Plant Resources of South-East Asia

No 9

Plants yielding non-seed carbohydrates

M. Flach and F. Rumawas (Editors)

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Foreword

A large majority of the world's 800 million food-insecure people live in rural areas and are directly or indirectly dependent on agriculture for their incomes and food. Plants yielding non-seed carbohydrates are a major source of food energy for humans and animals in general and for low-income, food-insecure people in particular. Most of these plants, including a large share of the root and tuber crops, are grown at subsistence level in the tropics and they are consumed fresh. These crops are important for household and national food security, both in terms of providing a large share of the needed food energy and for reducing fluctuations in poor people's access to the required food. In spite of their importance, they have received relatively low priority in agricultural research, development, and policies. As shown in this volume, these crops have the ability to produce substantial amounts of useful energy per unit of land and per unit of time. This potential is not fully realized because of the failure to undertake the necessary research and to disseminate available research results to farmers and the processing industry.

Hopefully, the content of this volume will make policymakers recognize the importance of increased emphasis of both public and private-sector programmes to enhance yields and production of plants yielding non-seed carbohydrates, including crop improvement research, and more appropriate food and agricultural policies. It is essential that such efforts consider the complete production, storage, transportation, and marketing system as well as the impact on people's food security and nutrition.

The Board and personnel of the PROSEA foundation are to be congratulated on this comprehensive state-of-art overview of plants yielding non-seed carbohydrates. It is the result of the collective effort of an international group of scientists. I hope that this volume will be instrumental in triggering additional recognition and support for these crops, including more research and development and better policies.

Washington, D.C., December 1995

P. Pinstrup-Andersen
Director General
International Food Policy Research Institute (IFPRI)

1 Introduction

1.1 Definition and species diversity

The plants yielding non-seed carbohydrates have been brought together into one group based on their main product: carbohydrates. Pulses and cereals that store starch in their seed have been excluded. They are dealt with in Prosea volumes 1 and 10, respectively. The plants considered in this volume produce and often also store carbohydrates, i.e. starches and/or sugars, as a reserve plant food. The starches and sugars form the main source of food energy for both humans and animals and – especially starches – are useful as a basic material for industry.
In terms of starch production, the starch crops are interchangeable. They have an approximately equal value as food, feed and also as industrial raw material, but may differ importantly in quality.
The same holds for the sugar-producing crops. The source of refined sucrose can only be deduced from impurities present in the sugar. Starch crops may be substituted for sugar crops to a certain extent because plants can convert starches into sugars. A few of the tapped palms, e.g. sugar palm (*Arenga pinnata* (Wurmb) Merrill) are able to convert starch into sugar on an appreciable scale. This conversion can also be done in industrial processes, e.g the high-fructose syrup (HFS) production process. Although plants may convert sugar into starch, it is not yet possible to do so on a large scale, either by exploiting plants or by means of industrial processes.
The major crops in the group include annuals and perennials. The annual crops store starch in their roots or tubers. Of the perennial genera, one palm genus (*Metroxylon* Rottboell) stores starch in the trunk, to be converted into sugar for development of the inflorescence. Although most sugar-producing palm genera usually store some starch in the trunk, most of the sugar is produced directly for growth and development of their inflorescences. One genus (*Musa* L.) stores starch first in the stem, for use later for both starch and sugars in the fruits. And one genus of the grass family (*Saccharum* L.) stores sugar in its stem.
This commodity group is very diverse. It contains monocotyledons as well as dicotyledons, from different families. The underground storage organs mostly vary from roots to tubers and stolons. The aboveground storage organs are mostly stems, more rarely trunks, and fruits. In this volume 54 important species are dealt with comprehensively in 33 papers. In addition, about 50 species that are minor producers of non-seed carbohydrates are described briefly in Chapter 3, and 107 with another primary use are listed in Chapter 4. The important species with another main use include breadfruit (*Artocarpus altilis* (Parkinson) Fosberg) and coconut (*Cocos nucifera* L.). Breadfruit (see Prosea 2) is a major staple crop on a number of Pacific islands, and coconut palm is an oil crop (see Prosea 14) which is also widely tapped for sugar.

1.2 Role of plants yielding non-seed carbohydrates

1.2.1 Geographic distribution

Most of the crops described in this volume have been cultivated since time immemorial. All the palms in the group have been domesticated in South-East Asia. The root and tuber crops have been domesticated there too, with a few notable exceptions such as the Irish potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas* (L.) Lamk) and cassava (*Manihot esculenta* Crantz), which were domesticated in Central and South America. Sweet potato is an old introduction (15–16th Centuries), cassava was introduced into South-East Asia some 200 years ago, but Irish potato has been introduced more recently. Cassava has been very successful and is now a common crop. Irish potato is quickly growing in importance in the tropics. At present, both crops are well dispersed throughout South-East Asia. Other crops originating outside the region include xanthosoma (*Xanthosoma* spp.) and some yams (*Dioscorea* spp.).

Outside South-East Asia the dispersal of sugar cane (*Saccharum officinarum* L.) is closely interwoven with the history of the slave trade, especially in Central and South America. Nipa palm (*Nypa fruticans* Wurmb) is now also found in West Africa. It was planted in the coastal belt of Nigeria in the 1940s. Sago palm (*Metroxylon sagu* Rottboell) was brought to West Africa and Central America in the 1980s for research purposes.

The present distribution of the main crops yielding non-seed carbohydrates over developing and industrialized countries is presented in Table 1. The dis-

Table 1. Distribution of the production (in weight and energy) of the main crops yielding non-seed carbohydrates, over developing and industrialized countries in 1992 (Sources: FAO, 1993; Flach, 1983).

Crop	World			Developing countries		Industrialized countries	
	$\times 10^6$ t	$\times 10^{12}$ kJ (edible portion)	% of total energy	% of total production	% of total energy	% of total production	% of total energy
Cassava	152.2	812.3	19.6	100.0	19.6	0.0	0.0
Irish potato	268.5	718.9	17.3	31.2	5.4	68.8	11.9
Sweet potato	128.0	539.5	13.0	98.4	12.8	1.6	0.2
Taro	5.6	22.6	0.5	92.9	0.5	7.1	0.0
Yam	27.8	103.3	2.5	99.3	2.5	0.7	0.0
Plantain	26.8	85.1	2.1	100.0	2.1	0.0	0.0
Sago palm (starch)	5.0	8.4	0.2	100.0	0.2	0.0	0.0
Sugar cane	1104.6	1855.7	44.8	93.1	41.7	6.9	3.1
Total		4145.8	100.0		84.8		15.2

Note: for percentage edible portion and energy content edible portion, see Table 6.

tinction into developing and industrialized countries does not follow the climatic zones exactly, but most developing countries are either tropical or subtropical. Despite its limitations, Table 1 presents an acceptable estimate of the distribution of the crops over the tropics and subtropics as compared with the rest of the world.

Table 1 also presents production in terms of weight and in energy, as the crops differ considerably in energy content. Only the edible part was considered when determining the energy content. In energy terms, sugar cane is the most important in the whole world, cassava is second, Irish potato a close third, and sweet potato a close fourth. All other crops are far less important. If only the developing countries are considered (in energy terms), the picture changes: sugar cane remains the first, cassava remains second, but sweet potato becomes third, Irish potato fourth and yam fifth, just before plantain. It is remarkable that Irish potato has achieved the fourth place in the tropics in recent years.

In total, the crops yielding non-seed carbohydrates provide food for an estimated 15% of the world population, compared with only 10% of the population in the tropics.

1.2.2 Area and production

The area under the crops and their production and yield over the countries in South-East Asia are presented in Table 2.

The FAO statistics on the crops yielding non-seed carbohydrates are less than satisfactory. Many of these are only smallholders' crops and are therefore overlooked by the enumerators. The statistics are sometimes dubious. For example, they show that Indonesia (and thus the Indonesian part of New Guinea) does not produce any taro and yam, but the half of New Guinea that is part of Papua New Guinea, produces quite a lot! It is also remarkable that plantains and cooking bananas feature little in South-East Asia except in Burma (Myanmar). Yet according to the statistics, that country does not produce dessert bananas! The production of plantains and other cooking bananas is estimated to be 40% of the total production of bananas (Valmayor & Wagih, this volume).

1.2.3 Nutritional aspects

There is a widespread misconception that the consumption of the crops yielding non-seed carbohydrates as a staple food leads to nutritional problems, especially with respect to the protein requirements of humans. In Table 3 the main constituents on a dry-matter basis of a number of these crops have been compared with rice. Except for cassava, sago palm, plantain and of course sugar cane, the crops contain a reasonable amount of protein. The protein content is highest in crops whose harvested produce may also be used for vegetative propagation.

If functional, structural and storage proteins are distinguished, the picture improves even more. Functional proteins, which are found in the contents of live cells, are the most nutritious. Their quality approaches that of animal protein. Structural proteins are found in cell wall material. They are also of good quality, but are usually difficult to digest. Storage proteins are usually of inferior quality. They are hardly found in the plants yielding non-seed carbohydrates.

Table 2. Area, production and yield of crops yielding non-seed carbohydrates in South-East Asia in 1992 (Source: FAO, 1993).

Crop	Burma (Myanmar)	Cambodia	Indonesia	Laos	Malaysia	Papua New Guinea	Philippines	Thailand	Vietnam	South-East Asia	World
Area (× 1000 ha)											
Cassava	5	13	1 333	5	41	11	160	1 442	278	3 288	15 757
Irish potato	15	.	41	5	.	.	6	1	30	98	18 031
Sweet potato	5	9	229	14	4	105	136	10	348	860	9 262
Taro	.	.	.	.	.	32	33	5	.	70	993
Yam	.	.	.	.	.	12	7	.	.	19	2 803
Plantain	.	.	.	.	.	.	.	.	.	.	.
Sugar cane	53	5	291	3	20	7	330	915	143	1 767	17 934
Production (× 1000 t)											
Cassava	48	64	16 318	67	430	113	1 320	21 130	3 000	42 490	152 218
Irish potato	154	.	554	35	.	.	67	12	290	1 112	268 492
Sweet potato	29	37	2 172	105	44	475	670	100	2 110	5 742	128 016
Taro	.	.	.	.	.	217	112	56	.	385	5 607
Yam	.	.	.	.	.	220	29	.	.	249	27 814
Plantain	245	.	.	.	.	.	.	.	.	245	26 797
Sugar cane	2 400	240	23 121	94	1 125	450	27 300	46 805	5 900	107 435	1 104 580
Yield (t/ha)											
Cassava	10.5	4.9	12.2	13.4	10.5	10.7	8.3	14.7	10.8	12.9	9.7
Irish potato	10.4	.	13.5	7.0	.	4.5	11.8	9.2	9.7	11.3	14.9
Sweet potato	5.4	4.1	9.5	7.3	12.0	4.5	4.9	9.7	6.1	6.7	13.8
Taro	.	.	.	.	.	6.7	3.4	11.0	.	5.5	5.6
Yam	.	.	.	.	.	17.8	4.0	.	.	13.1	9.9
Plantain	.	.	.	.	.	.	.	.	.	.	.
Sugar cane	45.3	48.0	79.6	28.7	56.3	66.2	82.7	51.2	41.3	60.8	61.6

Table 3. The main constituents per 100 g edible portion in the main crops yielding non-seed carbohydrates, as compared with rice (based on Platt, 1971).

Crop	dry matter (%)	dry-matter basis				energy (kJ)
		carbohydrates (%)	protein (%)	fat (%)	fibre (%)	
Cassava	40	92.5	1.8	0.5	2.5	643
Irish potato	20	85.0	10.0	trace	2.0	315
Sweet potato	30	85.8	5.0	1.0	3.3	479
Taro	30	85.8	6.6	trace	1.7	475
Yam	27	88.8	7.4	0.7	1.9	437
Plantain	33	93.0	3.0	0.6	0.9	538
Sago palm (dry starch)	100	92.5	1.5	0.5	1.5	1680
Sugar cane (white sugar)	100	100.0	0.0	0.0	0.0	1680
Rice	88	88.6	8.0	0.9	0.2	1478

In young storage organs both the functional and structural proteins are usually already present, and therefore these organs have a higher percentage of good quality protein. In older storage organs the starch content increases, which leads to a relative decrease in protein.

Thus, provided care is taken to eat a balanced diet, these crops are fully acceptable as a human food.

Refined sugar is almost exclusively comprised of carbohydrates. But, as shown in Table 4, unrefined sugar (jaggery) may contain other nutritious compounds. These and other compounds are also found in sap tapped from the inflorescences of palms (Table 5), and in palm wine and in the vinegar derived from it, but are almost completely absent from the distilled product.

Sometimes, other parts of the crops are consumed too. The leaves of root and tuber crops, especially of the *Araceae*, cassava and sweet potato are often used as a vegetable, thus supplying valuable protein. Banana flowers are also used

Table 4. Composition of unrefined sugar or 'jaggery' from sugar cane, coconut palm, toddy palm and *Caryota urens* (Source: The wealth of India 9, 1972).

	sugar cane	coconut palm	toddy palm	*Caryota urens*
moisture (%)	3.9	10.3	8.6	9.2
protein (%)	0.4	1.0	1.0	2.3
fat (%)	0.1	0.2	0.1	0.1
carbohydrates (%)	95.0	83.5	88.5	84.7
mineral matter (%)	0.6	5.0	1.8	3.7
Ca (mg/100 g)	80	1638	225	1252
P (mg/100 g)	40	62	44	372
Fe (mg/100 g)	11.4	•	•	•

Table 5. Chemical composition of sap tapped from the inflorescences of palms. For comparison the sap from tapping the trunk of oil palm is also given. Compiled and recalculated from various sources.

	sugar palm	toddy palm	nipa palm	coconut palm	oil palm
dry matter (g/l)	140–180	•	170–180	150–200	100–190
sucrose (g/l)	130–170	100–150	130–180	120–180	70–170
reducing sugars (g/l)	•	6–10	7–9	7–10	4–11
protein (g/l)	•	1	•	1–6	1.3
fat (g/l)	•	•	•	0.4	•
ash (g/l)	2–4	2	4–5	1–4	4
N (mg/l)	410	•	360	300–510	1000–2000
P (mg/l)	10	•	110	60–100	6–7
K (mg/l)	1200	•	1900	1200–2000	100–130
Ca (mg/l)	10	•	60	10–20	120–160
Mg (mg/l)	100	•	30	30–50	160–190
pH	8	6.5	7.5	7.2	6.6–7.4

as a vegetable. The growing point of a number of palms is eaten as palm cabbage.

1.2.4 Quality aspects

Very little needs to be said about the quality of sugar. Sugar is largely comprised of sucrose, a compound molecule which can be split into two molecules, fructose and glucose, the reducing sugars. Refined sugar consists solely of sucrose. Its source can only be recognized from cell remains in the sucrose, thus only by means of impurities.

The quality of starch is another matter. Starch is a polysaccharide, a glucose polymer with a high molecular weight. Various factors affect starch quality:

- *Size of the starch grains.* Large starch grains settle faster than smaller ones. Usually, the starch grains of younger plant parts are smaller than those of older ones: to a certain extent the starch grains increase in size with age. Small starch grains are easier to digest than larger ones.
- *Amylose versus amylopectin.* Starches contain some amylose, a non-branched polymer, and the rest is amylopectin, a branched polymer. Amylose is soluble in water and turns blue in the presence of iodine. Amylopectin is insoluble in water and turns brown in the presence of iodine. When gelatinized at high temperatures amylopectin yields a paste of a certain viscosity, which retrogrades with time. Gelatinization temperature, maximum viscosity and speed of retrogradation are the main factors determining the industrial uses of the starch.
- *Purity of the product.* Starch, especially starch for industrial purposes, should be white and clean and free from impurities. This purity depends on the washing process and thus also on the purity of the water used.
- *Erosion of starch grains.* Starch grains kept too long in water may erode irregularly because of microbial activity. This reduces the quality.

The properties of starch can be represented diagrammatically in an amylograph. In general, it can be said that all starches are economically valuable, provided they are pure and are produced in sufficiently large batches of constant quality. Only then are they of interest to the starch industry. If the starches are impure, or if the batches fluctuate in quality, they will fetch a lower price on the international starch market. This does not necessarily apply to starches that are converted into food products or high fructose syrup.
Inulin, the main carbohydrate in the Jerusalem artichoke (*Helianthus tuberosus* L.) cannot be digested by man, except when broken down by micro-organisms in the rectum. Hence its importance for diabetics, which in turn has led to the confusion with insulin, a hormone from the pancreas necessary to metabolize sugar in the human body.

1.2.5 Other uses

Palm leaves are often used for roofing. The leaves of the true sago palm are the best. If properly prepared and handled they may last for some twelve years. The leaves of the nipa palm are second best. They may last up to eight years. The long rachides of these two palms may be used to construct walls. The leaves of the toddy palm (*Borassus flabellifer* L.) may be used as well, but the fan leaves cannot easily be made into proper thatch ('atap'). The leaves of sugar palm and of coconut are only occasionally used as roofing, e.g. for livestock sheds. They are much less durable.
Palm wood can be very hard and thus durable. Only the outer bark of sago palm and of sugar palm is used, often as flooring. The wood of the toddy palm is reasonably durable.
Fruits of the sugar palm are irritating to the skin, even though they are eaten as a candy. Fruits of toddy palm can be used in the same way as those of coconut. Fruits of the sago palm are only used for ornamental purposes. Those of the nipa palm are hardly used at all.

1.2.6 Average and actual yield levels

In Table 6 the average world yields of the most important tropical crops yielding non-seed carbohydrates are presented, and compared with the high yields found in the literature. The common names of the crops are given, together with the literature reference for the high yield figures (column 1) and the reported high yields per crop combined with the number of days in which these were obtained (column 2). To facilitate comparison, these yields have been expressed in kiloJoules edible portion per ha and per day (column 5), using the tables compiled by Platt (1971) (columns 3 and 4). The average yields of the most important crops in 1992 have been taken from the FAO Production Yearbook (FAO, 1993), and the cropping period has been estimated (column 6). The average world yield of each crop per ha and per day of cultivation has been determined (column 7) using the same procedure as was used for the high yields.
This calculation procedure has some severe limitations. The world yields presented by FAO are averaged from highly divergent figures. The estimates of the duration of growth (column 6) are of limited value, as the duration of growth of a crop may vary greatly. Furthermore, the figures given by Platt are

Table 6. High experimental yields and average world yield in 1992 of some crops yielding non-seed carbohydrates, compared with rice.

1	2	3	4	5	6	7
Crop (Literature reference)	Reported high yield per ha in number of days	% edible portion	Food energy in kJ per kg edible portion	High yield (edible portion) in 10^3 kJ per ha per day	Average world yield per ha in number of days (in 1992)	Average world yield (edible portion) in 10^3 kJ per ha per day
Cassava (CIAT, 1969)	100 t roots in 305 days	83	6430	1750	9.7 t in 330 days	157
Irish potato (Kooman et al., 1995)	45 t tubers in 105 days	85	3150	1147	14.9 t in 120 days	332
Sweet potato (IITA, 1976)	43 t tubers in 122 days	88	4790	1486	13.8 t in 135 days	431
Taro (Plucknett et al., 1971)	129 t tubers in 365 days	85	4750	1427	5.6 t in 120 days	188
Yam (Rehm et al., 1976)	60 t tubers in 275 days	85	4370	810	9.9 t in 280 days	131
Plantain (Purseglove, 1972)	75 t fruits in 365 days	59	5380	652	12.5 t in 365 days	109
Sago palm (Flach, 1977)	25 t dry starch in 365 days	100	16800	1151	5.0 t in 365 days	230
Sugar palm (Smits, this volume)	25 t raw sugar in 365 days	100	14740	1010	5.0 t in 365 days	202
Sugar cane (Husz, 1989)	160 t cane in 300 days	10	16800	896	61.6 t in 270 days	383
Rice (IRRI, 1987)	7 t rice in 90 days	70	14780	805	3.6 t in 100 days	372

of limited value. For instance, young roots and tubers usually contain less dry matter than older ones, thus the amount of kiloJoules of the edible part may vary with age.

The calculation procedure is only valid for regions where crops can be grown throughout the year, i.e. tropical and subtropical regions with sufficient water. Soil preparation has been ignored, yet this appears to increase in importance as the cropping period becomes shorter. For instance, three crops of Irish potato may be grown in one year, but plantain and palms may occupy the same land for a number of years. Moreover, the palms have a long unproductive period: neither sago palm nor sugar palm start producing until after at least 8 years. Sago palm continues to produce for perhaps up to 40 years without replanting, whereas sugar palm produces for 3–4 years and then needs to be replanted.

Despite these limitations, Table 6 suggests some general trends. Root and tuber crops produce much more bulk than rice, but mainly because of their high water content. Their nutritional value in terms of energy amounts to approximately 30% of that of rice per unit of weight of the edible product.

All starch crops except for Irish potato and sweet potato have approximately the same average world yield (in energy terms) per ha per day (column 7). The rather high average world yield of Irish potato is caused by this crop's high yields in the temperate zone, where both breeding and cultivation are of a high standard. Sweet potato shows an even higher average world yield, probably thanks to the high yields in the United States, mainland China and Japan.

The average world yields of the sugar crops approach the yields of sweet potato and Irish potato. Palms do well, especially considering that they receive little attention in terms of research for cultivation and breeding. But the long unproductive period reduces average production.

The highest experimental yields in the crops shown in Table 6 are of the same order of magnitude, with the exception of plantain and yam, which yield much less.

1.2.7 Potential yield levels

If the other conditions are optimal, the dry matter production of a crop is determined by photosynthesis and thus by sunlight. In the tropics, temperature is more important for respiration than for photosynthesis. The gross potential dry matter production, assuming a half overcast sky, may be estimated at roughly 275 kg carbohydrate equivalents per ha and per day. This equals 46.10^5 kJ ha^{-1} day^{-1}. However, net food production is much lower, because of the following factors:

- The crop canopy does not close immediately, and therefore the use of sunlight is not optimised. This can be remedied to some extent by spacing the plants more closely.
- Nocturnal respiration uses up part of the carbohydrates.
- The edible percentage of the dry matter produced varies between the crops. In cereals, a maximum of 40% of the dry matter produced is edible. Some 50% is needed by the aboveground structure that carries the edible product and the remaining 10% is used for the root system. It may be possible to change this pattern somewhat by breeding in favour of the edible dry matter,

but it will never reach the 80% of edible dry matter attained by the root and tuber crops. The root and tuber crops produce the edible dry matter in the soil and thus do not need an elaborate aboveground structure to carry it. It may thus be assumed that the potential yield of edible dry matter of the root and tuber crops is twice that of the cereal crops.

