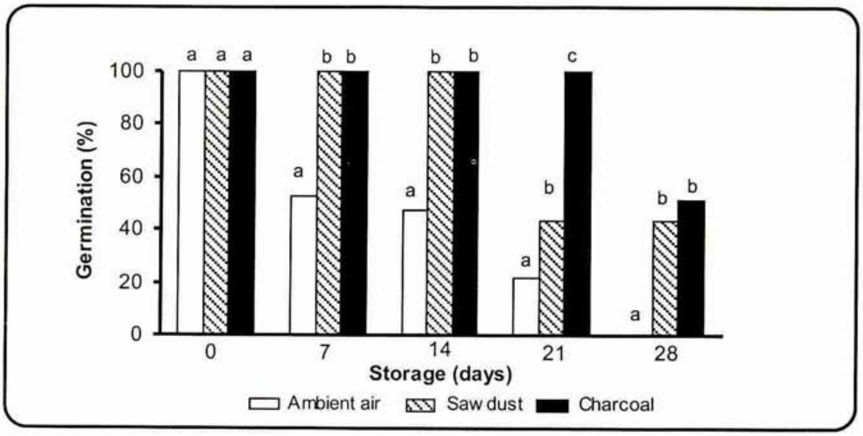

Figure 4.3. The germination percentage after different storage periods of seeds in ambient air, sawdust or charcoal, data transformed to √% (Steel and Torrie, 1980).

Columns bearing the same letter are not significantly different at P = 0.05.

Table 4.7. Emergence of rudimentary roots, in days after sowing; analysis of data transformed to √(x + ½) (Steel and Torrie, 1980).

Storage period (days)	Rudimentary root emergence (days)		
	Ambient air	Sawdust	Charcoal
0	20.3 a	19.7 a	20.3 a
7	27.3 b	25.0 b	24.3 b
14	29.7 b	27.3 bc	26.7 bc
21	30.3 b	28.3 c	28.0 cd
28	-	29.7 c	29.0 d

Means in a column followed by the same letter are not significantly different at Duncan's Multiple Range Test 5%.

Emergence of the rudimentary roots. The rudimentary root emerged earlier when seeds were sown directly (Table 4.7). The time needed was approximately 20 days. When the seeds had been stored longer, it took longer for the roots to be formed. The delay in emergence of the rudimentary root of seeds stored for 21 days was approximately 10 days for ambient air and 8 - 9 days for sawdust and charcoal; the differences between these two media were small.

Emergence of the scale leaf. Like the rudimentary root, the scale leaf emerged faster when the seeds were directly sown than after storage. The seeds without storage showed growth of the scale leaf around 32 days after sowing, but when the seeds had been stored for 7 to 28 days, the growth of the scale leaf was delayed, in particular after storage in air (Figure 4.4). The growth of the scale leaf after seed storage in both sawdust and charcoal was similar.

Leaf numbers and area. The number of leaves and the leaf area per plant for seedlings which had been growing for 100 days are presented in Table 4.8. The majority of the seeds which had been sown without storage grew into plants with 2 leaves within 100 days. One week storage in ambient air sufficed to limit growth to a single leaf, but 1 week storage in sawdust still gave a fair proportion of seedlings with 2 leaves and in charcoal there were some plants with 2 leaves even after 2 weeks of seed storage.

From the leaf areas in Table 4.8 it is clear that prolonged storage had adverse effects. Moreover, the single leaf of seedlings remained smaller if the seeds had been stored longer, particularly after storage in ambient air. In treatment combinations in which the seedlings had more than one leaf on average, the mean area per leaf worked out to about 50 cm^2. That was considerably smaller than leaf size of the best treatment combinations with only single-leafed plants (63 - 64 cm^2). This suggests that in plants with more than 1 leaf the higher rate of leaf production had limited the size of the first leaf.

Discussion

The results show that storage for 1 week or longer had adverse effects on all measured variables. After 2 weeks of storage in sawdust and charcoal all seeds still germinated, but the rate of growth and development was reduced after a storage period of 1 week, in these treatments as well, as evidenced by retarded germination (perhaps due to the time required to rehydrate the seeds before germination could start), and delayed emergence of the rudimentary root and the ligule. This reduced rate of growth persisted; it was still noticeable after 100 days in the number of leaves and leaf area per plant. This effect was similar to that of removal of half the endosperm in the previous experiment (Chapter 4.1).

Inter alia it is interesting to note that the rate of growth of the seeds planted without storage was much better than in Chapter 4.1. For the seeds in the growth chamber it took 126 days before the first bladed leaf had matured. Under the favourable growing conditions in this experiment most plants from freshly sown seed had formed a second leaf within 100 days!

Storage in sawdust and particularly in charcoal greatly improved survival and growth after planting in comparison with storage in ambient air, but the reduction in the rate of growth with each extra week of storage remains a serious shortcoming of these media.