The average yields in the world and the high experimental yields (energy terms) in Table 6 have been combined in Figure 1. The average net potential production of dry matter has been estimated as about 23.10^5 kJ ha^{-1} day^{-1}, which is half the gross potential production. The distribution pattern of the dry matter has been estimated at its theoretical maximum. For plantain, the palms and sugar cane the distribution pattern has not been estimated in Figure 1.

These rough estimates are open to the following criticisms. Firstly, the crops differ in photosynthetic efficiency. Sugar cane, being a C4 plant, has a higher photosynthetic efficiency than rice, especially at higher temperatures. This means that sugar cane can produce better than the other crops, especially at higher levels of irradiation. All the other crops are C3 plants, like rice, and have approximately the same photosynthetic efficiency. Secondly it is not known whether the pattern of dry matter distribution is comparable within each group of crops. The root and tuber crops in particular may contain discrepancies, and even less is known in this respect about plantain, palms and sugar cane.

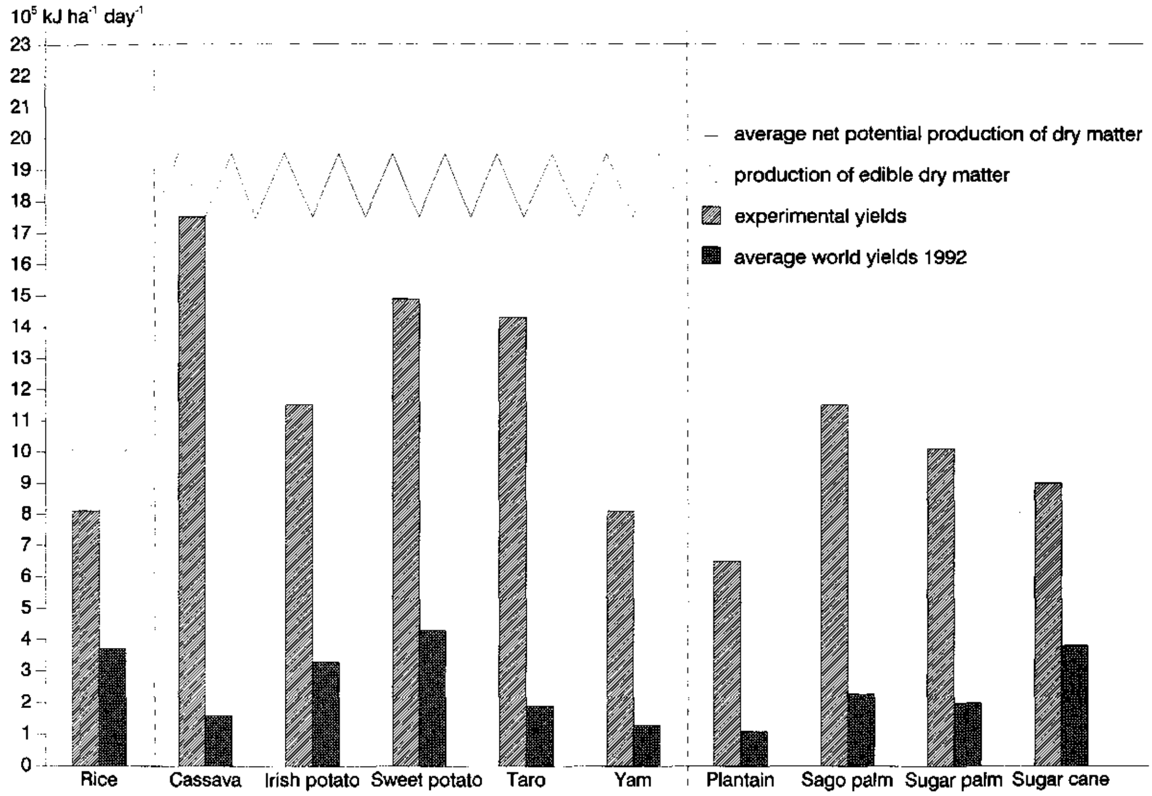


Figure 1. Average world yields (1992), maximum yields obtained in selected experiment stations in the tropics, and potential production of edible dry matter as compared with estimated net potential production of total dry matter for a number of tropical food crops in kJ per ha and per day.

These estimates of the highest possible yields are not absolute maxima. First, yields may be considerably higher in exceptionally favourable regions, where a lesser cloud cover is supplemented by ample water.
The figure clearly shows that the root and tuber crops have a far higher yield potential than cereal crops. And some root and tuber crops, especially yam, lag far behind in breeding (as does plantain). Improved cultivation techniques for palms could produce surprising results.

1.2.8 Root and tuber crops compared with cereals

The main advantage of root and tuber crops over the cereals is thus the partition of the dry matter production. They are able to produce twice as much useful dry matter as cereals. But this yield potential is not realized because research results are not disseminated adequately.
Cereals, however, have a distinct advantage because of their low (about 12%) water content, which facilitates their storage and transportation. Root and tuber crops with a moisture content of 60–80% are difficult to transport and can only be stored reasonably well if they have a dormant period, found only in Irish potato and in certain yams.

1.2.9 Perennial crops

Plantains and palms probably have a less advantageous partition of dry matter than root and tuber crops. But these perennial crops have a distinct agronomic advantage over annual crops: they remain in place for long periods. Tillering palms and plantain may be permanent land cover, and as such have an ecological advantage comparable to forest. On the other hand, these crops all have an unproductive period, during which they become established. This period may last 8 years in sago and sugar palms.
Sugar cane is actually a perennial, but is usually grown as an annual crop. Thanks to detailed knowledge of its agronomy it can be grown continuously as a monocrop on the same piece of land. It is usually grown as a ratoon for a number of years and replanted when yields become unsatisfactory.

1.2.10 Sweetening agents of plant origin

Sugar is the ideal sweetener, because it easily dissolves in water, its sweet taste has no unpleasant effects of bitterness or saltiness, and it is rather cheap. It shows, however, considerable disadvantages. For instance, it is a major cause of dental decay and it contributes to obesity. Therefore, there has been a continuing search for sweetening agents that are low in energy value and even more sweet than ordinary sugar. There are some artificial sweeteners like saccharin (300–500 times as sweet as sucrose), cyclamate (30 times as sweet as sucrose), and aspartame (100–200 times as sweet as sucrose) (Fox & Cameron, 1977).
The following sweetening agents of plant origin are found in the following plants (Fox & Cameron, 1977; Rehm & Espig, 1976):

- miraculin, in the fruits of *Richardella dulcifica* (Schum. & Thonn.) Baehni (syn. *Synsepalum dulcificum* (Schum. & Thonn.) Daniell), which is able to make sour-tasting food taste sweet;

- monellin, in the fruits of *Dioscoreophyllum cumminsii* (Stapf) Diels, which is 3000 times sweeter than sugar;
- thaumatin, in the arillus of fruits of *Thaumatococcus daniellii* (Benn.) Benth., which is about 3 times as sweet as saccharin;
- stevioside, in the dried leaves of *Stevia rebaudiana* (Bertoni) Hemsley, being 200–300 times as sweet as sucrose (Mohede & van Son, 1989).

Since the sweetening agents of plant origin mentioned above are not of carbohydrate origin, these natural sweeteners are not treated here but in the Prosea volume on spices.

1.3 Botany

1.3.1 Taxonomy

Taxonomically, this commodity group is extremely variable, comprising plants from many different families. Table 7 gives an overview of the major plants yielding non-seed carbohydrates, arranged according to plant parts used. The most important crops are taro, sweet potato, yams, cassava, Irish potato, sugar cane, sago palm, sugar palm and plantain.

1.3.2 Growth and development

The growth cycle

The crops yielding non-seed carbohydrates are usually propagated vegetatively, except for some of the palms that have to be propagated from seed, such as sugar palm, toddy palm and coconut. Most of the other crops are propagated from stem parts, suckers or tubers. Some have to be propagated from the produce harvested, which is clearly disadvantageous. They include yam, the aroids and Irish potato.

In general, the following consecutive phases can be distinguished in the growth cycle of the crops yielding non-seed carbohydrates:

- *Establishment.* The parts used for propagation establish by forming roots and shoots; their reserves, especially of carbohydrates, should be adequate for quick establishment. Water should be available. Strong sunshine is usually not favourable because high temperatures may result in water stress.
- *Development of leaf area.* The plants produce the leaf area necessary for optimal growth. Water, sunshine and nitrogen should be adequate. Weed competition may be especially important.
- *Accumulation of reserve food.* After forming the leaf area the plants form their sink and start accumulating reserves of food. High sunshine is usually favourable. But somewhat lower night temperatures and a sufficient supply of potassium are considered to be beneficial for translocation to the sink.
- *Ripening.* Some of the crops show marked symptoms of ripening: a diminishing leaf area, accompanied by slackening accumulation and even a cessation of the accumulation of reserve food.

Table 7. Major plants yielding non-seed carbohydrates, presented according to plant part used, family and genus.

Plant part used	Family	Genus	Species
Roots & tubers	*Araceae*	*Amorphophallus* Blume ex Decaisne	
		Colocasia Schott	* *C. esculenta* (L.) Schott
		Cyrtosperma Griffith	*C. merkusii* (Hassk.) Schott
		Xanthosoma Schott	
	Cannaceae	*Canna* L.	*C. indica* L.
	Compositae	*Helianthus* L.	*H. tuberosus* L.
	Convolvulaceae	*Ipomoea* L.	* *I. batatas* (L.) Lamk
	Cyperaceae	*Cyperus* L.	
		Eleocharis R.Br.	*E. dulcis* (Burm.f.) Trinius ex Henschel
	Dioscoreaceae	*Dioscorea* L.	* *D. alata* L.
			* *D. esculenta* (Lour.) Burkill
			* *D. hispida* Dennst.
	Euphorbiaceae	*Manihot* Miller	* *M. esculenta* Crantz
	Labiatae	*Plectranthus* l'Hérit.	*P. rotundifolius* (Poiret) Sprengel
		Stachys L.	*S. sieboldii* Miquel
	Leguminosae	*Pachyrhizus* Rich. ex DC.	*P. erosus* (L.) Urban
	Marantaceae	*Maranta* L.	*M. arundinacea* L.
	Nymphaeaceae	*Nelumbo* Adans.	*N. nucifera* Gaertner
	Solanaceae	*Solanum* L.	* *S. tuberosum* L.
	Taccaceae	*Tacca* J.R. & G. Forster	*T. leontopetaloides* (L.) O. Kuntze
	Zingiberaceae	*Curcuma* Roxburgh	*C. xanthorrhiza* Roxburgh
			C. zedoaria (Christmann) Roscoe
Stems/trunks	*Gramineae*	*Saccharum* L.	* *S. officinarum* L.
	Palmae	*Metroxylon* Rottboell	* *M. sagu* Rottboell
Peduncles of inflorescences	*Palmae*	*Arenga* Labill.	* *A. pinnata* (Wurmb) Merrill
		Borassus L.	*B. flabellifer* L.
		Caryota L.	
		Nypa Steck	*N. fruticans* Wurmb
Fruits	*Musaceae*	*Musa* L.	* *Musa* (AAB, ABB, BB, BBB groups)

* important throughout the tropics or in specific regions of South-East Asia.

Carbohydrate accumulation

Yam and Irish potato are the only crops in which sink formation and carbohydrate accumulation may start before the optimum leaf area has been attained. But in these crops too, carbohydrates accumulate quickest after the optimum leaf area has been reached. A comprehensive survey of literature data on root and tuber crops is shown in Table 8 (Wilson, 1977). Note that the data given may not be generalized for the crop, because they represent only one cultivar for each of the crops. Moreover, these data are only estimates. Consequently, the figures given show some marked limitations, which are less strict if the common name refers to one species only, but may be important where the com-

Table 8. Phases in the growth cycle of certain cultivars of crops yielding non-seed carbohydrates (Source: Wilson, 1977).

Crop	Sink	Phases in growth cycle (expressed in weeks and in % of total cycle)					Means of propagation
		establishment	development of leaf area	accumulation of reserve food	ripening	total	
Aroids	corm[1]	3 (9%)	5 (16%)	8 (25%)	16 (25%)	32 (100%)	tuber (pieces)
Cassava	tuberous root	4 (10%)	13 (30%)	25 (60%)	.	42 (100%)	stem (pieces)
Irish potato	stem tuber	2 (15%)	3 (23%)	6 (46%)	2 (15%)	13 (100%)	tuber (pieces)
Sweet potato	root tuber	1 (5%)	4 (17%)	18 (78%)	.	23 (100%)	stem (pieces)
Yam	stem tuber[1]	6 (13%)	11 (24%)	14 (31%)	14 (31%)	45 (100%)	tuber (pieces)
Plantain[2]	pseudostem/fruit	4 (8%)	30 (62%)	12 (25%)	2 (4%)	48 (100%)	suckers
Sago palm[2]	trunk	14 (4%)	90 (22%)	300 (75%)	.	400 (100%)	suckers

[1] With stem parts attached.
[2] 'Establishment' is only valid for the first crop; in the subsequent crops 'development of leaf area' coincides with rapid 'starch accumulation'.

mon name denotes a number of species in one genus (yams, *Dioscorea*) or even a number of genera in one family (aroids, *Araceae*).

Sugar cane may follow the same pattern as yam and Irish potato and so does sago palm, albeit during a much longer life span. The situation is quite different for banana, because of the dual nature of its sink. First, the pseudostem acts as a sink, but later this function is taken over by the fruits. In Ethiopia, the pseudostem of another member of the *Musaceae*, *Ensete ventricosum* (Welwitsch) Cheesman, is actually used as a starchy staple (Westphal, 1975).

Ripening

It is unclear whether ripening is caused by external factors (e.g. climate), which is an exogenous rhythm, or by internal factors of the plant, an endogenous rhythm. Once-flowering plants such as sago palm, plantain and sugar cane have an endogenous rhythm; they end their growth by flowering and fruiting and suckers may take over. Sago palm should be harvested before it starts flowering, then suckers take over. The same may hold for the *Araceae* and the edible canna.

In the other members of the group, except for most tapped palms, it is thought that both rhythms exist and that, ideally, they are mutually attuned. Usually, ripening can be described as an imbalance between the functions of the roots, the leaves and the sink. Root function becomes too limited to provide nutrients and/or water for both sink and photosynthetic apparatus. A choice is then usually made in favour of the sink. Clearly, such a phase of ripening would be strongly influenced by a water shortage and should be called exogenous. On the other hand, a programmed destruction of both photosynthetic apparatus and roots may exist, as appears to be the case in species of yam and in Irish potato. This form of ripening should be called endogenous.

In general, the phases of plant establishment and leaf area development should be made as short as possible. Prolonging the phase of rapid carbohydrate accumulation is probably advantageous, if at all possible. If there is an endogenous factor initiating a possible phase of ripening, then such a lengthening may only be realized through breeding. Sugar cane, plantain and sago palm have this endogenous rhythm, and in these crops carbohydrate accumulation is ended by flowering followed by fruiting. Irish potato and yam probably also possess an endogenous rhythmicity, as shown by their dormancy. The duration of growth in these crops is probably a varietal characteristic.

In Irish potato and yam there may be a connection between the dormancy before germination of the tubers, the endogenous rhythmicity and the onset of sink formation before maximum leaf area is attained. In sweet potato, the aroids and cassava the situation is less clear and needs further research. If there is no such endogenous rhythmicity in these crops, then their production could be increased by prolonging the phase of starch accumulation through agronomic measures.

More agronomic research needs to be done on the feasibility of prolonging the phase of carbohydrate accumulation, especially in the root and tuber crops. This phase is probably closely connected with the phase of ripening. To study this complex phenomenon the crops need to be grown under carefully controlled conditions.

The palms that are tapped in their inflorescences differ from the other crops yielding non-seed carbohydrates. In most tapped palms the trunk acts to a certain extent as a sink. At flowering, carbohydrates stored in the trunk are converted into sugars and transported to the developing inflorescence. These carbohydrates are augmented by the carbohydrate production of the still functional leaves. The products are intended for the development of flowers and fruits. This is especially important in the case of the sago palm, which flowers only once and then dies.

In sugar palm, which also flowers for an extended period at the end of its life cycle, the production of carbohydrates may be increased by prolonging its ripening phase. Then all carbohydrates in the previous sink, the trunk, will be exhausted, supplemented by the carbohydrates produced by the leaves during ripening.

Toddy palm, coconut and nipa palm are different again, since they are able to flower continuously. Their carbohydrates are produced directly for the growth of flowers and fruits. These carbohydrates are tapped from the flowering stalks as a sugary solution.

1.4 Ecology

The crops yielding non-seed carbohydrates differ in their optimal environmental requirements. It is therefore important to describe and compare their ecological potential and to define the range of optimal conditions for a high production of carbohydrates per unit of time and per unit of land area. And, in addition, it is useful to know how they are likely to perform outside these optimum ranges.

1.4.1 Climatic factors

Light

Influence of light usually is separated into light intensity and daylength. Both terms are interrelated in the total irradiation received.
Short days stimulate tuberization in cassava, yam and taro as well as in Irish potato. Such influence is unlikely in sweet potato, as this is a summer crop in the subtropics. In Irish potato cultivars grown in the temperate zone, the influence of short days on tuberization has been diminished by breeding. Short days are unlikely to stimulate flowering in perennial crops, except for sugar cane, where daylength fully controls flowering.
Total irradiation is of course important for all the crops. As shown in Figure 1, some highest yields already approach the theoretical maximum. This implies that the crop is at peak productivity during the growth phase of carbohydrate accumulation. This is probably also true for plantain, where carbohydrates accumulate initially in the pseudostem and only later in the fruits during the relatively short period of ripening.
It is often stated that aroid crops tolerate shade. The highest experimental yields as given in Table 6 and Figure 1 suggest otherwise. It is possible that the growth pattern of these crops is controlled more by temperature than by light.
Apart from the phase of rapid carbohydrate accumulation the crops may differ in their light requirements in other phases too. Some shade during establishment may have a slight detrimental effect (or even a positive effect) on plants that tiller near the mother plant (e.g. plantain, sago palm and the aroids). This does not hold for sugar cane, however. And in sago palm too, the shade of the mother plant is detrimental to the next generation after the phase of establishment.

Temperature

Experimental data on temperature requirements of the crops yielding non-seed carbohydrates are scarce, except for potato and banana. A generalized survey of literature data on temperature ranges and optimum temperature is presented in Table 9 (Westphal, 1985). The altitudinal ranges have also been taken into account, as temperatures decrease with increasing altitude. Most crops thrive in the lowland tropics, with the exception of Irish potato which favours cooler conditions.
Differences between day and night temperatures within the optimal range are usually advantageous for storage of dry matter in the sink. This is probably caused by two factors: circumstances favour sink development (Tsuno, 1970) and diminishing respiration.
The positive influence of differences between day and night temperatures has not been proven for palms and plantain.

Water

Water requirements of the crops may be given in comparison to the potential evapotranspiration (E_0). The actual water need of a crop (E_t) usually differs from E_0 because the evaporating surface differs from an open water surface.

Table 9. Temperature, altitudinal range and water requirements of certain crops yielding non-seed carbohydrates (Westphal, 1985).

Crop	Temperature (°C)		Altitude range at the equator (m)	Water requirements (mm)
	range	optimum		
Cassava	(15–)20–28(–32)	26	0–1000(–1400)	(500–)1000–1500(–2500)
Irish potato	(12–)15–20(–23)	18 (t night 10–14)	(400–)1000–2000	(500–)700
Sweet potato	(13–)18–25(–31)	24 (t night 20)	0–2100(–3000)	500–700(–1250)
Xanthosoma	13–29	24	0–1350(–1500)	(1000–)1400–2000
Taro	(15–)18–25(–27)	24	0–1800(–2100)	1750–2500
Yam	(23–)26–30(–33)	29	0–1000(–2000)	(600–)1000–1500(–3000)
Plantain	(22–)25–29(–31)	27	0–500(–1800)	2400
Sago palm	(23–)26–29(–30)	27	0–700	>2000
Sugar cane	28–38	30	0–700	(1500–)1800–2500

For instance, in a tropical rain forest E_t may exceed E_0 because of the well spread and dense leaf canopy. And in young crops E_t may be considerably lower than E_0, especially in the first period when the leaf canopy is not yet closed.
Potential evapotranspiration in the tropics is in the order of 3–5 mm water per day, with a mean of 4 mm per day (Monteith, 1977). Much higher rates of up to 10–15 mm per day are reported for irrigated crops in the semi-arid tropics and the subtropics, but this situation is excluded here. So, in general it may be concluded that only in well spread and dense canopies with adequate air circulation, can E_t exceed E_0. This situation may occur in the mature and well regulated canopy of palms, where the leaf area index (LAI) may reach a value of 6.5 (Flach, 1977). It may also be the case in a mature canopy of banana like 'Gros Michel' (Moreau, 1965). In none of the other crops does LAI normally exceed a value of approximately 4 (Wilson, 1977). Moreover, the leaf canopy is either too low or too dense, or both, to allow the necessary air circulation. It may therefore be concluded that among the crops yielding non-seed carbohydrates only mature plantings of palms and plantain may exceed E_0 in their water use. In all other crops E_t is at most equal to E_0 and often lower. See Table 9 for the water requirements of some of the crops.

Excess of water

If excess water does not run off, the crop has to tolerate waterlogging. Taro is such a crop. It may be cultivated at a high production level under conditions closely resembling those for wet rice.
The natural habitat of sago palm includes swamps, where it possesses a competitive advantage over other plants. It may produce pneumatophores under extremely wet conditions as a means to supply oxygen to the submerged roots. But under such conditions of permanent flooding the palm reportedly produces far less starch than under drier conditions. Although sago palm may also grow well under occasional flooding, even with brackish water, it grows best under less extreme conditions. Nipa palm is another crop that can withstand extreme

wet conditions. It occupies large tracts of mangrove under tidal influence with brackish water. But this crop will produce less or may even stop production when air humidity becomes too low. It seems that under such conditions transpiration prevails over production and transport of sugar. None of the other crops yielding non-seed carbohydrates will do well under conditions where the available water exceeds E_t.

Shortage of water

Plants/crops have various survival strategies when water is short (May & Milthorpe, 1962):
- ceasing growth and production before a serious water shortage develops (Irish potato, yam);
- deep rooting in order to use otherwise unavailable water in the soil (cassava, sweet potato, yam);
- temporarily diminishing transpiration (cassava, yam);
- temporarily lowering the water content of tissues.

Moreover, the ability to survive dry conditions may be influenced by methods of cultivation. For instance, all crops need water during establishment, but the amount needed and the urgency of timely availability is influenced by:
- the size of the parts used for vegetative propagation;
- whether these parts are planted aboveground or belowground;
- the presence of leaves at planting.

Planting large sets underground without leaves is an appropriate strategy under dry conditions.

Only yam is able to survive a drought of 2–3 months (Onwueme, 1978). The yam sets may remain dormant. When they start to grow they first develop roots and only later some xerophytic vines. However, even such adaptations will not prevent a loss, at the very least, in production per unit of time, compared with optimal conditions. During the development of leaf area a shortage of water will at the least result in slower growth, again leading to a decrease in production per unit of time. But the effects of drought may be somewhat retarded in deep-rooting crops. Cassava's strategy of shedding leaves at drought and resuming growth later will also result in lower yields.

It is generally believed that a slight water deficit during the phase of carbohydrate accumulation is advantageous, whereas plenty of water will promote vegetative development. The advantage of a slight water deficit is probably attributable to the limited cloudiness during drier periods. And, without clouds there is usually more irradiation, whereas night temperature tends to be lower. The phase of ripening is usually hastened by a water shortage and may be retarded by plenty of water.

1.4.2 Soil factors

Soil types

Root and tuber crops need an especially well structured and friable soil because this promotes the growth of their underground harvestable organs and facilitates harvesting.

Acidity

In general the optimum pH is between 5.5 and 6.5. The upper limit for cassava, sweet potato (Tsuno, 1970) and plantain (de Geus, 1973) is approximately 8, with varietal differences. The Irish potato shows a wider range, from 4.5 to 7.5. The coconut palm has a lower limit of 4.5. The lower limit for cassava and sago palm is as low as 4. Data on the extreme limits of aroid crops and yams are incomplete.

Salinity

Salinity is usually presented as the electrical conductivity (EC) of a saturated (soil) extract and expressed in milliSiemens per cm (mS/cm). The average salt concentration of sea water is 3.5%. A salt concentration of 0.35% corresponds with an EC slightly above 8 mS/cm.

Nipa palm is the most salinity-tolerant crop among the plants yielding non-seed carbohydrates. It grows well under tidal influence and probably needs brackish water, with an EC of 10 mS/cm or more. All other palms in the group still grow and produce reasonably well up to an EC of around 8 mS/cm, which is considered to be moderately salt tolerant.

Irish potato and banana are also moderately salt tolerant, but both cassava and yam are only poorly salt tolerant.

1.5 Agronomy

1.5.1 Cropping systems

Some plants yielding non-seed carbohydrates are collected from the wild, while others are cultivated in shifting cultivation and fallow systems, permanent upland cultivation, perennial crop cultivation, home gardens and corporate plantations (which may or may not be irrigated).

Most root and tuber crops are grown on a small scale for subsistence in shifting cultivation, fallow systems and in home gardens. In shifting cultivation cassava, with plantain and/or banana, is usually the last crop when the plot is in transition to fallow. Only cassava and sweet potato are also grown in permanent upland cultivation. Irish potato is only grown in permanent upland cultivation at higher altitudes as a cash crop. Taro may also be grown on permanently flooded land, as in wet rice.

Sugar cane is found in shifting cultivation and home gardens, where it is often grown on a small scale for chewing. In permanent upland cultivation the scale is larger and it may be grown either for on-farm production of raw sugar or the cane may be sold to a cane factory. In corporate plantations husbandry is of a high standard and the highest yields are reached.

Palms are still in the transition from collecting to perennial crop cultivation. Sago palm is a clear example. It has always been planted for subsistence on a small scale, with planting material obtained from especially selected very productive types. This has been possible because of the easy vegetative propagation by means of suckers. Sago palm is now being planted on quite a large scale in Sarawak on undrained deep peat. Some planting has also been started in Indonesia. But most sago starch is harvested from wild stands or from old neglected plantings. Coconut palm, of course, is planted regularly. Some of the palms in a stand may be tapped. Sugar palm and toddy palm are saved for production whenever they arise from discarded seed, although sometimes they are planted deliberately. Only the nipa palm growing in the extensive wild stands in brackish water under tidal influence in South-East Asia is exploited for collection of its sugary sap. Work is in progress to improve and increase production of all these palms.

1.5.2 Propagation

Most crops can be easily propagated vegetatively (Table 8).
Vegetative propagation gives rise to more or less genetically identical populations. In some of the root and tuber crops, e.g. aroids, canna, yam and Irish potato, pieces of the harvested product are used for planting. Up to 20% of the yam harvest may have to be used as planting material. Only cassava and sweet potato are propagated from pieces of stem, thus not diminishing the harvest. If these two crops are grown in areas with a pronounced dry season, special measures may be necessary to save and/or produce sufficient planting material.
Sugar cane is propagated from pieces of stem. The upper part of the stem which contains less sugar, may be used. But in corporate plantations special seed gardens are often maintained, because of the rather strict planting schedule.
Both sago palm and plantain are propagated from well-sized suckers, taken from productive mother plants. This reduces the juvenile stage in both crops, although this is far more important in sago palm than in plantain.
Sugar palm, toddy palm and coconut are only propagated from seed. With the exception of coconut, in these palms it is uncommon to select planting material. However, propagating sugar and toddy palm from seed from palms that are not harvested may lead to negative mass selection.

1.5.3 Husbandry

Root and tuber crops are grown similarly, albeit in different soils and also often at different altitudes. Vegetative parts are planted.

Nutrient removal and immobilization

The use of nutrients by plants can be put into two broad categories:
- nutrients taken up by the storage organ, the sink, are usually removed from the field at harvesting and thus lost for cultivation;
- nutrients in other plant parts are mostly immobilized during the growth cycle and are thus not available for recycling during growth. This does not hold for fallen leaves, which in perennial crops (e.g. plantain, palms) may play an important role in recycling.

Clearly, the nutrients removed when harvesting have to be replenished if they are not available in the soil. The same holds for the nutrients immobilized in other plant parts. All crops yielding non-seed carbohydrates need high potassium levels for optimal production. On average, starch crops need some 10–20 kg

of K per t of harvested dry matter and in addition 5–10 kg of N, and 2–5 kg each of P, Ca and Mg. Thus, each t dry matter in the main product removes nutrients in the order of magnitude of 10 kg N, 5 kg P, 20 kg K, 5 kg Ca and 5 kg Mg.
Cassava is a crop that can still be grown profitably on poor soils. It is able to take up the remaining nutrients, probably largely because of its symbiosis with a mycorrhiza. This is an advantage, but it may lead to severe soil exhaustion.

Crop rotation

Sugar cane may be grown successfully on the same land for a number of years, especially if the crop is ratooned.
In the dry season most crops are grown intercropped after wet rice. Only cassava and sweet potato are also grown as sole crops in larger plots.
Cereals are the first crop to be planted after a fallow has been cleared. The cereals can then use the available nitrogen. Root and tuber crops follow immediately as intercrops. Often a combination of long duration crops like cassava and plantain or banana is planted as the last crop, closing the cultivation period. Both cassava and plantain are able to compete to some extent with the returning forest.
If the fallow contains much grass, root and tuber crops are usually planted first, because grasses suffer from the same diseases and pests as cereals. Moreover, root and tuber crops make it easier to control grassy weeds.
In Hawaii, taro is grown like paddy in flooded fields, in rotation with wet rice, with excellent results. This enables good weed control.

Crop protection

Crop protection of sugar cane is rather well developed, because only a few clones, selected for their productivity, are grown industrially throughout the world.
Most of the other crops are not yet cultivated intensively and are usually only grown in small plots. Diseases and pests are therefore usually limited in their occurrence and are not a great risk.
As crops become cultivated more intensively, occupying larger contiguous areas, they become increasingly prone to diseases and pests. A good example of this is cassava; its diseases and pests are becoming more of a risk. Crop protection should therefore be developed concurrently with intensifying cultivation and breeding.
How frequently a crop needs to be weeded often depends on how quickly its canopy closes. Cassava, for instance, needs a long time to do so, but sweet potato quickly covers the soil, smothering weeds.

1.6 Harvesting and post-harvest handling

1.6.1 Sugar cane

The best time to harvest cane can be determined fairly accurately. Once harvested, sugar cane can be kept for only a few days without appreciable losses. If the cane has been burned before harvesting, deterioration sets in even more rapidly. A large cane sugar factory therefore needs to organize harvesting in a strict schedule. Small farms delivering their own cane at will to such a factory may adversely affect sugar content and recovery.

1.6.2 Root and tuber crops

The harvesting period of roots and tubers varies to a certain extent. The best way to preserve the roots and tubers is to leave them in the soil as long as possible.

At harvest, they need to be lifted from the soil. Care should be taken to harvest the product undamaged, as all damage leads to infection by micro-organisms and thus to deterioration. The roots or tubers should be stored in a dark, cool and well-ventilated spot. Even then most crops cannot be stored well, except for yam and Irish potato, which become dormant.

Damaged cassava deteriorates especially rapidly and can be kept for only a few days. Sweet potato is somewhat easier to store. Undamaged tubers can be kept for a number of weeks.

1.6.3 Sago palm

The sago palm has a clear advantage over the root and tuber crops, i.e. that the period of harvesting can be lengthened at will to over one year, without appreciable losses. The best time for harvesting is at flower initiation, but the amount of starch in the trunk increases slowly until the seed starts to form. The only disadvantage of harvesting at this time is that the next crop from the suckers will mature later.

1.6.4 Palm tapping

In principle the inflorescences of all palms may be tapped for their phloem sap. Whether they are exploited depends on:

- whether other products of the palm may have more important economic uses,
- the growth habit of the palm,
- whether the structure of the inflorescence makes tapping possible,
- the ease of reaching the inflorescence.

What actually happens in palm tapping is that the phloem sap intended for the production of flowers and fruits is used for the production of sugary sap. For tapping, the main axis of the inflorescence must be of a certain length. Usually the axis is pretreated so that it can be bent over and to enhance sap flow. The mechanism of pretreatment is not yet fully understood.

If a palm contains reserve food in the trunk, this may be removed from the trunk by tapping. The direct products of photosynthesis may also be removed by tapping. Both processes occur in the sugar palm. In lowlands this palm grows for 7–8 years and only then starts to flower, from top to bottom. The trunk may contain up to 125 kg of starch, which may be extracted in the same way as from the sago palm. During tapping, however, the starch collected in the trunk, and the products of ongoing photosynthesis in the attached leaves are converted into tappable sugar. Over the years of tapping, more sugar is

therefore usually produced than is contained in the starch in the trunk. Cultivation should therefore aim at keeping the leaves productive for as long as possible. In the nipa palm only the direct products of photosynthesis are tapped, as little or no starch appears to be present in the underground stem.
Sometimes the growing points of trunks are also tapped. Then the phloem sap intended for the production of leaves is used for sugar production. This sap has a somewhat different composition. Such tapping is usually more detrimental to palm growth than tapping of the inflorescences.
Even the trunks of felled palms lying on the ground may be tapped, though only for relatively short periods.

1.7 Processing and utilization

1.7.1 Sugar cane

The processing of sugar cane both industrially and in home production on small farms follows the same pathway. The juice is pressed out and the sap is boiled until the sugar concentrates, using the pressed-out cane (bagasse) as a fuel. In factories the thickened sap is then purified, ultimately producing crystallized sugar. Small farms usually produce jaggery, a brown sticky and hygroscopic sugar, still containing all dissolved parts of the sap.
In the factory processing of sugar cane a residue of reducing sugars is produced: the molasses. This is often used for the production of alcohol or as an animal feed.

1.7.2 Root and tuber crops

Cassava is often washed, cut and dried if it is to be stored. Thin slices dry easily and can be stored as such. When sliced more coarsely it is often sold as an animal feed. It may also be pressed mechanically into pellets for animal feed.
In Africa, a number of processed products are often made from roots and tubers, such as gari. Gari, prepared from cassava, consists of washed, peeled and grated roots fermented in jute sacks under heavy weights to press out the excess water. Fermentation increases the protein content, as a result of micro-organism action. After drying, the gari keeps for some time.
Cassava can also be used for the production of starch, because of its low sugar and protein content.
Flakes may be prepared from all kinds of root and tuber crops. These also keep after drying. Unfortunately, gari and flakes are little known in South-East Asia.
In industrialized countries, sweet potato may be preserved by canning. Although the crop is also used for starch production, especially in Japan, it is less suitable for this because of its usually high sugar content.

1.7.3 Sago palm

The sago palm trunk needs to be ground for processing, in order to obtain the starch. The core or pith of the trunk cannot be eaten fresh by man. Grated debarked trunk, however, can be fed to animals, especially horses, pigs and chickens. Under the 2 cm layer of bark, the pith is softer than in Irish potato and thus easy to grate. The starch can then be washed out of the pith. The starch is dried for industrial purposes. In areas where it is the staple, the starch may be preserved under water, where it deteriorates slowly. If kept wet but out of water it acquires a characteristic smell of lactic acid. The most common way of preparing this product for eating is to add hot water to wet starch and then stir with a stick. The resulting glue-like mass is eaten with a number of side dishes of vegetables and meat.

The starch can also be baked into various shapes. The product obtained in this way can be preserved easily and be eaten dipped in coffee, tea or other liquids such as a soup.

1.7.4 Tapped palms

For sugar production, the sap of palm tapping is collected and dehydrated by cooking in an open pan, which also results in jaggery. The sap from tapping contains all the elements that were intended for the production of flowers and fruits. This provides an excellent substrate for the growth of micro-organisms, especially yeasts. Therefore, potassium bisulphite is often used to stop their growth. The sugary sap is then handled in the same way as sugar cane sap. It is even possible to produce crystallized sugar from palm sap.

The juice from palm tapping may also be sold fresh. Each kind of palm juice possesses its own, often characteristic taste, and contains up to 16% sugars, mainly sucrose. Some of the sucrose may have broken down into reducing sugars, depending on the cleanliness of the tapping vessels and the time between harvesting and consumption.

Immediately after tapping, the sugar starts to convert into alcohol (palm wine) because of the action of yeasts. After two to three days the alcohol percentage of the sap may reach 12–15%. This product is called wine or beer. It mostly also already contains some acetic acid and tastes sour.

The palm wine may be distilled to give higher, but usually largely unknown, percentages of alcohol (between 20% and 60%). The palm wine can also be converted into vinegar. If the product is then kept for some time, the concentration of acetic acid increases. The final product may then be diluted with water to obtain vinegar.

Wine and vinegar still contain most of the nutrients that were present in the fresh sap and are thus quite nutritious.

1.8 Genetic resources and breeding

Sugar cane breeding has a long history and therefore there are good collections of cultivars in the national research stations throughout the world. Sugar cane breeding is also well developed.

Collections of genetic material of the main root and tuber crops are maintained by the relevant international research institutes under the auspices of the Consultative Group for International Agricultural Research (CGIAR). The Centro Internacional de Agricultura Tropical (CIAT) in Colombia maintains a collection of cassava. The International Institute of Tropical Agriculture (IITA) in Nigeria does likewise for yams. The Centro Internacional de la Papa (CIP) in

Peru possesses a collection of Irish potato and the Asian Vegetable Research and Development Center (AVRDC) in Taiwan maintains a collection of sweet potato. The same institutions, alone and in combination, also conduct research on the crops and exchange cultivars.

Very little work on maintenance of collections is being done on the other crops in the group. Often, small collections are available in the countries where the crops are grown, but breeding of these crops is almost non-existent. The International Plant Genetic Resources Institute (IPGRI) in Rome, Italy, is encouraging the establishment of gene banks, especially for the neglected crops.

1.9 Prospects

1.9.1 Non-seed carbohydrates as food

Despite having a much higher potential yield than the cereals, the root and tuber crops are still mainly subsistence crops and are used as a fresh product on only a limited scale. Their high water content (60–90%) compared with 12–15% for cereals makes them difficult to store and heavy to transport. Only the products favoured for their taste have a good chance of retaining and even improving their position. Yam and Irish potato have good prospects: both of these crops can be stored more easily than the others.

The increasing prosperity of most of the developing countries means that the use of non-seed carbohydrates may decrease further as they tend to be replaced by cereal crops, notably rice and also by mostly imported wheat. Rice is already gaining in importance, replacing the starch crops that are often considered to be 'poor man's food'. Bread, mostly produced from wheat, is gaining an important position, especially for breakfast and mainly in cities. It is expected to increase in importance throughout South-East Asia.

The 'poor man's crops' are important at subsistence level. In some areas (e.g. New Guinea), people subsist almost entirely on the starch crops. It has been rightly stated that they are important for both household and national food security (Onwueme & Charles, 1994). Their importance probably outweighs the production and trade figures. The crops do not receive the infrastructural support they need for promotion and development. Their strategic food importance should be recognized and appropriate food policies should be designed and developed to improve their supply systems to make them competitive. This could be helped by making them into products that are easier to store.

Sugar cane will probably retain its important position in the world mainly as an industrial crop. All countries will, if possible, try to produce their own sugar, if only for strategic reasons.

The tapped palms also produce sugar. Their sugar (and also the unrefined cane sugar produced by small farmers) possesses some special qualities not to be found in refined cane sugar. There will always be a market, albeit limited, for this product, however hygroscopic it may be. Nowadays it is even exported to Europe on a limited scale. Although the tapped palms produce more energy per unit area and per unit of time than sugar cane, production is so difficult to mechanize that replacement of sugar cane by either nipa, sugar or toddy palm is unlikely. This may only happen on a limited scale in countries with much cheap labour and with climates and soils less suited to sugar cane.

1.9.2 Non-seed carbohydrates as industrial raw material

The other trend is for the starch crops to become more important whenever their products (e.g. starch and high fructose syrup) can be used directly as an industrial raw material for food, feed and other purposes.
The market for prime quality starches is growing fast. The starches must be produced in sufficiently large quantities and be of a consistently good quality. For instance, up to 50% of wheat flour in bread can be replaced by pure starches, provided the starch is white, clean and has no peculiar smell. This would provide developing countries with an opportunity to reduce wheat imports. High fructose syrup, which can easily be produced from starch, is also gaining importance, especially in bakery products and in the production of soft drinks. Starch is also used as a filler in pills, to size paper and textile, and in the manufacture of glues. There is also potential in the market for animal feed. As this product should contain some protein, the starch need not be pure. Both these potential markets are only for crops that are produced competitively (primarily cassava and sago palm).

1.9.3 Non-seed carbohydrates in energy cropping

Back in the 1920s in what is now Sarawak, a research project was completed on the production of fuel alcohol from the sap tapped from nipa palm (Dennett, 1927). It proved that this was an economically viable proposition, although the fuel was more expensive than gasoline. Unfortunately this pilot project was never implemented on a practical scale, because fuel prices in the region fell after the discovery of the huge oil reserves in present-day Brunei.
As mentioned above, starch can be converted into sugar and sugar into alcohol. And alcohol can be used as gasohol, a mixture of 20% ethanol and 80% gasoline, as a replacement for pure gasoline. 96% ethanol, called power alcohol, can be used pure in specially modified engines. Theoretically, 1 kg of sucrose yields 0.65 l of ethanol, whereas 1 kg of starch can be hydrolysed into 1.1 kg of sucrose and consequently be converted into 0.71 l of alcohol. Up to 10% may be lost during conversion due to the formation of yeasts. Thus, the factor for converting sugar into ethanol can be set at 0.6 and that for converting starch into ethanol at 0.64. The energy content of mineral oil is around 36 MJ/l, compared with 21 MJ/l for 96% ethanol.
In the 1970s the feasibility of producing fluid energy to replace mineral oil again became the focus of attention, because of the oil crisis. Some theoretical and practical research on this was conducted in the decade after this crisis. Although oil prices subsequently fell again, which led to a diminishing of research, it now seems that the production of substitutes for oil will gain new impetus, because of increasing prosperity in South-East Asia and also because of increasing concern about environmental aspects (power alcohol is a renewable resource and its use produces fewer noxious by-products than oil does).
The production of power alcohol from crops is feasible, albeit under a number of restrictions. First, one needs to consider the energy balance. The production process should, in total, produce more energy than it consumes. The industrial process of converting starch into sugar, followed by conversion of sugar into alcohol and finally distilling the low grade alcohol, the beer, into 96% alcohol,

usually costs about as much energy as it yields. Only if the crop also yields another – combustible – product, a residue, is the energy balance positive. This is because only the combustible residue is converted into additional energy. This picture will change only if important technological advances are made in techniques to separate alcohol and water, to replace the energy-consuming distillation. Thus crops could already be selected for the presence of a combustible residue.

Crops producing appreciable amounts of additional combustible residue include the perennial crops sugar cane and sago palm. Sugar cane bagasse can be used. However, sugar cane is usually produced in a highly mechanized operation, which also requires energy. Sago palm bark is combustible and possibly so is the residue ('hampas') left after washing out the starch, if dried. Nipa palm gives only a slightly positive energy balance, because the sugary sap is obtained solely by human labour. Most other starch and sugar crops need fuel from other resources for the production process.

The second requirement is for prices for starches and/or sugar to be low, otherwise these products will not be used for conversion into energy. This may change, however, if oil prices rise.

Third, the operation must be economically feasible. This implies that the production of fluid energy will be limited to areas where labour is plentiful and cheap.

Fourth, other crops (such as oil palm and other oil crops) may well show a far more interesting energy balance.

Fifth, the production of energy crops should not compete with the production of food and feed. Sugar cane is at a disadvantage in this, as it requires prime soils which could be used for various other crops. Sago palm thrives on badly drained heavy soils that cannot be used for other crops without expensive improvements. Nipa palm grows on soils under tidal influence of brackish water – the potentially acid sulphate soils that can only be used for other crops after prolonged and expensive treatment.

In the not too distant future the production of alternative fluid energy will probably be taken up again, because of the rapidly growing demand for energy in the world and the diminishing oil reserves.

1.9.4 Research

The research efforts on the crops yielding non-seed carbohydrates are governed by:

- the importance of the crops in industrialized countries. This is especially true for Irish potato and sweet potato. Most of the research on Irish potato has been done in the temperate industrialized countries, although this is now changing thanks to an international research institute, the Centro Internacional de la Papa, in Peru. Most of the research on sweet potato has been done in Japan and in the United States. Recently, research has been developed in mainland China.
- commercial interest in the crop. A good example is the research on sugar cane. Sugar cane is one of the best researched crops in the world, although it is a typical tropical crop.

All other crops are mainly of local interest. Only if research is developed locally will these crops receive the attention they so badly need. This has been clearly demonstrated for taro in Hawaii and, more recently, for sago palm.