The findings suggest that the worsening results after prolonged storage are closely correlated with seed moisture content at the time of planting. Salak seeds rapidly lose

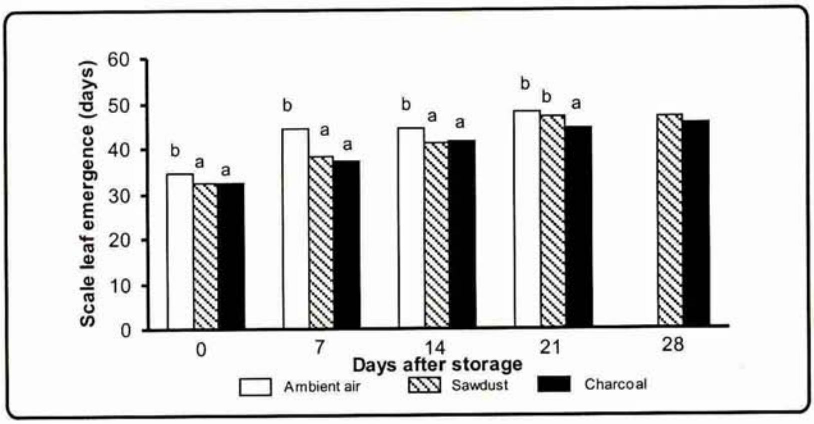

Figure 4.4. Time of emergence of the scale leaf after different seed storage treatments.
Columns bearing the same letter are not significantly different at P = 0.05.

Table 4.8. Number of leaves and leaf area (cm²) per plant, 100 days after planting; analysis of data after transformation to √(x + ½) (Steel and Torrie, 1980).

Storage period (days)	Ambient air		Sawdust		Charcoal	
	Number	Area	Number	Area	Number	Area
0	1.6	81 fg	1.6	86 g	1.7	85 g
7	1.0	64 def	1.4	72 fg	1.6	74 fg
14	1.0	37 bc	1.0	63 def	1.2	67 ef
21	1.0	34 b	1.0	53 de	1.0	56 de
28	0.0	0.0 a	1.0	49 cd	1.0	51 d

Means which have a letter in common are not significantly different at Duncan's Multiple Range Test 5%.

moisture, especially during the first week of storage. Nearly 50% of seed moisture was lost after 28 days in storage. The initial seed water content was so high, i.e. about 60% of total seed weight, that substantial moisture losses in storage are to be expected, contributing to the recalcitrant character of salak seed.

Sawdust and charcoal help to preserve viability of stored seeds; charcoal gave better results than sawdust. This may be due to the ability of charcoal to absorb water vapour from the surrounding air. Charcoal had 13% of moisture while sawdust had only 7%. Moreover, perhaps the fine charcoal particles ensured a closer contact between seed surface and medium than sawdust. The higher humidity around the seeds in media containing 7 - 13% moisture may have been able to delay irreversible dehydration of seeds (by limiting transpiration). Charcoal and sawdust can be used to store the seeds for as long as 21 days before planting. This should be long enough to allow for long distance transport. Other variables showed similar responses to duration of storage and the corresponding loss of water. Thus high seed water content is important for successful germination of salak.

According to Agrawal (1986) there are two important factors during storage, i.e. relative humidity of the atmosphere and temperature. Seeds will attain a characteristic moisture content at a given relative air humidity (RH) and temperature: the equilibrium moisture content. Rice and sunflower are examples of orthodox seeds. At RH between 75 and 90%, seeds have a moisture content of 14.4 to 18.4% for rice and 8.0 - 15.0% for sunflower at room temperature. During this experiment the RH values ranged from 75 to 81%. After 28 days storage in ambient air all seeds were killed, and the germination percentage dropped sharply even after 7 days. This result is very different from that reported for the orthodox group (Agrawal, 1986), but is in accordance with Schuiling and Mogea (1991) who reported that after a week in storage 50% of salak seeds lost their viability; after two weeks of storage all seeds were unable to germinate. Dickie et al. (1993) reported that palm seed cannot withstand desiccation, therefore seed banks and cryopreservation will pose problems. All of this supports the conclusion that salak seed is recalcitrant.

The media should be able to hold water permanently. Therefore, it is important to investigate the equilibrium between media water content and relative humidity in the storage room in combination with room temperature. Evaporation is mainly determined by humidity and temperature. Temperature during seed storage strongly influenced the germination of *Chrysalidocarpus lutescens* (Broschat and Donselman, 1988). No seed stored at 5 °C germinated, but the germination percentage remained above 50% for 420 days when seed was stored at 23 °C. The species belongs to the palm family and exhibits a recalcitrant seed character.

It is also necessary to experiment with different particle sizes of the storage media, because presumably the finest particles protect the seed more effectively. This may also lower the rate of seed respiration by reducing the supply of oxygen. One of the methods to store seeds of the orthodox group is to put them in sealed tins under low air pressure. This also reduces seed respiration.

Recently, a method of seed preservation based on ultra-drying was developed in China and the United Kingdom (Anonymous, 1990b). But also this technique was mainly designed for orthodox seeds. Appropriate technology for recalcitrant seeds is not readily available. In Malaysia, a method has been developed to preserve recalcitrant seed (Anonymous, 1990b). Excised embryos of jackfruit, dried to 8% moisture content, still germinated (80%). It may be worthwhile to test this technique on seeds of monocotyledons, such as salak.

Conclusions

1. Salak seed is recalcitrant. The seed has a high moisture content which rapidly drops in ambient air, associated with reduced viability: after 1 week of storage only 60% germinated, after 4 weeks germination failed completely.
2. Storage in sawdust (7% moisture) and in particular in charcoal (13% moisture) greatly improved germination and growth rate of the seedlings, but nevertheless every extra week of storage in these media reduced the rate of growth; 100 days after planting this was still reflected in lower numbers of leaves and a smaller leaf area per plant.
3. There is a close correlation between seed moisture content and successful germination.
4. Further research is needed, first to improve preservation of moisture and second to explore other approaches to successful long storage.