Today, the International Society for Tropical Root and Tuber Crops (ISTRC) is important in maintaining contacts between researchers on all aspects of root and tuber crops. The emphasis used to be on organizing meetings once every four or five years for scientists working on root and tuber crops from all over the world. Nowadays, smaller regional meetings are preferred. There are scientific organizations for other crops in the commodity group, such as the International Association for Research on the Plantain and other Cooking Bananas (IARPCB). Every four to five years a scientific symposium is organized on sago palm. Such meetings could be important in advancing research.

Except for sugar cane, the crops yielding non-seed carbohydrates still largely form a neglected group. This is partly because of social factors. Most crops are grown in small plots and largely by subsistence farmers. In mainly rice-consuming South-East Asia the crops are considered as the food for the poorer part of the population. Moreover, as a food, these crops are still associated – wrongly so – with low quality, poor in protein.

The main economic disadvantages of the crops are their high water content, associated with bulk, and their poor keeping quality.

The potential of the crops, especially their potential high yield, is slowly being recognized. Starch is the main energy source for humans and animals and is becoming an even more important industrial raw material.

One could envisage a development in the future in which the production of fuel alcohol is the primary basis of the market for starch and sugar, mainly as a renewable and clean source of fluid energy. A second somewhat higher price level would then be attained with its use as a feedstock, for industrial products and animal feed. The highest price level would be for human consumption, fresh or prepared.

Much needs to be done in developing the entire chain from production to consumption if this scenario is to be achieved.

2 Alphabetical treatment of species

Amorphophallus Blume ex Decaisne

Nouv. Ann. Mus. Hist. nat. Paris 3: 366 (1834).
ARACEAE
x = 13 (14); *A. konjac*: $2n$ = 26 (24, 36, 39); *A. muelleri*: $3n$ = 39; *A. paeoniifolius*: $2n$ = 26, 28; *A. variabilis*: $2n$ = 26

Major species and synonyms

- *Amorphophallus konjac* Koch, Wochenschr. Gartn. Pflanzenk. 1: 262 (1858). Synonyms: *A. rivieri* Durieu ex Carriere (1870), *Hydrosme rivieri* (Durieu ex Carriere) Engler var. *konjac* (Koch) Engler (1879), *Amorphophallus mairei* Leveille (1915).
- *Amorphophallus muelleri* Blume, Rumphia 1: 143 (1837) ('*mulleri*'). Synonyms: *A. blumei* (Schott) Engler (1879), *A. oncophyllus* Prain (1893), *A. burmanicus* Hook.f. (1893).
- *Amorphophallus paeoniifolius* (Dennstedt) Nicolson, Taxon 26: 338 (1977). Synonyms: *A. campanulatus* Decaisne (1834), *A. rex* Prain (1893), *A. gigantiflorus* Hayata (1916).
- *Amorphophallus variabilis* Blume, Rumphia 1: 146 (1837). Synonym: *Brachyspatha variabilis* (Blume) Schott (1856).

Vernacular names General: Amorphophallus, elephant foot yam, sweet yam, konjac (En). Amorphophallus, kouniak (Fr).

- *A. konjac*: Devil's tongue, konjac (China and Japan), konnyaku (Japan) (En). Philippines: pungapung (Tagalog), bulangan (Mangyan). Vietnam: khoai n[uw]a.
- *A. muelleri*: Indonesia: badur (Javanese), acung (Sundanese), kerubut (Sumatra).
- *A. paeoniifolius*: Elephant yam, telinga potato (En). Indonesia: suweg (cultivated), walur, eles (wild). Malaysia: loki, ubi kekek. Philippines: pungapung (Tagalog), anto (Bisaya), bagong (Bikol). Cambodia: toal. Laos: duk düa (general), kabuk (southern). Thailand: buk (general), bukkhungkhok (south-eastern), man-suran (central). Vietnam: khoai n[uw]a, n[uw]a chu[oo]ng.
- *A. variabilis*: Indonesia: cumpleng (Javanese), acung (Sundanese), lorkong (Madurese).

Origin and geographic distribution The genus *Amorphophallus* originates from and is mainly distributed in the Old World, especially in the tropics from Africa to the Pacific Islands, but also extending to temperate areas in China and Japan. The genus is not well known, the total number of species is possibly more than 170.

- *A. konjac* originates from southern and south-eastern China, Vietnam and possibly Laos. It occurs wild and cultivated and easily escapes from cultivation. Its cultivation is most important in China and Japan but it is also known in Indo-China and the Philippines, and occasionally elsewhere (e.g. Hawaii).
- *A. muelleri* occurs wild from the Andaman Islands eastwards through Burma (Myanmar) into northern Thailand and south-eastwards to Indonesia (Sumatra, Java, Flores and Timor). It is occasionally cultivated (e.g. on Java).
- *A. paeoniifolius* occurs wild and cultivated from Madagascar eastwards via India and South-East Asia to Polynesia, including also southern China and northern Australia. Because it easily escapes from cultivation and naturalizes, its exact origin is unknown.
- *A. variabilis* is only known wild in Indonesia (Java, Madura, Kangean Islands).

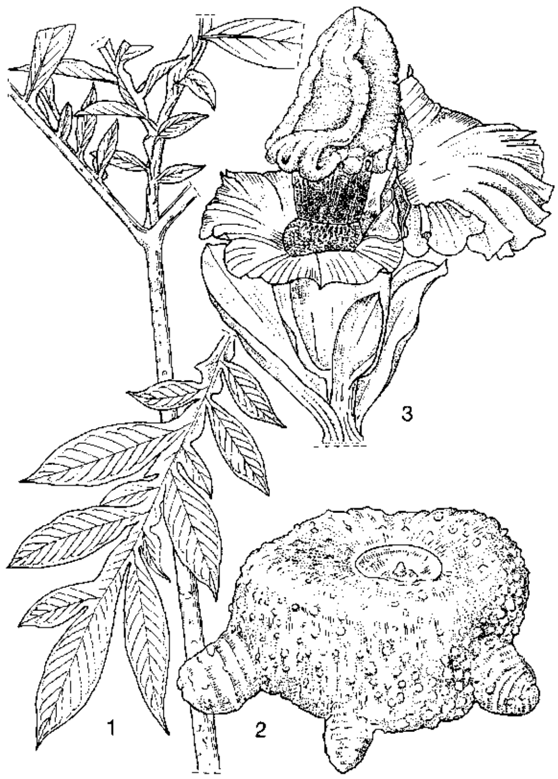
Uses Tubers from most *Amorphophallus* species can be made edible in times of food scarcity, usually after peeling, slicing and repeated washing and boiling in water to remove toxic and irritating substances. The remaining flour is used to make a porridge, a type of curd or for making a kind of bread. The 4 species mentioned are also used for food under normal conditions; *A. paeoniifolius* (important in India, Sri Lanka and parts of Indonesia) and *A. konjac* (important in China and Japan) in particular are widely cultivated. In Japan, *A. konjac* tubers are used to prepare a traditional dish ('ito konnyaku') which is gel-like in appearance and texture and is made by adding slaked lime to a colloidal solution of the flour in water, and then heating this. Small one-year-old tubers of *A. konjac* are considered a delicacy.

The young leaves and the fruits of several species are used as a vegetable. In the Philippines and in India, all parts are also used as fodder. Besides its value as food, the flour prepared from the tubers is also used industrially in China and Japan (e.g. the gluco-mannan in *A. konjac* has film-forming characteristics useful in preparing stabilizers and emulsifiers for food, drinks, cosmetics and in drilling fluids). The tubers can also be used to prepare acid and alcohol. Many uses of *Amorphophallus* are reported in traditional medicine: against dysentery, earache, cholera and respiratory problems, to reduce blood pressure and cholesterol level, to cure rheumatic pains and digestive problems. Potentially, all *Amorphophallus* species can be cultivated as ornamentals.

Production and international trade *Amorphophallus* tubers are mainly produced in home gardens or collected from the wild and consumed locally, and only the remainder is available for local trade. No statistics are available for South-East Asia. The often large tubers are easily damaged and are therefore difficult to transport. In China and Japan some *A. konjac* is cultivated on commercial scale. In China konjac cultivation is about 2000 years old; in 1995 30 000 ha were planted for commercial production. In Japan, production of *A. konjac* flour increased from 70 000 t per year before 1940 to 130 000 t in 1967 from 17 000 ha. More recent data are not available. Japan also imports tubers from other countries (e.g. from Indonesia; before 1940, especially *A. variabilis*), but no statistics are available.

Properties Per 100 g edible portion, tubers of *A. paeoniifolius* contain approximately: water 75–79 g, protein 1–5 g, fat 0.4–2 g, carbohydrates 18 g (starch 4.5–18 g, sugar 0.1 g, mannan 0–9 g), fibre 0.6 g, Ca 50 mg, P 20 mg, Fe 0.6 mg, vitamin A 434 IU. The energy value is 420 kJ/100 g.
The starch granules vary in shape and size, diameter from 5–19 μm.
Per 100 g edible portion tubers of *A. konjac* contain approximately: water 78.8 g, protein 1.2 g, fat 0.2 g, carbohydrates 19 g, fibre 0.8 g, ash 0.8 g, Ca 43 mg, P 22 mg, Fe 0.6 mg, vitamin A 270 IU. The energy value is about 340 kJ/100 g. The carbohydrates consist of starch, but mainly (more than 50%) of mannan, a polysaccharide of mannose and glucose, which, in combination with water becomes very viscid and is attractive for many industrial processes. The mannan granules are 10–20 times larger than starch granules and are amorphous.
The mannan content of *A. muelleri* is higher than that of *A. variabilis*, which is why attempts to exploit the former commercially were made in Indonesia before the Second World War. All species (especially the wild ones) have acrid tubers, due to the presence of calcium oxalate crystals and alkaloids (possibly allied to conicine).
Fresh *A. paeoniifolius* leaves contain per 100 g approximately: water 85–88 g, protein 2.5–3.5 g, fat 0.4–0.6 g, carbohydrates 2.5–3.5 g, fibre 4–7 g and calcium oxalate 400 mg.

Description Perennial herbs with subterranean, naked tubers. Tubers often depressed globose and large at maturity. Leaves solitary, or several as a result of leaf growth on accessory tubers; petiole cylindrical, solid, usually blotched or flamed, smooth to rough; blade tripartite, each of the 3 segments multifid with decurrent, erect to spreading leaflets (side lobes) which vary greatly in number; just like the tuber, the appertaining leaf becomes larger every year until an inflorescence is formed. Inflorescence solitary on the tuber, partly enveloped by a well-developed spathe; peduncle cylindrical, solid, usually blotched or flamed, smooth to rough; spathe seemingly funnel-shaped, tubular or campanulate, but on one side free and with overlapping margins, variously coloured and marked, withering and often falling off after anthesis; spadix female in lower part, becoming male in the upper part via a transitional zone, with a well-developed asexual part (appendix) at the top; flowers unisexual, lacking a perianth; female flowers with 1–4-celled ovary, style more or less absent to well-developed, stigma entire or lobed; male flowers with 1–6 stamens; anthers subsessile and 2-celled, dehiscent by an apical pore; male part and appendix of spadix fall off after anthesis, after which the female part elongates greatly. Fruit a 1–3-seeded, subglobose or elongated berry, usually red or orange, the upper ones maturing first.



Amorphophallus paeoniifolius (Dennstedt) Nicolson – 1, leaf with leaf segment; 2, tuber; 3, inflorescence.

– *A. konjac*: tuber up to 30 cm in diameter and 20 cm long, weighing up to 10 kg, brown, seasonally producing numerous rhizomatous offsets; petiole up to 100 cm × 8 cm, smooth or with scattered punctiform warts at the base, dirty whitish-pinkish with large dark green spots and smaller white dots; blade up to 2 m in diameter, highly dissected, rachises narrowly winged; leaflets elliptical, 3–10 cm × 2–6 cm; peduncle up to 110 cm × 5 cm; spathe 10–60 cm × 10–55 cm, limb erect, undulate or folded longitudinally with spreading margins, outside dark purplish-brown with scattered blackish-green spots, inside dark brown, glossy; spadix 15–110 cm long; fruit unknown.

- *A. muelleri*: tuber up to 28 cm in diameter, weighing up to 3 kg, dark brown outside, yellow inside, developing no seasonal offsets; petiole 40–180 cm × 1–5 cm, smooth, green to brownish-green with numerous pale green spots; blade 75–200 cm in diameter, very dissected, carrying epiphyllar bulbils on the major ramifications; leaflets lanceolate, 10–35 cm × 4–9 cm; peduncle 30–60 cm × 0.5–3 cm; spathe 7.5–27 cm × 6–27 cm, limb semi-erect or spreading, brownish-purple or greyish-green outside, inside purplish or brownish with greenish or brownish spots; spadix longer than spathe, 8–30 cm long; berry cylindrical to ovoid, 12–18 mm long, bright red, up to 1000 per infructescence, 2–3-seeded.
- *A. paeoniifolius*: tuber up to 30 cm in diameter and 20 cm long, weighing up to 25 kg, dark brown, producing seasonal rhizomatous offsets up to 10 cm × 4 cm; petiole up to 200 cm × 20 cm, shallowly corrugate to strongly echinate-verrucate, pale to dark green with numerous pale blotches and small dark dots; blade up to 3 m in diameter, highly dissected, rachises winged; leaflets rounded-ovate to lanceolate, 3–35 cm × 2–12 cm; peduncle 3–20 cm × 1–8 cm, elongating to 1 m length in fruiting; spathe 10–40 cm × 15–60 cm, limb spreading and strongly undulating, pale green to dark brown with paler spots outside, inside glossy dark brown; spadix shorter or longer than spathe, 7–70 cm long; berry cylindrical, 1.5–2 cm × 8–10 mm, bright red.
- *A. variabilis*: tuber up to 15 cm in diameter and 8 cm long, weighing up to 1.5 kg, white, producing seasonal rhizomatous, spindle-shaped offsets 1–1.5 cm long; sometimes 2 leaves are produced; petiole up to 120 cm × 3.5 cm, smooth, pure green or variegated green-brown-green; blade up to 125 cm in diameter, rachises narrowly winged; leaflets elliptical to lanceolate, 4–34 cm × 2–12 cm; peduncle 8–120 cm × 0.4–3 cm; spathe 6–23 cm × 5–20 cm, limb strongly reflexed at margin, green with black dots outside, creamy white to pale green or brown inside; spadix usually much longer than spathe, 9–58 cm long; berry orange-red, 1–3-seeded.

Growth and development For *A. muelleri* the development on Java is as follows. In November (beginning of the rainy season), the subterranean tuber starts developing one leaf which exhausts the reserves of the tuber completely. During the rainy season a new tuber generally larger than the old one forms at the base of the leaf. At the beginning of the dry season (May–June) the leaf dies and the tuber enters a dormant period lasting 5–6 months. In November, the cycle starts again. When the tuber is large enough (2–3 kg) it develops an inflorescence instead of a leaf. In May, the seeds are ripe but they also remain dormant for 5–6 months. In the next growing season (November–May) the seed develops into a plantlet about 10 cm tall, consisting of one leaf and a subterranean tuber of 1–2 cm in diameter, weighing 5–10 g. The leaf dies in May, the tuber develops a new leaf from November on, reaching 30 cm height, bearing some small bulbils, and a new tuber of 8 cm in diameter weighing 300 g. In May the leaf dies. In November, a new leaf up to 1 m tall develops with bulbils about the size of a 1-year-old tuber. Ultimately the new tuber is 20–25 cm in diameter, weighing 2–3 kg. In November the following year the tuber develops an inflorescence. In Thailand (northern latitude), flowering is in May.

A. konjac tubers normally start flowering when 4 years old (in March–April in China). *A. paeoniifolius* flowers between March and July in India, Thailand, Peninsular Malaysia, the Philippines, Vietnam (northern latitudes) and in November on Java (southern latitude). On Java *A. variabilis* flowers between June and December and bears fruits from July–January.

Normally, female flowers are receptive only a short time and usually 2 days before the pollen of the same plant is mature. Cross-pollination seems necessary. Nevertheless, in several species seed does not develop or develops only apomictically (e.g. in *A. muelleri*, *A. konjac*). The mannan content of the tubers is highest just before the leaves wither and is independent of the tuber size.

Other botanical information

- *A. konjac*. Because it has been in cultivation for 2000 years and also naturalizes easily after escaping from cultivation, it is no longer clear which characters belong to the true wild plant. *A. konjac* can best be subclassified into cultivar groups and cultivars. In China, many landraces exist.

- *A. muelleri*. There is some confusion about the correct name, because of the poor original type material and description. Its triploid genome points to a recent origin by hybridization or autopolyploidy. This may also explain the apomictic development of the seed, the development of bulbils and the low pollen production.
- *A. paeoniifolius*. A very variable species, local populations of which haven often been described as new species. It also forms a crop–weed complex, easily escaping from cultivation and naturalizing. The wild and cultivated forms have been described as separate taxa (wild: var. *sylvestris* Backer, var. *paeoniifolius*; cultivated: var. *hortensis* Backer, var. *campanulatus* (Decaisne) Sivadasan) but a subclassification into cultivar groups and cultivars seems more appropriate. Many cultivars have been distinguished already.

In China, *A. albus* Liu & Wei is also cultivated for its edible tuber.

Ecology *Amorphophallus* usually grows in secondary vegetation, in forest margins and thickets, teak forests, village groves, usually under some shade, up to 700(–900) m altitude for *A. muelleri*, *A. paeoniifolius* and *A. variabilis*, up to 2500 m for *A. konjac*. Shade, up to 50–60%, promotes tuber production. The optimum average temperatures range from 25–35°C for *A. muelleri*, *A. paeoniifolius* and *A. variabilis*, and from 20–25°C for *A. konjac*, with optimum soil temperatures of 22–30°C.

A. paeoniifolius develops best with an evenly distributed rainfall of 1000–1500 mm during the growing period. Dry conditions stimulate tuber growth. In China, *A. konjac* develops best when soil moisture is at 75% of the field capacity, preferably dropping to 60% when the tuber is maturing; in Japan it grows in areas with an average rainfall of 1000–1200 mm during the growing season (May–October).

Amorphophallus is found in many different soil types but never under swampy conditions. It prefers well-drained soils with a high humus content. A deep sandy-loamy soil with pH 6–7.5 is favourable; clay soils are unsuitable because they hamper tuber development.

Propagation and planting *Amorphophallus* can be propagated from seed, tubers or tuber parts, bulbils (if available) and by tissue culture. Seed propagation is not a normal practice; seed is not always available and moreover it has a dormancy period of 5–6 months. The dormancy of *A. muelleri* seed can be broken by keeping seed for 6 days in running water. Propagation from tubers or tuber parts is most common. Small tubers or pieces of 2–4-year-old mother tubers, each with one or more apical buds, are preferred. A disadvantage of tuber propagation is that it requires a large amount of tubers (about 25% of the harvest). Bulbils can be planted like small tubers. One hectare of *A. muelleri* can produce about 50 000 bulbils and 1.8 million seeds (with about 60% germination). Tissue culture is still experimental but promising.

Good soil preparation is beneficial for good growth. Compact soils should be ploughed well and where waterlogging may occur the crop is preferably planted on ridges. Planting holes of 60 cm × 60 cm × 45 cm are recommended, the bottom filled with a mixture of soil, manure and fertilizer. Planting material is sometimes dipped in liquid cow dung and in a solution of disinfectant (e.g. 2% copper sulphate) first. In Indonesia, tubers are also planted upside down to stimulate lateral bud growth. Planting is done at the beginning of the rainy season. Planting distances vary with the plant material used, e.g. seeds at 10 cm, bulbils at 35–70 cm, tubers at 35–90 cm. Normally, tubers become larger at wider spacings, but tuber growth is also influenced by the size of the planting material, water availability and soil fertility.

Most *Amorphophallus* is planted in home gardens by smallholders and intercropped with numerous other crops. In estate farming, *A. paeoniifolius* is often planted under betel palm, coconut, banana or coffee, *A. konjac* is interplanted with grain crops like maize and sorghum, or grown under shade trees (e.g. *Paulownia tomentosa* (Thunb.) Steud.).

Husbandry In the growing season the crop is weeded manually, mechanically or sprayed 2–4 times with herbicides. The crop is also earthed up within 1–3 months of planting. In areas without sufficient rainfall, irrigation is sometimes practised. Mulching is recommended (e.g. in Japan for *A. konjac* 3–10 t mulch of grain straw or wild herbs per ha per season). Recommendations for fertilizer application vary per country and area. In India, for *A. paeoniifolius* per growing season and per ha, 25 t organic manure, 20 kg N, 40 kg P_2O_5 and 80 kg K_2O is recommended at planting, and again 20 kg N after 2–3 months.

Crop rotation is recommended when weeds or diseases become too dominant. In Japan, however, a permanent cropping system for *A. konjac* exists (called 'jinenjo'), in which young and old plants are grown mixed together like a semi-natural vegetation, in which only older tubers are harvested at the end of the growing season and the rest are left in the ground. In this system a minimum input of chemical fertilizers, herbicides and pesticides is combined with large amounts of mulch. In other countries, all tubers are often collected at the end of the season, stored and replanted at the beginning of the new season. It is difficult to mechanize *Amorphophallus* cultivation because the tubers are easily damaged and are then susceptible to diseases.

Diseases and pests In general, no serious diseases and pests are known for *Amorphophallus*. Reported diseases are: footrot, caused by *Sclerotium rolfsii*, often in badly drained fields; dry rot, caused by *Botryodiplodia theobromae*, often under hot and humid conditions; white leaf disease; bacterial leaf blight; dasheen mosaic virus; konjac mosaic virus. Reported pests are: *Galerucida bicolor* (attacking the leaves), *Araecerus fasciculatus* (attacking the tubers), and various scale insects, caterpillars and nematodes. Remarkably few diseases and pests occur in the semi-natural 'jinenjo' cropping system in Japan.

Harvesting Normally, harvesting occurs at the end of the growing season, when leaves start to wither. Tubers are carefully dug up because damage will facilitate infection by diseases and pests.
In China and Japan, *A. konjac* cultivated for food is harvested one year after planting, when the tubers are small but sweet and juicy. For industrial purposes the tubers are harvested after 3 years.
A. muelleri propagated from small tubers is harvested 2.5 years after planting, whereas plants raised from bulbils are already harvestable after 1.5 year.
A. paeoniifolius propagated from small tubers can be harvested after 4 growing seasons, whereas plants raised from pieces of 4-year-old tubers are harvestable one year after planting.

Yield Yield data are scarce because most *Amorphophallus* is harvested from home gardens when needed. Individual *A. konjac* tubers weigh about 200 g after 1 year, 1–2 kg after 3 years, and can reach 9–13 kg after 4 years. At a planting distance of 70 cm × 70 cm, a 4-year-old crop may produce about 200 t tubers per ha. Yield of dry flour per ha is reported to be about 7.5 t.
Individual *A. muelleri* tubers may weigh up to 3 kg. At a planting distance of 70 cm × 70 cm, a 3-year-old crop yields about 50 t tubers per ha.
Individual *A. paeoniifolius* tubers may weigh up to 25 kg, but normally weigh 4–13 kg. Yield per ha depends on various factors, such as the size of the planting material. On average 22.5 t/ha is reported for India under rainfed conditions; with planting material of 500 g, average yield is 30–43 t/ha, with 1000 g 40–45 t/ha, with 4000 g as much as 85 t/ha.
Individual *A. variabilis* tubers can weigh up to 1.5 kg. At a planting distance of 70 cm × 70 cm a yield of 30 t/ha is theoretically possible.

Handling after harvest The natural dormancy of *Amorphophallus* tubers means that they can remain in the field for some months without quality loss. Planting material separated from the harvested product can best be stored under dry, dark and cool (10°C) conditions. Frost and temperatures above 40°C may kill the material.
Harvested tubers are cleaned first by removing earth, roots and leaf parts, then peeled or grated, and the eyes (buds) and any rotten parts removed. Then they are sliced, washed several times and cooked in water, and the starchy substance that settles out is dried, pulverized and sieved, to give a flour that is ready for consumption. Many variants of preparation exist, depending on region and species. For the production of mannan from *A. konjac* or *A. muelleri*, sliced tubers are quickly dried first because within 24 hours the gluco-mannan breaks down enzymatically in the presence of moisture. The dried parts are then pulverized carefully, to avoid damaging the mannan particles in the cells. The remaining powder is sieved and winnowed, to leave a yellow-grey sand-like powder, the so-called iles-mannan flour consisting of gluco-mannan particles. Each particle is surrounded by a thin layer which should be removed by careful grinding. The remaining flour can be stored well and is ready for further industrial applications. About 80 kg iles-mannan flour can be obtained from 1 t fresh tubers.

Genetic resources Germplasm collections of *Amorphophallus* are available in many institutes dealing with tuber crops such as the Research & Development Centre for Biology (Bogor, Indonesia; *A. muelleri*, *A. variabilis*), the Malaysian Agricultural Research & Development Institute (Kuala Lumpur, Malaysia; general collection), the Philippine Root Crop Research & Training Centre (Visayas State College of Agriculture, Baybay, Philippines; *A. paeoniifolius*), the Central Tuber Crops Research Institute (Kerala, India; general collection), the Institute of Botany (Kunming, China; *A. konjac*, general collection), the Gunma Agricultural Experiment Station (Konnyaku Branch, Gunma-ken, Japan; *A. konjac*), and Leiden botanical garden (the Netherlands; living plant collection of 120 species).

Breeding The agriculturally more important *Amorphophallus* species are difficult to breed because they are only propagated vegetatively. In India, China and Japan, breeding programmes exist to develop cultivars with a low calcium oxalate content, high mannan content, high yield, and short growing period. Since genetic variability in the existing cultivars and landraces is rather limited, research is also focusing on increasing variability by crossing with wild species.

Prospects Although *Amorphophallus* is rather popular in certain regions in Asia including South-East Asia, it is unlikely to gain more prominence in agriculture. It will remain a relatively important crop in times of food scarcity. The long growing cycle (3–4 years), the relatively large amount of tubers needed as planting material and the difficulty of mechanizing cultivation are serious drawbacks, so easier crops are preferred for research investments.

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Arenga Labill.

DC., Bull. Sc. Soc. Phil. 2: 162 (1800).

PALMAE

$x = 16$

Major species and synonyms

- *Arenga microcarpa* Beccari, in Schum. & Hollr., Fl. Kaiser Wilhelmsland: 16 (1889), synonyms: *Arenga gracilicaulis* Bailey (1898), *Didymosperma humile* (non Reinw. ex Kunth) Schum. & Lauterb. (1901), *D. microcarpum* (Beccari) Warb. ex Schum. & Lauterb. (1901).
- *Arenga obtusifolia* Martius, Hist. nat. palm. 3: 191 (1838), synonym: *Saguerus langkap* Blume (1843).
- *Arenga pinnata* (Wurmb) Merrill – see separate article.
- *Arenga tremula* (Blanco) Beccari, Philip. Journ. Sci. 4: 612 (1909), synonyms: *Caryota tremula* Blanco (1827), *Wallichia tremula* (Blanco) Kunth (1841), *Didymosperma tremula* (Blanco) H.A. Wendl. & Drude (1878).
- *Arenga undulatifolia* Beccari, Malesia 3: 92 (1889), synonym: *Arenga ambong* Beccari (1907).
- *Arenga westerhoutii* Griffith, Calc. J. Nat. Hist. 5: 474 (1845).

Vernacular names General: Arenga, sugar palm (En). Arenga, palmier à sucre (Fr). Sugar palm is particularly applied to *A. pinnata* and *A. westerhoutii*.

- *A. microcarpa*. Indonesia: aren sagu (Indonesian), sagu baruk (Talaud Islands), pepe tinggi (Halmahera). Papua New Guinea: wana kuk (Jal, Madang), wokabim (Bogia, Madang), iri (Pogatumo, Sumo).
- *A. obtusifolia*. Indonesia: langkap (Indonesian), bolangan (Sumatra), langko (Sumatra). Malaysia: rangkap, pangkap. Thailand: langkap (southern).
- *A. tremula*. Philippines: dumyaka (Tagalog), abigi (Bikol), baris (Bagobo).

- *A. undulatifolia*. Indonesia: aren gelora (Indonesian), aping (Dayak), take (Central Sulawesi). Malaysia: bangkala (Kedayan, Sabah), toki (Bajau, Sabah), aping (Iban, Sarawak). Philippines: ambong (Sulu), bat-bat (Tagbanua), caong (Luzon).
- *A. westerhoutii*. Malaysia: langkap (Penang), anowe kutare (Malaka), gtor (Perak). Thailand: langkap (Yala, Pattani), rangkap (southern), rangkai (central).

Origin and geographic distribution *Arenga* comprises 22 species ranging from India, southern China, Ryukyu Islands and Taiwan, throughout South-East Asia and Christmas Island to northern Australia, with the greatest diversity on the Sunda Shelf.

- *A. microcarpa* is native to Indonesia (from Sangihe and the Talaud islands through the Moluccas to Irian Jaya) and Papua New Guinea. It is sometimes cultivated in this area (e.g. in Sangihe and Talaud Islands).
- *A. obtusifolia* occurs in Thailand, Cambodia, Peninsular Malaysia, Sumatra and Java.
- *A. tremula* is found in the Philippines, Hainan, Taiwan and the Ryukyu Islands.
- *A. undulatifolia* occurs in Indonesia (Kalimantan, Sulawesi), Malaysia (Sarawak, Sabah) and the Philippines.
- *A. westerhoutii* is native to Peninsular Malaysia, Vietnam and Thailand.

Uses The taller *Arenga* palms store large quantities of starch in their stem that are later converted into sugar to be translocated to the inflorescences. The sugar can be drawn off in the juice by tapping the peduncle and rachis of the male inflorescence. By far the most important sugar producer in the genus is *A. pinnata*, but other species are used similarly. The starch of the stem can also be harvested. For instance, in Sangihe and the Talaud Islands *A. microcarpa* is cultivated for its starch production from which, for example, cookies known as 'bagea' in North Sulawesi are baked; in Hainan, starch is extracted from *A. tremula*.

The cabbage (young tops) of all species is edible and used as a vegetable, although consuming large quantities e.g. of *A. tremula* can provoke toxic effects. The leaves are used for thatching and wickerwork. The petioles and midribs are used to make baskets (*A. tremula* in the Philippines), arrows for blowpipes (*A. undulatifolia*) and plugs for blowpipe darts are made from the pith of the petiole of *A. undulatifolia* in the Philippines.

Fruits of most species are poisonous and are sometimes used medicinally and criminally. The wood of some species is used to make small utensils or is even used in construction, but it is said not to be durable (e.g. *A. obtusifolia*, *A. westerhoutii*). All species have recognized or potential ornamental value.

Production and international trade Of the *Arenga* sugar palms, only products of *A. pinnata* are traded beyond the local market. Few statistics are available. In the Talaud Islands, about 30 000 t of starch is produced annually from 20 000 ha of *A. microcarpa* planted in village gardens.

Trade in seed and seedlings of *Arenga* for ornamental planting is still very limited.

Properties Hardly any data are available on the nutritional composition of the edible parts, nor on the specific properties of the carbohydrates.

The fleshy mesocarp of the fruits usually contains many oxalate crystals, making the flesh inedible.

Description Dwarf to large, solitary or clustered, usually unarmed, usually hapaxanthic, sometimes pleonanthic, monoecious, shrubby, stemless or tree palms. Stem with distinct internodes, usually obscured by persistent fibrous leaf bases and sheaths. Leaves flabellate, usually induplicate and imparipinnate; sheath covered with hairs or scales, often extending into a ligule,

Arenga microcarpa Beccari – habit.

eventually disintegrating into a mass of black fibres; petiole usually well developed, slender to robust, channeled or ridged, hairy; leaflets single-fold, arranged or grouped regularly and held in several planes, or deeply lobed and wavy, distal margins jaggedly toothed with small sharp teeth, variously tomentose to glabrescent. Inflorescences usually interfoliar and produced in a basipetal sequence (hapaxanthic type) or in acropetal sequence (pleonanthic type), usually solitary and branched to 1–2 orders, usually unisexual with pistillate inflorescences tending to be distal to the staminate ones and sometimes much larger; peduncle very short to well developed, slender to massive, with conspicuous bracts; rachillas erect or pendulous, distant or crowded, slender to massive, bearing a loose to dense spiral of triads; flowers in triads, sessile, consisting of one female between two males, but by abortion of one sex the inflorescences usually unisexual; male flower ellipsoidal, sepals and petals 3, coriaceous to fleshy, stamens (6–)20–90(–300); female flower globose, sepals and petals 3, coriaceous to fleshy, ovary trilocular, stigmas 2–3. Fruit a globose to ellipsoidal drupe, often triangular in cross-section, exocarp smooth and variously coloured, mesocarp fleshy with numerous raphides, endocarp not differentiated. Seed 1–3, usually ellipsoidal, hard, with homogeneous endosperm, lateral embryo and remote-tubular germination.

- *A. microcarpa*. Medium-sized hapaxanthic tree, growing in clusters. Stem 4–8(–14) m tall, internodes 20 cm long, 12 cm in diameter. Leaves on the stem 5–10; sheath 50–80(–130) cm long, near margin rather fibrous; ligule 40 cm long; petiole 25–40(–100) cm long, about 2 cm in diameter, surface rough; blade in outline 4–6 m × 1.4 m with 40–60(–70) leaflets on either side; there are 8 upright leaflets on either side of the base of the blade; leaflets in groups of 2–4, linear, 40–110 cm × 2–5 cm, flat, margin sparsely praemorse. Male inflorescence single or multiple, 60 cm × 30 cm; peduncle about 10–15 cm × 2.5 cm; rachillas 30, slender, 45–80 cm long. Female inflorescence always single, size similar to the male one. Fruit globose, about 1.5 cm in diameter, bright red.
- *A. obtusifolia*. Pleonanthic tree, growing in clusters. Stem up to 20 m tall, internodes 10–15 cm long, 15–30 cm in diameter, stoloniferous; stolons up to 15 m long, 2 cm in diameter. Leaves on the stem about 8; sheath 20 cm long, near margin slightly fibrous; ligule 40 cm long; petiole 40 cm long, 4–6 cm in diameter, surface rough; blade in outline 3–4 m × 2.2 m with about 90 leaflets on each side; leaflets linear, 80–110 cm × 3–4 cm, flat, margin sparsely praemorse. Male inflorescence single, 60 cm × 40 cm; peduncle 20 cm × 5 cm; rachillas 40, slender, 40 cm long. Female inflorescence similar to the male one. Fruit globose to ovoid, 5 cm × 3.5 cm, dark red.
- *A. tremula*. Hapaxanthic shrub, growing in clusters. Stems up to 4 m tall, internodes 15–20 cm long, 8–12 cm in diameter. Leaves on the stem about 6; sheath up to 40 cm long, rather fibrous near margin; ligule tubular, about 15 cm long; petiole 80 cm long, 0.8 cm in diameter, surface rather rough; blade 2 m × 1.2 m with up to about 60 leaflets on each side; leaflets not grouped or in groups of 2–5, linear, 60–100 cm × 2–3.5 cm, upright, flat, margin sparsely praemorse. Male inflorescence single or multiple, 40–60 cm × 30 cm; peduncle 20 cm × 3 cm; rachillas 50, slender, 20–50 cm long. Female inflorescence similar to the male one. Fruit globose, 1–2 cm in diameter, bright red.
- *A. undulatifolia*. Medium-sized hapaxanthic tree, growing in clusters. Stem 4–8 m tall, internodes 15 cm long, 20 cm in diameter. Leaves on the stem about 10; sheath up to 50 cm long, not fibrous; ligule about 40 cm long, rather thorny; petiole 200 cm long, 8 cm in diameter, surface rather rough; blade 5 m × 1 m, with 30–50 leaflets on each side; leaflets linear, 60–120 cm × 6–20 cm, undulate, along margin with many distinct lobes. Inflorescence single or multiple, when multiple usually one large female between various smaller males; male inflorescence 40–60 cm × 20–40 cm, peduncle about 20 cm × 4 cm, rachillas 5–10, slender, 60–120 cm long; female inflorescence similar to the male ones. Fruit globose, 3–4 cm long, 2.5–3 cm in diameter, dull red.
- *A. westerhoutii*. Hapaxanthic tree, not growing in clusters. Stem 12 m tall, internodes 20–40 cm long, 40 cm in diameter. Leaves on the stem 6–12; sheath 50–150 cm long, fibrous; ligule 40 cm long, fibrous; petiole 100–190 cm long, 9 cm in diameter, surface rough; blade 5.9–6.8 m × 3.1 m with about 100 leaflets on each side, arranged in one plane; leaflets linear, 130 cm × 9.5 cm, flat, margin praemorse. Male inflorescence single, 90–200 cm × 80 cm; peduncle 50 cm × 10 cm; rachillas 60–70, slender, 60 cm long. Female inflorescence similar to the male one. Fruit globose, 4–4.5 cm in diameter, blackish green.

Growth and development In a humid environment (in litter or about 2 cm underground) seed may start to germinate. In 2–3 months time, a narrow tubular cotyledonary sheath, 2–5 cm long, bearing an embryo, develops laterally from the seed and grows down vertically into the ground. The size of the cotyledon depends on the species, shrubs having a short and small one, tree species a larger one. Later on, a radicle arises from the terminal part of the cotyledon and grows down vertically, followed by 4–10 adventitious roots which arise radially around the radicle. From the base of the radicle a plumule grows up to the soil surface and the first obovate seedling leaves may appear aboveground after 3–6 months. The stem never branches. Inflorescences arise from every node on the stem of mature plants. Of the 22 species in *Arenga*, in 17 species (including four of the five described here) growth of the stem is terminated by the reproductive phase, flowering taking place from the top downwards, after which the tree dies (hapaxanthic type); in 5 species (including *A. obtusifolia* described here) flowering starts at the base of the mature stem, proceeding upwards continuously, not followed by the death of the tree (pleonanthic type).

Other botanical information Of the 22 described species in the genus *Arenga*, 10 species and one subspecies are endemics. The endemics are usually shrubs, consisting of small and rare populations.

In *A. tremula* 2 subspecies are distinguished:

- subsp. *tremula*: leaf blade with about 60 upright leaflets on each side, the leaflets in groups of 2–5; male inflorescence single or multiple; petals of male flower ellipsoid, 8–10 mm × 6 mm; anthers 3–4 mm long. Occurring in the Philippines.
- subsp. *longistamina* Mogea: leaf blade with about 28 leaflets on either side which are arranged in one plane and not in groups; male inflorescence always single; petals of male flower oblongoid, 9–12 mm × 5 mm; anthers 6–7 mm long. Occurring in Hainan, Taiwan and the Ryukyu Islands.

Ecology *Arenga* palms are found mainly in primary per-humid tropical forest, rarely in secondary forest, from sea-level up to 1700 m altitude. *A. microcarpa* and *A. obtusifolia* occur up to 700 m altitude, *A. tremula* is restricted to the lowlands, *A. undulatifolia* occurs up to 1500 m and *A. westerhoutii* up to 1400 m altitude.

Agronomy Hardly any specific information on agronomic aspects is available for the *Arenga* species considered here. Most probably, these practices will be similar to those for *A. pinnata*. On the Talaud Islands, an annual production of starch of 1.5 t/ha has been reported for *A. microcarpa* from village gardens.

Genetic resources and breeding There are no *Arenga* germplasm collections or breeding programmes. In Indonesia, a living collection of 11 *Arenga* species is available in the Bogor Botanical Gardens.

Prospects Because most *Arenga* species are useful for sugar, starch and thatch production, and potentially have ornamental value, they deserve much more scientific attention. Germplasm collection is needed urgently as many species have become very rare.

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Arenga pinnata (Wurmb) Merrill

Int. Rumph. Herb. Amb.: 119 (1917).

PALMAE

$2n = 32$

Synonyms *Arenga saccharifera* Labill. (1801).

Vernacular names Sugar palm, areng palm (En). Palmier à sucre, palmier areng (Fr). Indonesia: aren, enau, kawung. Malaysia: enau, kabong, berkat. Philippines: kaong (Tagalog), bagobat (Bisaya), hidiok (Bisaya). Burma (Myanmar): taung-ong. Cambodia: chuëk', chraè. Laos: ta:w ta:d (northern). Thailand: chok (southern), tao (northern). Vietnam: b[us]ng b[as]ng, do[as]c, do[as]t.

Origin and geographic distribution Sugar palm is thought to be indigenous where it is encountered at present, except for the Pacific Islands and a few places in Africa where it has been introduced. This implies that its origin lies in an area covering South-East Asia up to Irian Jaya in the east, extending north-eastwards to the

Ryukyu Islands (Japan) and north-west to Annam (Vietnam) and the eastern Himalayas. It is mostly found near villages. It is found growing wild in primary or secondary forest.

Uses All parts of the palm are used, and for a multitude of products. The main products are derived from tapping the inflorescence stalks: a sweet aromatic juice, both fresh ('nira') and fermented ('toddy'), vinegar resulting from continued fermentation, and yeast made from the residue deposited during fermentation; above all the dark-red palm sugar, obtained from the juice, and widely used in all kinds of dishes, sweets, drinks and preserves. The juice is flavoured by adding leaves of *Garcinia* L. and bark of *Xylocarpus* Koen. and several *Ulmaceae*, which make the juice more bitter and improve storability; alcohol can be distilled from the palm wine.

Other food products are starch, extracted from the pith of the trunk, which may be used to prepare speciality foods such as 'bakso' (Indonesia), and the grubs of the palm beetle (*Rynchophorus ferrugineus*) which are reared on fallen stems and eaten raw, fried or cooked. Young leaves, still white, are eaten in the same way as palm cabbage. Bees collect excellent honey from the flowers, and sweetmeat ('kolang kaling', Indonesia) is made by boiling the white endosperm of immature seeds with sugar. The production of these secondary foodstuffs is limited where tapping takes precedence.

Products from fibrous material take second place after those derived from tapping. Fibres are recovered from the roots, the pith of the trunk and leaf stalks, but most important are the long black-grey fibres ('ijuk', Indonesia) surrounding the trunk. The latter, although coarse, are extremely durable even in seawater and have frequently been used for cordage on ships, and as a cover to protect wooden poles in soil and seawater against worms and insects. 'Ijuk' mattresses are laid on roadbeds along the coast to stop burrowing prawns from surfacing with their mud piles. The fibre is also used to make sieves, to construct roofs, to reinforce concrete; heavy-duty brushes and brooms the world over bristle with 'ijuk' fibres. 'Ijuk' paint brushes clean and paint ship hulls in a single operation.

The fine pulp occurring between the leaf sheaths used to be used for tinder and to caulk boats. Short ropes can be used as a portable fire lighter; the rope remains glowing in all weathers. Stout bristles between the thin fibres near the leaf bases have been used as pens and arrows. A bundle of these bristles makes a veritable torch, burning brighter when swung and producing a beam of light as the core burns deeper and glows more intensely. The bristles are sometimes used for burning as scent material. Fibres from the leaf stalks and roots are used for fishing-lines, snares and fine matting. The roots growing from the base of the stem are sometimes cut into fibrous boards for orchid cultivation.

The impressive leaves are also put to many uses. They serve to construct temporary shelters and the unfurling, still white leaves are used as hanging decorations for festivities. The leaflets are used in basketry, their stalks for brooms and sate sticks. Young leaflets may be eaten, but at a somewhat later stage they substitute for cigarette paper and serve as fastening ribbon. The large leaf stalks are used as firewood and to make walking sticks and musical instruments. Walking sticks can also be made out of the inflorescence stalks.

The green peel of the unripe fruit is poisonous and causes serious skin reactions on contact because of the calcium oxalate crystals; it is sometimes used to protect fish ponds from barefoot intruders. The pulped fruit in water brings fish to the surface. The seeds are favoured by pigs and used to bait wild pigs; many toys in the villages used to be carved from the seeds.

The trunk consists of a soft starchy core with many tough fibres and a woody cylinder. The attractive black and yellow wood of the trunk is used for flooring, furniture, tool handles, and as a fuel wood of high calorific value. The trunk base is easily hollowed to obtain a durable barrel or a water conduit.

Medicinal uses have been reported for the young roots (kidney stones), old roots (toothache), the fermented juice (the alcohol obtained through distillation and mixed with several herbs and roots of other plants is considered a general-purpose medicine), the sugar (laxative) and the fine pulp occurring between the leaf sheaths (to speed up recovery from burn wounds). The trees are sometimes planted to mark boundaries or to prevent landslides. In certain regions, dowry is paid in the form of a few sugar palm trees.

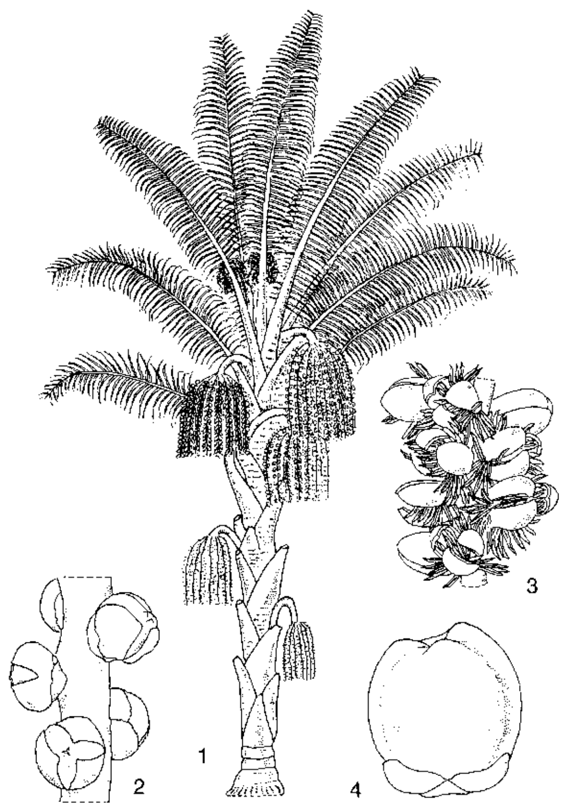
Production and international trade Almost all products of sugar palm are locally traded and used. Export data are scattered and probably incomplete. In 1986, 200 t palm sugar per month were exported from Indonesia to Australia; in 1994 the export price was about US$ 3.0 per kg. In 1985 one of five exporters of palm fibres shipped 400 t, representing a value of about US$ 550 000.

Most of the exported fibre passes through Singapore. Starch is exported on a small scale. Canned 'kolang kaling' production and export is steadily increasing. Sugar palm is still a smallholder crop, but in Indonesia commercial plantations are being established. Through a national sugar palm promotion project, Indonesia hopes to achieve selfsufficiency in sugar through sugar palm and nipa palm.

Properties The palm juice contains 5–21% sugar. The sugar crystallizes beautifully into pale-yellow storable sugar of good quality under the right cooling and stirring conditions. The palm sugar contains 75% sucrose (saccharose) and a maximum of 6% reducing sugars, which is low and considered a desirable quality. Starch should be white and dry, obtained through repeated washing and settling. The fibres are graded into five length classes, the longest and thickest ones (up to 2 m long) being most expensive.

Description A moderate to tall unbranched, hapaxanthic, solitary palm. Roots black, very strong, extending far (sometimes more than 10 m) from the stem and going as deep as 3 m. Trunk 10–20 m long and 30–65 cm in diameter, covered by bases of broken-off leaves and long black-grey fibres; crown dense, with 12–20(–28) erect to spreading leaves. Leaves 6–10(–12) m long, pinnate; petiole 1–1.5(–2.3) m long, with sheath at base; leaflets numerous (80–130(–155)), strap-like, 140–180 cm × 8–11 cm, crowded along the rachis and held in several planes, with auricles at base, rounded or obtuse and toothed at apex, glabrous above, scabrous beneath. Inflorescence usually unisexual, pendulous, often more than 2 m long, arising from leaf axil, peduncle breaking up into a number of flower-bearing spikes; female inflorescences 3–7, formed at the top, male ones 7–15, appearing later and lower on the stem; flowers with 3 coriaceous sepals and a 3-lobed corolla, tubular at the base; male flowers up to 11 500 per inflorescence, with many stamens, greenish to bronzy when still closed, yellowish when open; female flowers up to 15 000 per inflorescence, with a globose, trilocular ovary. Fruit a globose to ellipsoid drupe, 5–8 cm long, fleshy, first green, later turning yellow and black after falling, 2–3-seeded. Seed black.

Growth and development Germination is very unpredictable, taking from one month to more than a year, and is remote-tubular. A tube emerges from the germpore near the apex of the seed and enters the soil. The radicle and plumule appear from the side of this tube, followed by 3–4 roots which grow straight up. Soon the radicle and these early roots are overtaken by the normal adventitious roots.



Arenga pinnata (Wurmb) Merrill – 1, flowering tree; 2, part of pistillate rachilla; 3, part of staminate rachilla; 4, fruit.

The rosette stage takes 3–5 years and the trunk growth phase 5–10 years, depending mainly on temperature, but also on competition for light. The rate of leaf production during trunk formation greatly depends on the growing conditions, but it is of the order of 3–6 leaves per year. Fifty leaves may be the maximum over a palm's life. The last two leaves emerge simultaneously, signalling the onset of flowering. These leaves expand fully, but the few remaining primordia and the growing point itself 'petrify': they become woody without further growth. The first inflorescences emerge from the axil of the uppermost leaves and bear female flowers. Flowering gradually proceeds downwards: 3–7 female inflorescences are followed by 7–15 male inflorescences, although the latter may include a few which bear female flowers as well or which are completely female. Sometimes the formation of lower-positioned female inflorescences can be induced by removing the top female inflorescences. Buds lower on the trunk tend to be underdeveloped and in the natural state the palm dies before it is their turn to bloom. Sometimes completely male trees are encountered which are known to produce larger amounts of sugary juice (called 'puso lolon' trees in North Sulawesi). The trunk serves as a store for starch that is accumulated after the rosette stage in the parenchyma of the pith. When flowering starts the starch is converted into sugar and dissolved in the stem fluid. As with *Metroxylon sagu* Rottboell, additional sugar is produced by photosynthesis in the functional leaves. The flowers are presumably cross-pollinated since there is little overlap in flowering of female and male inflorescences of the same palm. Bees pollinate flowers, but small flies also swarm in large numbers around male inflorescences. Each female inflorescence carries thousands of fruits which take 12 months from flowering to maturity if the palm is not tapped. One palm may produce as many as 250 000 seeds.

In the natural state the palm dies after the fruit of the inflorescences near the top have matured, that is about 2 years after flowering starts. Skilful tapping can extend the tree's lifespan by 10 years or more. Since a load of growing fruit is essential to keep the palm alive, few or no female inflorescences are tapped. The art of tapping is to tap so little that fruits do not starve, but to tap sufficiently to delay their maturation indefinitely. Overtapping results in the lower green leaves breaking off, followed by massive premature fruit fall and death. The sagging of these leaves is the first sign that the palm is bleeding excessively. An optimal tapping intensity maintains an adequate sap stream to the fruit, ensuring a minimal rate of fruit growth.

A smallholder in North Sulawesi pointed out a tree which he had been tapping for 15 years! This implies a leaf age of more than 15 years. The extended life of the leaves under judicious tapping must contribute substantially to total sugar yield over such long periods. One documented tree produced more than 20 000 l of sugary juice within a period of three years. This represents some 12 t sugar from one tree.

Ultimately, tapped trees produce fruit too; if tapping is stopped in time the unripe fruits can be used for 'kolang kaling' production. The remaining starch level in the trunk is too low to make extraction worthwhile (less than 20 kg for tapped trees).

Ecology Sugar palm grows best in warm conditions with a maximum amount of light and abundant water supply on very fertile soils. It can, however, grow under a wide variety of conditions, both in equatorial and seasonal climates, from sea-level up to 1400 m altitude, on all soil types from heavy loam to loamy sand and lateritic soils that are not regularly inundated. The growth rate drops substantially where growing conditions are less favourable. Wild in primary or secondary forests, it occurs especially on sites poor in nutrients and in marginal areas such as denuded hillsides. The age of first flowering depends strongly upon the altitude, being 5–7 years at sea-level and 12–15 years at 900 m altitude.

Propagation and planting Normally, people drop the seed where they would like the palm to grow. Sometimes wild seedlings are collected and transplanted. In a nursery, the following procedure has proved successful. Ripe, black fruits under superior palm trees are collected. Seed left behind after the fruit has decayed may also be collected. They are cleaned in water and those that float are removed. Seed with fungal or bacterial growth near the pore is also discarded. Then they are scratched on a rough stone to scarify the thin black outer layer down to the underlying brown layer, close to the pore. Filing down to the white endosperm may result in more seed rotting. The seed is left to soak in water or wet sacks for 24 hours. Then it is sown in coarse sand kept moist, with the germpore pointing downwards. Air humidity should be high during germination. After 3 weeks, some 75% have germinated; these are transferred to plastic containers when the germination tube is 2–3 cm long and before the upward-growing roots have formed, since these break off easily. A heavy-gauge polythene is used since flimsy material is easily perforated by the roots. Seed should be planted so deep that the germination tube does not dry out. The seedlings stay alive in heavy shade but growth is minimal under such conditions. Direct sunlight stimulates an early appearance of the first leaf. The seedlings can be planted out when the second leaf has unfurled. The young seedlings should be hardened off in the nursery before transplanting.

To obtain a closed stand under fair growing conditions, the palms may be spaced 6 m × 7 m (about 250 trees/ha). Intercropping with fast-growing woody legumes that can be coppiced may be advisable to provide shade for the young palms and firewood to boil the juice. Wind-breaks may be needed in exposed sites to prevent breakage of leaves.

Husbandry Crop care is limited to occasional weeding. Manures and fertilizer are not applied. However, appreciable amounts of nutrients, notably K and N, are removed by tapping. Based on data obtained in 1933, this amounts to (%): N 0.041, P 0.001, K 0.12, Mg 0.0096 and Ca 0.016. Fertilization does strongly increase the size of the leaves. Shortly before the rosette stage ends, the palms should be provided full light.

Diseases and pests No serious diseases and pests occur. Consequently, crop protection chemicals are not normally used. On Java, a locust species (*Valanga nigricornis*) has been reported to attack leaves. Locally, caterpillars of *Artona catoxantha*, *Elymnias hypermnesta-nesaea* and *Hidar irava* have been observed eating young leaves. Top death of young plants has been reported and is possibly caused by flies of *Atherigona arenga*. Sometimes, caterpillars of *Batrachedra* spp. are observed on the male inflorescences. The top of young trees is occasionally damaged by the common coconut top borer (*Oryctes*). In North Sulawesi people use one of the sharp bristles of the palm to pick in the hole and kill the larvae inside, normally resulting in continued survival and good growth of the palm. In a young plantation, damage was caused by mice eating the sweetish growing tip of the seedlings. Rats may eat the ripening fruit.

Harvesting Tapping is preceded by pre-treating the peduncle of the inflorescence by beating it and swinging it about. The peduncle of both male and female inflorescences can be tapped, but the latter are tougher and pre-treatment less often results in a satisfactory flow of juice. When the first male inflorescence is almost fully expanded, the scales covering the peduncle are removed. Then the beating and swinging starts. This is done to cause some internal ruptures so that the juice will continue to flow later on after cutting. The frequency and duration of the pretreatment differ widely in the various regions. Some reports mention beatings over only a 3–7 day period. In North Sulawesi, at about 900 m altitude, the peduncle is treated five times during five weeks, and the stalk is tapped for 6–12 months. In general pretreatment and tapping periods are longer with increasing altitude. The first beating is light, otherwise the peduncle may wilt. Subsequent beatings are steadily intensified. The peduncle is beaten from the base upwards, stripwise until the entire circumference has been treated. The beating is moderated during the rainy season and for light-coloured peduncles. The peduncle is also swung about to rupture vessel connections close to the trunk where the mallet cannot reach.

The pretreatment and the subsequent cutting of the peduncle are timed in accordance with the condition of the male flowers. The inner perianth with the stamens of a flower bud is removed, and the interior colour and striping of the outer perianth indicate the development stage. The peduncle is almost ready to be cut when a watery sap oozes from the scar. Gradually the sap becomes more viscous until it turns hyaline yellow. This is also the time that bees are attracted by a dry yellow exudate on the inflorescence. Shortly after this stage the flowers open. The villagers first cut a single spike to see whether it bleeds for more than a day. If it does, the peduncle is cut with a single stroke aimed at making a clean cut close to the point where it bifurcates into the spray of flowering spikes. The length of the remaining peduncle determines the maximum duration of the tapping period.

For unknown reasons, it is customary in Indonesia not to collect the juice during the first day; in Peninsular Malaysia people used to wait for several days. To produce 'toddy' a bamboo vessel is fixed under the dripping peduncle end. It is inoculated with some old toddy to introduce the yeast (*Saccharomyces* spp.) that converts the sugar into ethanol. Sometimes additives are used to obtain a specific taste or strength. When sugar is to be produced from the sap, the bamboo vessels need to be cleaned each time they are replaced. This is done by drying them in the smoke of a fire or by rinsing with boiling juice.

For sugar production, a very thin slice is cut from the peduncle twice a day, as this results in less but sweeter sap. For 'toddy' the slices are thicker, also depending on the desired alcohol content. If rather thick slices are cut, a large palm may yield some 60 l of fairly sweet juice per day for several months, but this is often associated with signs of over-tapping: sagging leaves which eventually fall down, and massive drop of unripe fruit. After each cut, the peduncle end is covered with some material – usually a large leaf – to protect it from the sun; this promotes the sap flow.

The starch is harvested in the same way as that of the sago palm. The tough fibres in the pith make it harder to obtain the starch. Normally the villagers choose trees that have failed to respond to tapping treatments. These palms yield the highest quantities of starch (100–125 kg/tree). The thick, very hard wooden zone surrounding the pith makes it very laborious to open the stem.

The 'kolang kaling' is produced from immature fruits, which are burned or cooked and then peeled; finally the endosperm of the young seeds is boiled with sugar. The 'ijuk' is cut with a machete for the first time at an age of 4–6 years; scissors have also proved practical. Farmers in three different regions in Indonesia claim to have better growth of the trees when the 'ijuk' is removed regularly.

Yield In North Sulawesi, village stands of sugar palm of all ages currently produce about 70 kg sugar per ha per day. This adds up to an annual yield of 25 t sugar per ha. The sugar yield of such stands of unselected material is limited, because about half the palms do not bleed. When the first three treated inflorescences of a palm fail to bleed satisfactorily, people give up and it is left for the fruit and sometimes for starch extraction. Sometimes such trees are felled with the top downhill by partly cutting through the stem so that it stays connected to part of the root system. Then the top is cleared of leaves, and a large amount of sugary juice can be collected by slicing ever deeper in the heart cabbage. This destructive method yielding large quantities of sugary juice for some 10 days is mainly used for the trees that could not be tapped successfully, and during special festivities for the production of toddy.

One tree may yield enough sweetmeat to fill about 2000 one-litre cans. Moreover, the fruit of tapped trees can still be used for making 'kolang kaling'. A 15 m high palm with a diameter at breast height of 40 cm contains 100–150 kg starch; in a mechanized large-scale operation even extraction of the remaining starch might be worthwhile. About 15 kg of 'ijuk' fibre can be gathered from a tree, 3 kg of which are valuable long fibres. The annual yield of these superior fibres is about 150 kg/ha. All these components add up to an appreciable yield, and it is not surprising that a family is considered well-off as long as it is tapping 3–4 sugar palm trees.

Handling after harvest The juice is evaporated in open pans. To prevent the liquid from boiling over, some fatty or oily material (castor beans, coconut endosperm, tung seeds) is added. As soon as the liquid turns dark red and begins to set, the sugar is poured into moulds. If the sugar is to crystallize at this moment, vigorous stirring should be applied while stopping the heating altogether. For the stirring normally large wooden forks are used. Because of impurities, palm sugar does not store well. Keeping quality may be improved by adding sodium bisulphate or lime (CaO) during evaporation.

Genetic resources No substantial germplasm collections are being maintained. A survey including many different regions in Indonesia revealed large differences in productivity between trees not related to tapping techniques and soil types, indicating potential for selection.

Breeding In North Sulawesi, selection of superior trees to obtain seed for propagation is carried out in several sugar palm stands. It appears that selection may raise the percentage of palms that bleed well from 50 to 85. In Java, large heavy-bearing trees are often used to produce 'kolang kaling'. Since these trees do not produce offspring for the next generation, the practice may amount to a negative selection.

Prospects The future for sugar palm seems bright, even though the maritime world no longer depends on 'ijuk' fibres. Limited, largely local demand has so far hampered large-scale production of palm sugar and its by-products. However, calculations based on the sap flow of a 15 m high tree of 40 cm girth being tapped during the last 10 years of its 20-year lifespan show the scope for improving yields. The average daily yield over this period was about 30 l juice or about 5 kg sugar. Because intervals of several months sometimes occur between the tapping of 2 successive inflorescences and there are occasional mishaps caused by failure of the pretreatment of an inflorescence, a palm may be in production for only half that time. Based on these figures, impressive annual yields per ha have been calculated. For instance, a stand of 200 palms per ha with 85% of the tappable palms bleeding well, with an average of about 34 palms per year, may produce annually well over 25 t sugar per ha. However, tapping extracts considerable amounts of K, N, Ca and Mg from the system. Therefore, adequate cropping techniques, including fertilization, should be designed and tested to create optimal conditions for sugar-palm cultivation.

Meanwhile, large sugar-palm plantations are being established in Indonesia; several so-called transmigration timber estate schemes have included sugar palm planting. High rates of return are anticipated provided large (export) markets can be supplied. The estates will generate a great deal of employment and in certain areas will protect unstable sites. Especially with the reduced sugar production from sugar cane due to urbanization, the increased demand by a growing population, and the relatively easy refining of the palm sugar, there should be a very large local market within Indonesia.

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W.T.M. Smits

Borassus flabellifer L.

Sp. pl.: 1187 (1753).
PALMAE
$2n = 36$

Synonyms *Borassus flabelliformis* L. (1774).

Vernacular names Toddy palm, wine palm, palmyra palm (En). Palmier à sucre, rônier, rondier (Fr). Indonesia: lontar (general), tal (Java), siwalan (Sumatra), tala (Sulawesi). Malaysia: lontar, tah, tai. Burma (Myanmar): tan bin. Cambodia: thnaôt. Laos: ta:n. Thailand: tan (general), tan-yai (central), not (southern). Vietnam: th[oos]t n[oos]t, th[oos]t l[oos]t.

Origin and geographic distribution *B. flabellifer* is distributed from India through South-East Asia to New Guinea and North Australia. It is particularly abundant in India, Burma (Myanmar) and Cambodia, where it is frequently planted. It is almost generally assumed that *B. flabellifer* is a selection by man from the more diverse *B. aethiopum* Mart. of Africa. Its distribution probably followed Indian trade routes in prehistoric times.

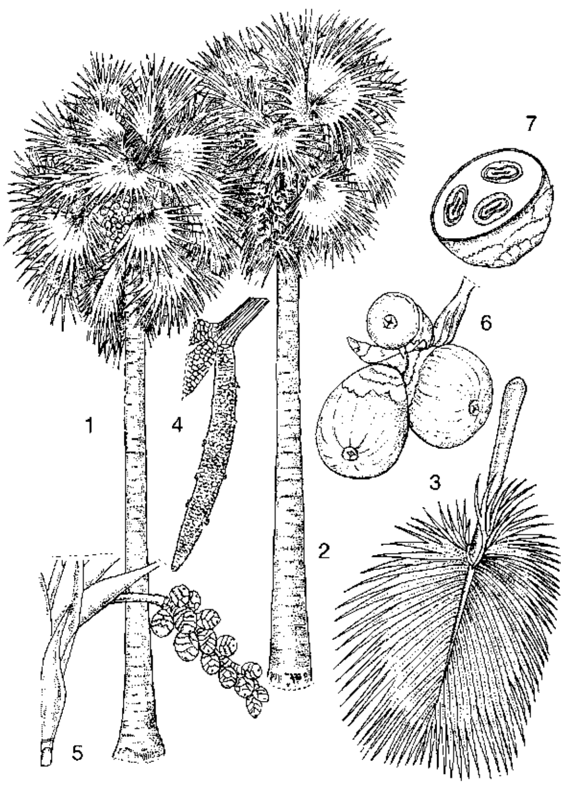
Uses All parts of the toddy palm are used. In India it is called the tree with 800 uses. The main product is the sap obtained from tapping the inflorescences (in *B. aethiopum*: tapping of the growing point of the trunk), which may be drunk immediately or be processed into sugar or be allowed to ferment for a few hours to become toddy. This mild palm wine with 5–6% alcohol content may later be converted into distilled ethanol (arrack) or vinegar. The leaves were formerly used to write on. They may still be used as thatch ('atap') and are said to last at least two years. They are also used for baskets, brushes and buckets; the fibres of young leaves can be woven into delicate patterns. Petioles are often used as poles for fencing or as firewood and can be split into fibre, to be used for weaving and matting. The lowest 10 m of the trunk has hard and strong wood, good for constructing buildings and bridges. The somewhat softer middle part can be split into boards. The soft upper 10 m of the trunk contains some starch, which may be harvested in times of food scarcity. The wood and leaves are also used as fuel. The seedlings (underground and tuber-like) are sometimes grown for use as a starchy vegetable, and eaten boiled or raw, but they may be slightly toxic. In Burma (Myanmar) they are considered a delicacy. The growing point of the palm (palm heart or palm cabbage) is also edible. The tender mesocarp of young fruits is cooked in curry. The ripe fruit has a yellow edible pulp with a distinctive aroma. The young solid or gelatinous endosperm of the seeds is also eaten fresh or in syrup. In Burma (Myanmar) and Cambodia, toddy palms are often planted as a windbreak or to delimit fields. Innumerable traditional medicinal uses are known for all parts of the toddy palm.

Production and international trade Toddy palm is mainly grown for subsistence and is primarily produced by smallholders. Surplus production may be sold on local markets. No statistics are available on production and trade, but there are some statistics on palm stands. In Sri Lanka there are 10 million palms on 25 000 ha (two-thirds in Jaffna district), and in India 60 million palms (two-thirds in Tamil Nadu). Central Burma

(Myanmar) has 2.5 million palms on 25 000 ha, and central Cambodia has 1.8 million palms. In 1968 the toddy palm sugar production in Cambodia was estimated at 35 000 t per year, and the national consumption at 10 000 t. Stands in Thailand have nearly been eradicated. In Indonesia toddy palm is found in Central and East Java and on Madura, totalling 0.5 million palms on 15 000 ha. There are also large stands in Sulawesi and on the Lesser Sunda Islands, and some in the Moluccas and in south-eastern Irian Jaya. In Burma (Myanmar) and Cambodia smallholders own 30–40 toddy palms on average (25 male, 15 female trees).

Properties The sap of toddy palm contains 17–20% dry matter. It has a pH of 6.7–6.9(–7.5) and per litre contains some proteins and amino acids (360 mg N), sucrose 13–18%, P 110 mg, K 1900 mg, Ca 60 mg, Mg 30 mg, vitamin B 3.9 IU, and vitamin C 132 mg. The 7–9 g/l reducing sugars are probably formed through enzymatic or microbiological reactions immediately after tapping. The ash content of the sap is to 4–5 g/l.
A rather large fresh fruit may weigh 2790 g (100%): perianth lobes 175 g (6.3%), exocarp 120 g (4.3%), mesocarp fibre 66 g (2.4%), mesocarp edible pulp 1425 g (51.0%) and 3 seeds 1004 g (36.0%). The 3 seeds consist of shell 394 g, endosperm 609 g and embryo 1 g.

Description Robust, 25–40 m tall, solitary, pleonanthic, dioecious palm. Stem massive, straight, up to 1 m in diameter at base, conical up to about 4 m high, thereafter cylindrical and 40–50 cm in diameter, occasionally branched, covered by leaf bases when young, rough and ringed with leaf scars when older, fringed at the base with a dense mass of long adventitious roots. Leaves (30–)40(–60), arranged spirally, leathery, induplicate, strongly costapalmate; sheath open when young, later with a wide triangular cleft at the base of the petiole; petiole woody, 60–120 cm long, deeply furrowed; margins of sheath and petiole armed with coarse, irregular teeth; blade suborbicular to flabellate, 1–1.5 m in diameter, divided along adaxial folds to about half its length into 60–80 regular, stiff single-fold segments that are about 3 cm broad at base. Inflorescence interfoliar, peduncled, shorter than the leaves, the male and female dissimilar. Male inflorescence massive, up to 2 m long, consisting of about 8 partial inflorescences of three rachillae each; rachilla spike-like, fleshy, 30–45 cm long, bearing spirally arranged imbricate bracts, connate laterally and distally to form large pits, each containing about 30 flowers, exserted singly in succession from the pit mouth; flowers 3-merous with 6 stamens. Female inflorescence unbranched or with a single first order branch, covered with sheath-like bracts; rachilla massive, fleshy, thicker than the male one, bearing large cupular bracts, the first few empty, the subsequent ones each subtending a single female flower with several empty bracts above the flowers; flowers larger than male ones, 3-merous, tricarpellate. Fruit a globose to subglobose drupe, 15–20 cm in diameter, 1.5–2.5(–3) kg in weight, dark purple to black; petals persistent, brittle, not imbricate; exocarp smooth, thin, leathery; mesocarp thick, juicy, fibrous, often fragrant, yellowish; endocarp usually comprising 3 hard bony pyrenes. Seed shallowly to deeply bilobed, pointed; endosperm sweet and gelatinous when immature, hard and ivory-like with a central cavity when mature.



Borassus flabellifer L. – *1, habit female palm; 2, habit male palm; 3, leaf; 4, male inflorescence branch; 5, female inflorescence; 6, infructescence; 7, fruit with 3 pyrenes (cross-section).*

Growth and development Normally when planted, seed of toddy palm starts to germinate within 45–60 days. Germination is remote-tubular, i.e. a tubular sprout (hypocotyl) emerges from the seed, protected by a cotyledonary sheath, and grows down into the soil up to 90–120 cm depth; the top of the sprout becomes tuberous, about 15 cm long and 2.5 cm wide, and stores nutrients from the endosperm of the seed. When growth continues the tuberous part sends forth roots, separates from the sheath and begins to grow upright. In 9–12 months the tip of 1–2 sword-shaped eophylls (first seedling leaves with a blade) emerge above the ground, after which true leaves follow. After a rosette-stage of 4–6 years, trunk formation starts. The trunk grows about 30 cm in height per year. Under optimal ecological conditions 14 leaves unfurl per year, or one leaf per 26 days. The crown then possesses up to 60 leaves. The longevity of unfurled leaves can thus be estimated at 4 years and 4 months. Under marginal ecological conditions, only 8 leaves unfurl per year, or one leaf per 45 days. The crown then possesses 30 visible leaves. Leaf longevity is then 3 years and 9 months. The palm starts flowering and fruiting 12–20 years after germination, usually in the dry season. Under optimal ecological conditions (e.g. sufficient water supply) more leaves and up to 50% more inflorescences are produced than under marginal conditions. Toddy palms can become very old (over 150 years), but their economic lifetime is about 80 years (older trees become too tall to be exploited safely).

Other botanical information The widespread fan-palm of the less dry areas of tropical Africa is *B. aethiopum* Mart. In the literature, *B. aethiopum* has often been considered synonymous with or retained as a variety under *B. flabellifer*. *B. aethiopum*, however, is a much more massive plant than *B. flabellifer*, often with a ventricose stem and leaves with very many more completely rigid leaflets forming a gently undulating leaf surface. In *B. flabellifer* the stem is not ventricose and the leaves have fewer, less rigid leaflets, forming a deeply grooved surface. The *Borassus*, occurring in Indonesia from East Java eastwards, differs slightly from *B. flabellifer* (petals in fruit imbricate at the base, absence of scales on the leaf blades, less branched male inflorescence) and has been described as a different species: *B. sundaica* Beccari. In this article, *B. sundaica* is for the time being considered to be conspecific with *B. flabellifer*.

Ecology Toddy palm is mainly cultivated in the drier parts of its geographical range, where the sugar palm (*Arenga pinnata* (Wurmb) Merrill) and the coconut (*Cocos nucifera* L.) cannot compete. It is usually grown in strictly seasonal tropical or subtropical climates on sandy soils. It is a very adaptable palm, however, growing well in dry areas with 500–900 mm average annual rainfall and is quite drought resistant. It also grows in per-humid areas with up to 5000 mm average annual rainfall and survives waterlogging quite well. Its optimum mean annual temperature is around 30°C, but it withstands extreme temperatures of 45°C and 0°C as well. It can be found on any kind of soil, preferring soils rich in organic material. It prefers altitudes around sea-level, but can be found up to about 800 m altitude. Toddy palms very often provide shelter to many animals (birds, bats, rats, squirrels, mongooses, monkeys) and plants (orchids, ferns and other epiphytes).

Propagation and planting Toddy palm is propagated solely by seed. Large healthy seeds are sown 10 cm deep and spaced 3–6 m apart, preferably directly in the field because seedlings are difficult to transplant. They are usually planted in groups, in order to facilitate tapping.

Husbandry Toddy palm does not require much attention once it has established. It responds well to water supply and manure. To tap the inflorescences, some leaves are cut away for easy access. Palms are cut down when they become too tall to be climbed easily. Thinning the plantations to favour more productive female trees is recommended. In Burma (Myanmar) and Cambodia, toddy palm is usually cultivated by smallholders as a cash crop in addition to their main product, rice. Working time has to be divided between the two crops: rice usually requires most labour in the wet season, toddy palm in the dry season.

Diseases and pests Toddy palm hardly suffers from diseases and pests. Toddy palms growing in rich black soil or soil liable to flooding may succumb to bud-rot, caused by the fungus *Phytophthora palmivora*, also occurring on the more widely cultivated coconut. The first symptoms are spots on green leaf blades, which spread inwards to the bud. The bud then starts to rot and putrifies. The fungus can successfully be combated by killing and burning diseased palms.

Termites may occasionally attack seedlings. Certain beetle species (*Oryctes* and *Rhynchophorus*) feed on dead plant material, but may at dense populations become harmful for living palms. It is therefore necessary to clean stands of all kind of debris. Snakes and other venomous creatures sheltering in the crown may present a hazard to the tapper.

Harvesting Tapping normally starts when the palm is 25–30 years old and may continue for 80 years. To harvest sap, the tapper must climb the palm trunk just before the inflorescences open. The leaves below the point of tapping are cut off so that the inflorescences can be reached, and the rather strong spines on the petioles of other leaves close to the tapping point are trimmed off. In male palms a number of partial inflorescences (usually about 12) are tied together after the flower buds have been stripped off. The stalks of these inflorescences are then systematically squeezed with tongs daily. After three days the tops of the stalks of the inflorescences are cut off and a bucket made of a leaf of the palm is hung on the end. This leaf bucket is supported by a basket, also made from a palm leaf or from bamboo internodes (Thailand). In female palms the inflorescences are handled individually: flowers are broken off and the flowering stalks are then squeezed for a number of days with larger tongs, to make them supple enough to be bent into the bucket, and to enhance the sap flow. Each morning the tapper climbs the palm, removes the bucket with sap and empties it into a container. In order to prevent early fermentation the sap receptacle has to be cleaned thoroughly. Sometimes tappers have two buckets, one is hung in the sun after cleaning, while the other is in use. The next day the buckets are interchanged. Two buckets are generally used if the sap is to be sold fresh. If there is only one bucket, some slaked lime ($Ca(OH)_2$) is put into it to prevent fermentation and deterioration; this affects the flavour of the sap. If bamboo buckets are used, they are placed on a fire for a moment after thorough cleaning. Small pieces of bark from various tree species containing tannins (e.g. *Shorea roxburghii* G. Don, *Lannea coromandelica* (Houtt.) Merrill), or the leaves of *Anacardium occidentale* L. and *Schleichera oleosa* (Loureiro) Oken are used as a substitute for slaked lime. For each tapping a new slice as thin as possible is cut off from the tapped end of the stalk with a razor-sharp knife kept especially for this purpose. In the evening the operation has to be repeated. The nightly flow of sap is nearly double that of the flow in daytime. A tapper may be able to handle 30–40 palms in a working day. The more skillful of the tapper is in climbing and tapping, the better the yield. On Madura, Timor, Sawu and Roti, where palm tapping still is practised on a sizable scale, bamboo scaffolding may be erected to make it easier for tappers to move from one palm to another high above the ground. The tapper then has a helper, who walks along on the ground, carrying a larger receptacle for the sap. The sap flow of an individual tree may continue for 3–6 months per year. If the fruits of toddy palm can be sold, as in Madura, tapping is restricted to male palms.

Yield The sap obtained through tapping comes from the phloem. The sugar in the bleeding sap is derived from photosynthates, either directly from the leaves or indirectly after storage as starch in the trunk. The starch stored in the top of the trunk should be considered as a reserve that the plant can draw on in less favourable periods. Although both male and female inflorescences of *B. flabellifer* are tapped, the latter are preferred because of their higher yields. The sap in the inflorescences is intended to enable the plant to produce flowers, fruits and seeds, but much more can be produced than is necessary for this purpose, and therefore it can be 'milked'. The annual production of palm sap varies from 100–600 l per palm and the corresponding sugar yields vary from 16–70 kg per palm. Sugar yields of 19 t/ha per year are possible at a density of 275 palms per ha. The yield varies greatly between palms.

If toddy palms are cultivated for their fruits, yield per tree averages 200–350 fruits per year, i.e. up to 130 t per year if there are 275 female trees per ha.

B. aethiopum is normally tapped from the terminal bud; this causes the tree to die. Sap yields can be as high as 6 l per day and 169–246 l per year per palm. In some areas it is tapped by making an incision in the stem; it can stay alive after such tapping. The sap in the terminal bud or the stem normally fuels tree growth.

Handling after harvest After harvest the sap may be boiled down into brown palm sugar. It is strained through a coconut leaf sheath sieve to remove debris and the added bark or leaf parts, and is then poured into an open pan that is heated. When the liquid thickens it is poured into half coconut shells and allowed to cool and solidify. This sugar is highly hygroscopic, as it contains all the dry matter from the sap. The quality of the sugar is good. In Indonesia for example, the fine toddy palm sugar from Madura is superior to that made from *Arenga* in West Java and commands better prices on Javanese markets. If no slaked lime is used, the sap may start fermenting in the bucket while this is still hanging on the palm. It may then be used as palm wine or toddy. The wine can be distilled, thus becoming arrack with an alcohol percentage of 20–60%. To make vinegar the palm wine must be kept in a cool and dark spot for some time.

In areas where the local production of toddy palm sugar is wholly dependent on the availability of wood as fuel, wood is often a limiting factor (e.g. in Burma (Myanmar) and Cambodia). About 5 kg wood is needed to produce one kg sugar.

Genetic resources No germplasm collections of toddy palm are known to exist.

Breeding There are no records of any breeding or selection work. Only in the state of Tamil Nadu (India) is some research on genetic variation being done. The genotypes in use have probably been selected by man for over 2000 years.

Prospects The main impediment to regular cultivation of toddy palm is the long juvenile period of 8–14 years. Under favourable ecological conditions other palms with a shorter juvenile period will be preferred for tapping. A second impediment is the rather high labour requirement for tapping and the large amounts of fuel (wood) needed for preparing the sugar. Only under seasonal climatic conditions in areas with an excess of cheap labour and ample availability of wood for fuel can toddy palm still have a competitive advantage. Toddy palm is under pressure in all the countries where it is grown. In areas where coconut can be grown, toddy palm may be eradicated for phytosanitary reasons.

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M. Flach & Y. Paisooksantivatana

Canna indica L.

Sp. pl.: 1 (1753).

CANNACEAE

$2n = 18$, sometimes 27

Synonyms *Canna coccinea* P. Miller (1768), *C. edulis* Ker-Gawler (1823), *C. orientalis* Roscoe (1826).

Vernacular names Canna, Queensland arrowroot, Indian shot (En). Balisier, canna (Fr). Achira (Sp). Indonesia: ganyong (Javanese, Sundanese), buah tasbeh (Javanese), ubi pikul (Sumatra). Malaysia: daun tasbeh, ganjong, pisang sebiak. Philippines: tikas-tikas (Tagalog), kukuwintasan (Tagalog), balunsaying (Bisaya). Burma (Myanmar): adalut, butsarana. Cambodia: ché:k té:hs. Laos: kwàyz ké: so:n, kwàyz ph'uttha so:n. Thailand: phuttharaksa (general), phutthason (northern). Vietnam: chu[oos]i hoa, dong ri[eef]ng, khoai dao.

Origin and geographic distribution Canna is a native to South America but is now cultivated pantropically and in other warmer regions of the world. In many regions, including South-East Asia, it has also become naturalized.

Uses Canna produces edible rhizomes which can be eaten raw but are usually consumed after boiling or cooking in various ways. Flour can be made from the rhizomes by peeling, drying and milling. The starch is used in foods and also as sizing or laundry starch. In Vietnam, it is used for noodles. Young shoots can be eaten as a green vegetable. The leaves are suitable for wrapping and as plates. Both the leaves and the rhizomes can be used as cattle feed. Canna is also well known as a garden ornamental because of its beautiful flowers and foliage of various colours. The black and hard-coated seeds are used as beads or made into rosaries. They are also used in percussion instruments and rattles, especially in Africa.

In Java pounded seeds are used in a poultice to relieve headache. Juice extracted from grated rhizomes is used against diarrhoea. Mush made from the rhizome is taken as a remedy for yaws in Cambodia. In Hong Kong a decoction of fresh rhizomes is prescribed in acute hepatitis. Crushed fresh rhizomes are applied topically for traumatic injuries in traditional medicine in Indo-China. In the Philippines a decoction of the rhizomes is used as a diuretic and macerated rhizomes in water are applied to alleviate nose bleeding.

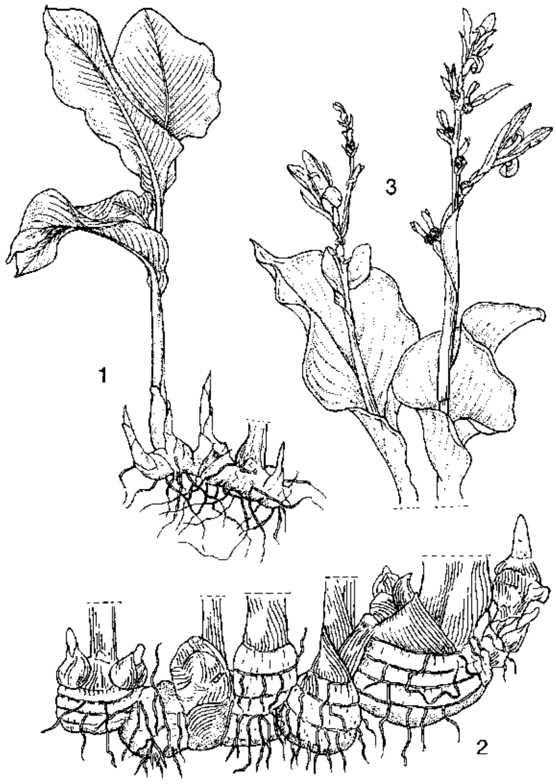
Fumigated stems and leaves are used as an insecticide.

Production and international trade In Australia starch is produced from canna and traded internationally as Queensland arrowroot (about 2000–4000 t per year). World consumption, however, is very low. In South-East Asia, canna is mostly planted for home consumption and seldom enters the markets. It is most important in South America.

Properties Per 100 g edible portion, rhizomes of *C. indica* contain approximately: water 75 g, protein 1 g, fat 0.1 g, carbohydrates 22.6 g, Ca 21 mg, P 70 mg, Fe 20 mg, vitamin B 0.1 mg, vitamin C 10 mg. The carbohydrates consist of more than 90% starch and about 10% sugar (glucose and sucrose). The starch produced is a shiny yellowish powder with very large (125–145 μm × 60 μm) irregularly shaped grains. It is highly soluble and easily digestible. After cooking, the starch is glossy and transparent.

The approximate composition of fresh leaves used as fodder is: water 90%, protein 1%, fat 0.2%, carbohydrates 7%, ash 1.4%; the digestibility is about 20%.

Description Rhizomatous, perennial, erect, robust herb, up to 3.5 m tall. Rhizome branching horizontally, up to 60 cm long and 10 cm in diameter, with fleshy segments resembling corms, covered with scale leaves, and thick fibrous roots. Stem fleshy, arising from the rhizome, usually 1–1.5 m tall, often tinged with purple. Leaves arranged spirally with large open sheaths, sometimes shortly petiolate; blade narrowly ovate to narrowly elliptical, up to 60 cm × 15–27 cm, entire, base rounded to cuneate, gradually attenuate to the sheath, apex acuminate, midrib prominent, underside often slightly purplish. Inflorescence terminal, racemose, usually simple but sometimes branched, bearing single or paired, irregular, bisexual flowers; bracts broadly obovate, 1–2 cm × 1 cm; sepals 3, ovate, acute, 1–1.5 cm × 0.4–0.9 cm; corolla 4–5 cm long, the lowermost 1 cm fused into a tube, lobes free; lobes 3, linear, 3–4 cm × 0.3–0.6 cm, pale red to yellow; androecium petaloid and forming the showy part of the flower, composed of an outer whorl of 3 staminodes and an inner whorl of 2 connate staminodes (one of which forms a large lip or labellum) and 1 fertile stamen; outer staminodes spathulate, 4–6 cm × 1–1.5 cm, often very unequal in length or only 2 clearly visible,



Canna indica L. – *1, habit; 2, rhizome; 3, inflorescences.*

fused at the base, reddish; labellum narrowly oblong-ovate, 4–5 cm × 0.5–0.8 cm, yellow spotted with red; stamen 4–5 cm long, petaloid portion involute, anther 0.7–1 cm long and adnate to the petaloid portion at base; ovary inferior, trilocular, style fleshy, 4–5 cm long, reddish, adnate at base to androecium. Fruit a loculicidally dehiscent ovoid capsule, 3 cm × 2.5 cm, outside with soft spines. Seeds numerous, globose, 0.5 cm in diameter, smooth and hard, blackish to very dark brown.

Growth and development Rhizome cuttings develop into harvestable plants in 6–8 months after planting. In tropical regions flowering starts a few months after planting and flowers continue to appear as long as the plant lives. In regions where frost can be expected rhizomes should be lifted and overwintered at about 7°C.

A rhizome is considered mature when the triangular slit in the outer scale leaf of the rhizome has turned purple.

Other botanical information *C. indica* is a problematic species complex in which flower colour as well as length, number and shape of staminodes are extremely variable. Sometimes chromosome countings of $2n = 27$ are reported (triploid species). Numerous, mainly unnamed cultivars exist. In the Andes of South America, two cultivars are well known: 'Verdes' with dirty white 'corms' and bright green foliage and 'Morados' with violet 'corms'.

The present-day ornamental garden cannas are an assortment of probably over 1000 cultivars. Most of these fall into two main groups of complex hybrids: *Canna* ×*generalis* L.H. Bailey (principal progenitors are *C. indica*, *C. glauca* L., *C. iridiflora* Ruiz & Pavon and *C. warszewiczii* A. Dietr.; flowers up to 10 cm diameter, not tubular at base, petals not reflexed, staminodes and labellum erect or spreading) and *Canna* ×*orchiodes* L.H. Bailey (principal progenitors: *C. flaccida* Salisb., *C.* ×*generalis* cvs Crozy cannas; flowers up to 20 cm in diameter, tubular at base, petals reflexed, staminodes wavy and exceeded by the labellum). Many cultivars are available in those hybrid complexes, with handsome yellow, pink, orange, red or variegated flowers and green, crimson, purple or variegated foliage.

Ecology Canna grows well in various climates. A well distributed annual rainfall of 1000–1200 mm is satisfactory. It seems to be daylength neutral, as it grows and flowers under a broad range of photoperiodic conditions. It is affected by drought, but tolerates excessive moisture (but not waterlogging). It is very tolerant of shade. Normal growth occurs at temperatures above 10°C, but it also survives high temperatures of 30–32°C and tolerates light frost. Canna grows from sea-level up to 1000(–2900) m altitude. It thrives on many soils, including those marginal for most other tuber crops (e.g. weathered, acidic latosols). Preferred soils are deep sandy loams, rich in humus. It tolerates a pH range of 4.5–8.0.

Propagation and planting Canna is mostly propagated by rhizome cuttings ('corms'). Sometimes seeds are used, but because of the risk of hybridization, rhizomes are preferred to maintain the genetic identity of the clones. Young tips of rhizomes are used for vegetative propagation, not the old brown parts. Small portions of the rhizomes, bearing at least two healthy buds, are planted 50 cm apart, about 15 cm deep. Entire rhizomes can also be planted. If planted too close, the plants soon become too crowded, resulting in poor performance. It is best to plant during the rainy season, otherwise watering is needed. Canna is planted in beds that have been ploughed or dug thoroughly and mixed with plenty of manure and compost.

Husbandry The edible cannas are common home garden plants in South-East Asia. In Australia, most field operations like planting, maintenance, harvesting, and milling are mechanized. Weeding is required and earthing up is recommended. Grass mulch on the beds helps to conserve the moisture in the soil and adds nutrients but may be a hiding place for beetles. Monthly manuring with liquid manure or artificial fertilizer gives better results.

Diseases and pests Generally, canna is a hardy plant with only a few diseases and pests. *Fusarium*, *Puccinia* and *Rhizoctonia* spp. are possible fungal diseases. Beetles and grasshoppers may feed on the foliage, and cutworms (*Agrotis* spp.) attack the rhizomes.

Harvesting Plants are pulled or dug out for the rhizomes. Plants grown from rhizome tips can be harvested 4 months after planting, but harvesting after 8 months gives higher yields, because then the rhizomes have swollen to their maximum. Rhizomes should not be allowed to become much older than 10 months as they become tough and less suitable for consumption or starch production.

Yield Rhizome yield ranges from 23 t/ha at 4 months to 45–50 t/ha at 8 months, to 85 t/ha after a year. Reported starch yields are 4–10(–17.5) t/ha.

Handling after harvest The freshly harvested rhizomes should be handled with care. As they are mainly consumed locally, the time between harvesting and consumption is usually short. For the commercial production of flour, rhizomes are processed immediately after harvesting. To obtain the starch the rhizome is grated, water is added and the fibrous pulp is decanted. Cleaned rhizomes can be stored safely for several weeks under cool and dry conditions. To store rhizomes for longer periods, they should be kept frost-free but not too dry (in Japan, for example, in pits 30 cm deep in the field).

Genetic resources There are many species and cultivars of *Canna* L. and the genus seems to be in no danger of genetic deterioration. However, it is important to conserve older and less popular cultivars and clones, to conserve the vast genetic diversity. No comprehensive germplasm collections exist at present.

Breeding Selection among locally available cultivars should be a first step to improve the crop. Manual cross-pollination for the production of new hybrid cultivars is possible. Hybridization of canna is presently done solely for the purpose of producing new ornamental cultivars.

Prospects Canna is currently utilized locally only and not widely traded, but prospects for improvement are promising. Commercial production of canna flour under the name of Queensland arrowroot in Queensland, Australia, shows that this crop can be of commercial value to other countries as well. Research may uncover markets for its valuable starch, e.g. in easily digestible speciality foods. Systematic plant breeding is needed to improve rhizome yield and quality.

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H.C. Ong & J.S. Siemonsma

Caryota L.

Sp. pl.: 1189 (1753), Gen. pl. ed. 5: 497 (1754).

PALMAE

$2n = 28$ (*C. urens*); $2n = 32$ (*C. mitis*); $2n = 34$ (*C. cumingii*)

Major species and synonyms

- *C. cumingii* Loddiges ex Martius, Hist. nat. palm. 3: 315 (1853), synonym: *C. merrillii* Beccari (1905);
- *C. mitis* Loureiro, Fl. Cochinch.: 569 (1790);
- *C. rumphiana* Martius, Hist. nat. palm. 3: 195 (1838), synonyms: *C. maxima* Blume ex Martius (1838), *C. no* Beccari (1871), *C. aequatorialis* Ridley (1925);
- *C. urens* L., Sp. pl.: 1189 (1753).

Vernacular names General: Fishtail palm (En). Cambodia: 'ânnsaè. Thailand: taorang. Vietnam: m[os]c.

- *C. cumingii*: Philippines: pugahan (Filipino), anibong (Tagalog), anivung (Ibanag).
- *C. mitis*: Indonesia: genduru (Javanese), saray (Sundanese), bulung talang (Kalimantan). Malaysia: merdin, dudok, rabuk. Philippines: pugakang-suuy (Filipino), barukan (Tagbanua), bato (Tagbanua). Cambodia: 'ânnsaè tô:ch. Laos: ta:w h'a:ngz. Thailand: taorang-daeng (southern), khuangmu (northern). Vietnam: d[uf]ng d[if]nh.
- *C. rumphiana*: Indonesia: nibung besar (Moluccas), suwangkung (Sundanese), andudu (Balinese). Malaysia: rabuk gunung, baroh. Philippines: takipan-tilos (Filipino), bagsang (Bisaya), anivung (Ibanag). Thailand: taorang-yak (southern). Vietnam: m[os]c n[uw][ow]ng.
- *C. urens*: Faux sagoutier (Fr). Cambodia: 'ânnsaè. Laos: ta:w h'a:ngz. Thailand: taorang (central, southern). Vietnam: m[os]c den, d[uf]ng d[if]nh ng[uws]a.

Origin and geographic distribution The genus *Caryota* occurs from Sri Lanka, India and southern China southwards throughout South-East Asia to northern Australia and the Solomon Islands. *C. urens* has probably been dispersed by man from India and Sri Lanka to Thailand and Vietnam. Further south-east *C. rumphiana* takes its place, in the Philippines together with *C. cumingii* and in Indonesia together with *C. mitis*.

Uses *Caryota* species are multi-purpose palms. The trunk yields starch (larger specimens are favoured for this). As the bark is very hard, the starch is only harvested in times of food scarcity. Inflorescences may be tapped for sugar or palm wine, especially those of the tallest species *C. rumphiana* and *C. urens*. The palm cabbage (apex) is usually bitter and can only be eaten cooked. The fruits and seeds are edible but the mesocarp contains irritating needle-like crystals. The seeds may be used as a masticatory, instead of the seeds of *Areca catechu* L.

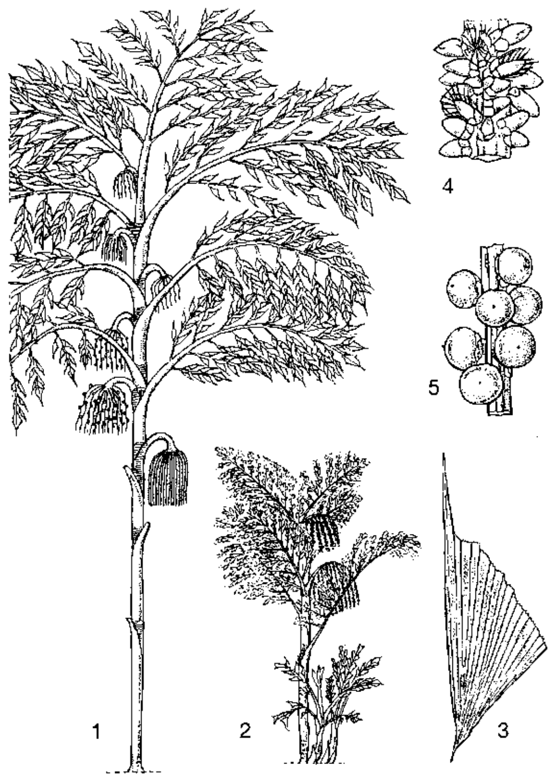
Leaf sheath fibre ('kittul') is durable and often harvested for thatch, cordage, and to make brushes and brooms. The woolly hairs on leaf sheaths, petioles and rachis are often used as tinder or as wadding. They may also be used to caulk wooden boats. The finer fibre can also be spun into fishing lines or coarse threads for sewing.

Timber of *C. urens* is used for construction and agricultural utensils. All species have ornamental value and are often planted as such.

Production and international trade *Caryota* species are rarely traded beyond the local market, and no production statistics are available. Sri Lanka exports kittul fibre from *C. urens*.

Properties The chemical composition of the palm-sap jaggery (crude sugar) per 100 g is: protein 1.8–2.3 g, sucrose 76.6–83.5 g, reducing sugars 0.8–0.9 g, pectin, gums, etc. 6.6–8.3 g, ash 1.7–2.0 g.
Fermented sap contains 3–4% alcohol, 1% reducing sugar, and 0.3% acetic acid.
The wood is very hard. The bark has attractive black and white venation.

Description Moderate to tall, solitary or clustering, hapaxanthic, monoecious, unarmed palms. Stem with elongated internodes, surrounded at first by persistent fibrous leaf bases and sheaths, later on becoming bare and conspicuously ringed with narrow leaf scars. Leaves induplicately impari-bipinnate (pinnate in juveniles); sheath triangular, disintegrating into strong black fibres, surface covered with a dense felty indumentum and caducous dark brown scales; petiole scarcely to well developed, channeled above, rounded below; leaflets very numerous, borne regularly along the secondary rachises, obliquely wedge-shaped with more or less equal larger veins that diverge from a swollen base, upper margins very irregularly toothed. Inflorescence axillary, starting at the top of the stem and continuing downwards, solitary, bisexual, subtended by several bracts at the base of a single peduncle, terminating in many simple pendent branches; flowers arranged in triads, usually one female between two males, the latter open and are shed before the female flowers; flowers 3-merous; male flowers usually elongate and with numerous (up to 100) stamens; female flowers usually globular, with 0–6 staminodes and trilocular ovary. Fruit globose, 1–2-seeded, smooth, variously coloured; mesocarp fleshy and filled with abundant very irritant needle-like crystals; endocarp not differentiated. Seed irregularly subspherical with ruminate endosperm; germination remote-tubular.



Caryota mitis Loureiro – 1, habit; 2, habit of palm with tillers; 3, leaflet; 4, part of inflorescence branch; 5, part of infructescence branch.

- *C. cumingii*: Solitary slender palm, 5–8 m tall, up to 20 cm in diameter. Leaves up to 1.5 m long, petiole very short, pinnae about 10 on each side of the midrib, up to 1 m long; leaflets up to 20 cm long. Inflorescence up to 80 cm long, peduncle 3 cm in diameter, branches up to 50 cm long; stamens 6, flowers small. Fruit purple, 12–17 mm in diameter, containing 1 globose seed.
- *C. mitis*: Strongly tillering palm, 5–12 m tall, 5–15 cm in diameter. Leaves 2–4 m long, petiole 50–100 cm long; leaflets 7–25 cm × 2.5–15 cm. Inflorescence 25–50 cm long; peduncle curved, 10–15 cm long; branches 25–45 cm long; stamens 15–27. Fruit orange to dark red, 7–15 mm in diameter, 1-seeded, densely punctate.
- *C. rumphiana*: Robust solitary palm, 10–25 m tall, 20–45 cm in diameter. Leaves 4–6 m long, petiole long; pinnae in 10–20 subopposite pairs, 50–150 cm long; leaflets 20–45 cm × 5–20 cm. Inflorescence 0.5–2 m long; peduncle long, up to 10 cm in diameter; branches 50–175 cm long; stamens about 40. Fruit dark red, 2–3 cm in diameter, 1–3-seeded.
- *C. urens*: Robust solitary palm, 13–20 m tall, up to 45 cm in diameter. Leaves up to 6 m long, petiole long and robust; pinnae 1.5–1.8 m long; leaflets 10–20 cm long. Inflorescence 3–4 m long; branches 35–40 cm long; stamens 40–45. Fruit reddish, about 2 cm in diameter, 1–2-seeded.

Growth and development At the end of the vegetative period (after the last leaf has unfolded), the trunk starts flowering from the uppermost leaf axil bud downwards. *C. urens* grows for about 15 years, then starts flowering from the crown downwards to the base for 5–10 years. After the last inflorescence has fruited the palm dies. During the fruiting period, which may last several years, the starch accumulated in the trunk is used to fuel flowering. Any persisting leaves also produce carbohydrates for flowering and fruiting.

Other botanical information The genus *Caryota* (about 12 species) is closely related to the genera *Arenga* Labill. (about 17 species) and *Wallichia* Roxburgh (about 7 species) with which it forms the tribe *Caryoteae* in the subfamily *Arecoideae*; all are distributed in South-East Asia (with extensions to India and southern China). The three genera can easily be distinguished: *Caryota* has bipinnate leaves, bisexual inflorescences, usually numerous stamens and ruminate endosperm; *Arenga* and *Wallichia* have pinnate leaves, normally unisexual inflorescences, and homogeneous endosperm; *Wallichia* has 6 stamens, *Arenga* numerous. *Caryota* is due for taxonomic revision, because the identity of most species is not clear. *C. rumphiana* is very variable; in the Philippines two varieties are distinguished: var. *philippinensis* Beccari (identical to *C. maxima* Blume ex Martius) and var. *oxyodonta* Beccari. In Peninsular Malaysia a form has been described as: *C. obtusa* Griffith var. *aequatorialis* Beccari, which is identical to *C. aequatorialis* Ridley.

Ecology *Caryota* is found in subhumid to humid climates, from sea-level up to about 2000 m, in secondary and primary forests.

Propagation and planting Propagation is only by seed. In Sumatra, seed of *C. rumphiana* is said to germinate only after ingestion by a palm civet (*Paradascursus* sp., 'luak').

Husbandry Only *C. urens* is cultivated commercially, mainly in Sri Lanka and India and occasionally in Peninsular Malaysia. The other species are wild, but often cultivated in gardens for ornamental purposes.

Harvesting Before reaching maturity, selected inflorescences are prepared for tapping by beating with a wooden stick and are then tied with a string to keep them in a proper shape. If possible, a number of inflorescences are tied together. A concoction of herbs, salt and ash may be applied to the tip of the inflorescence. Tapping begins 3–4 days later by making a fine angular slash. A receptacle, usually a piece of bamboo, is hung under the tapping point to catch the sap. The inflorescence is cut afresh in the morning and evening for 3–4 months, until none remains. In India lime or powdered bark of tannin-rich trees is added to the collection pots, to prevent early fermentation.

Yield In *C. urens*, daily sap yield per inflorescence is 7–14 l, or 20–27 l per palm. Total annual yield per palm may amount to 675–810 l containing 13.5% sucrose and a trace of reducing sugars. This corresponds to 90–110 kg of sugar.

Handling after harvest After harvest the sap may be boiled in an open pan to produce jaggery. If the sap is allowed to ferment for 12 hours it turns into a pale or cloudy wine with a rather sour taste. Fermented toddy may still be boiled down to a thick syrup and be preserved as a treacle. The treacle can be allowed to crystallize to form a sweetmeat. Fibre from the leaf sheaths becomes very pliable after being steeped in linseed oil.

Genetic resources and breeding No germplasm collections or breeding programmes are known to exist for *Caryota*.

Prospects Only *C. urens* is promising for the production of carbohydrates. Stands of wild species may easily be depleted in times of famine, because of the exploitation for starch or palm cabbage. The ornamental value of all species is an important argument for preservation.

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M. Flach & H.C. Ong

Colocasia esculenta (L.) Schott

Melet. bot.: 18 (1832).
ARACEAE
$2n = 28$

Synonyms *Colocasia antiquorum* Schott (1832), *C. esculenta* (L.) Schott var. *antiquorum* (Schott) Hubb. & Rehder (1939).

Vernacular names Taro, old cocoyam, dasheen, eddoe (En). Taro (Fr). Indonesia: bentul, talas, keladi. Malaysia: keladi, keladi China, birah keladi. Papua New Guinea: anega, ba, biloun. Philippines: gabi (Tagalog), abalong (Bisaya), natong (Bikol). Cambodia: tra:w. Laos: bo:n, phüak. Thailand: phuak (general), bon-nam (southern), tun (northern). Vietnam: khoai n[uw][ows]c, m[oo]n n[uw][ows]c, khoai s[oj].

Origin and geographic distribution Taro originated in South-East or southern Central Asia, where it was probably cultivated before rice. Today taro is grown throughout the West Indies and in West and North Africa. In Asia, it is widely planted in south and central China and is grown to a lesser extent in India. It is now a staple food in many islands of the Pacific including Papua New Guinea, where it has prestigious as well as economic value, playing an important role in traditional gift-giving and ceremonies. In Indonesia, taro is a staple food on the Mentawai Islands and for Melanesians in Irian Jaya. It is cultivated to a lesser extent in Bogor and Malang in Java and on Bali. In Malaysia, taro has been used for more than 2000 years and is now found throughout the country. Taro is grown throughout the Philippines but is most important in eastern and central Visayas and the Mindanao and Bikol regions.

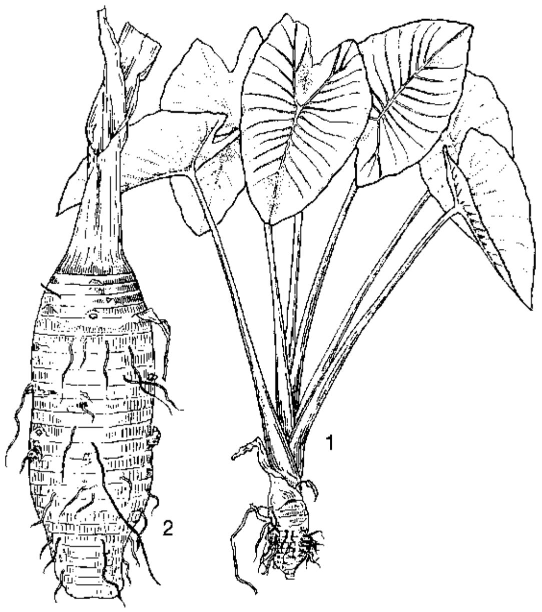
Uses When cooked, taro corms, cormels, stolons, leaf blades and petioles can be eaten. Taro corm puree makes an easily digested, low-allergenic baby food. Waste leaves, corms and peel can be cooked or fermented into silage for animal feed. Most taro in South-East Asia is consumed by humans, but it also has uses in religious festivals and in folk medicines and is fed to livestock, primarily pigs.

In areas of Indonesia where rice is not grown, taro is eaten as a staple, baked, boiled or cooked in bamboo tubes. In Java, confections are prepared from taro flavoured with coconut and sugar; fried taro slices and taro chips are popular snacks. The leaves are used in preparing 'buntil' (salted fish with spices, grated coconut and vegetables, wrapped up and steamed in a taro leaf), and petioles are cooked. In Malaysia, taro is cooked in similar ways and also plays a role in religious festivals. Leaves are boiled and eaten as salad with spicy sauce, and petioles are cooked with coconut milk, meat and prawns. Taro in the Philippines is used primarily when more popular starches and green vegetables are in short supply. Corms are boiled, chipped and fried or made into confections. In Hawaii and parts of Polynesia, the corms are cooked and pounded into a paste that is allowed to ferment to produce 'poi'. A steamed pudding is made from grated taro and coconut.

Production and international trade No reliable statistics are available on world and national production and price. FAO reports a world production of 5.6 million t from 1 million ha in 1992. In South-East Asia, taro is grown predominantly by smallholders, and there is potential and interest in expansion. For example in Indonesia, taro and other root crops are being promoted to reduce dependence on rice. In Papua New Guinea, taro is produced in both the lowlands and highlands with a total annual production in 1993 of about 438 000 t on 77 000 ha. In the Philippines, 112 000 t were produced on 33 000 ha in 1992.

Properties If eaten raw or undercooked, all parts of the plant are acrid and will irritate the mouth and throat, but acridity is reduced or eliminated by cooking and fermenting. The cause of acridity is still uncertain, but it is thought to be related to bundles of needle-shaped crystals of calcium oxalate and one or more chemicals associated with them. Taro is easily digested, practically non-allergenic and has very small starch particles, diameter 1–6.5 μm. Per 100 g edible portion (fresh) corms contain approximately: water 70 g, protein 1.1 g, carbohydrates 26 g, fibre 1.5 g, vitamin C 15 mg. The energy value averages 475 kJ per 100 g. Leaves contain 4.2 g protein. Taro contains protein inhibitors but these are destroyed during cooking.

Description An erect, herbaceous plant growing to a height of 1 m or more, perennial, but most often grown as an annual. Root system adventitious, fibrous, and shallow. Storage stem (corm) massive (up to 4 kg), cylindrical or spherical, up to 30 cm × 15 cm, usually brown, with lateral buds located above leaf scars giving rise to new cormels, suckers or stolons. Leaves peltate consisting of long (sometimes over 1 m) petiole and large, heart-shaped blade, 20–50 cm long. Inflorescence a spadix surrounded by a spathe and supported by a peduncle that is shorter than the petioles; male and female flowers small, located separately on the spadix, female flowers at the base, green, and



Colocasia esculenta (L.) Schott – 1, habit of plant; 2, corm.

separated from the male flowers at the top by a band of white sterile flowers; more white sterile flowers scattered in the female region; spadix tipped by a sterile appendage; ovary unilocular with 36–67 ovules and a sessile stigma. Fruiting head a cluster of densely packed berries, each containing 1–10(–35) seeds. Seed less than 2 mm long, ovate, and conspicuously ridged longitudinally.

Growth and development Growth of leaves on main plants is slow during establishment, but is rapid from 1.5–2 months after planting, with most rapid leaf growth between 3–5 months after planting. During the fourth or fifth month, leaf size, leaf dry weight, leaf area, leaf area index (about 3) and plant height reach their maximum. Leaf number varies and there is a continuous turn-over of leaves. After peaking, leaves become smaller with shorter petioles and leaf number decreases. Main corm growth begins as early as 2 weeks after planting, with rapid corm growth beginning 2 months after planting under rainfed conditions and 3–5 months after planting under irrigated conditions. Corms reach maximum weight at 10–11.5 months when rainfed and 12–15 months when irrigated, but are usually harvested before this time.

Sucker growth generally begins 2.5 months after planting. The number of suckers depends on cultivar and management.

Other botanical information There are 2 types of taro. The dasheen type has a large central corm with a few small cormels which are generally not eaten. The eddoe type produces a smaller central corm surrounded by large, well-developed cormels which are the main harvestable yield. Although the eddoe type is frequently classified as a separate species, *C. antiquorum* Schott, it is more generally accepted that it is a variety, *C. esculenta* var. *antiquorum* (Schott) Hubb. & Rehder, of a very variable species that includes both dasheens and eddoes.

In South-East Asia there are many taro cultivars, and these are distinguished by morphological characteristics as well as time taken to mature. Colour of corm flesh, lateral buds, petioles, and leaf blades are also used to differentiate cultivars.

Ecology Taro tolerates a wide range of environments and management systems. When grown as a rainfed crop, best yields are obtained when rainfall is 2000 mm/year or more and evenly distributed. Taro also grows well in wetlands including paddies with a continuous supply of flowing water, furrow-irrigated fields, and raised beds in poorly drained swamps. Eddoes are often more drought-hardy than dasheens. Temperatures of 25–30°C and high humidity favour growth. Taro is grown from sea-level up to 1800 m in the Philippines, 1200 m in Malaysia and 2700 m in Papua New Guinea, although it is very slow to mature at the latter altitude. In Papua New Guinea, it is as frost hardy as sweet potato. Taro is shade tolerant and is often grown as an intercrop with tree crops. Some cultivars tolerate high salinity. Taro grows on a variety of soils but good yields require high fertility. In Malaysia it is reported to tolerate soil pH 4.2–7.5.

Propagation and planting Farmers propagate taro vegetatively. Corm pieces, whole small corms, cormels and stolons can be planted, but suckers and head-sets (corm apex plus 15–30 cm attached petiole bases) are usually preferred. Stolons are preferred in some parts of Malaysia. Large head-sets and suckers are generally more reliable than small ones, resulting in more vigorous growth and giving higher yields. Planting material should be taken only from healthy plants, avoiding plants with root or corm rots and obvious symptoms of dasheen mosaic virus.

When corms are marketed with head-sets attached, farmers depend on suckers for planting material. Management practices which provide adequate suckers are needed. Sucker number can be increased by wide spacing, shallow planting

and nitrogen applied at a higher rate than recommended for maximum corm yield.
Planting is done in hand-dug holes or machine-made furrows or ridges; usually holes and furrows are only partially filled at planting. In South-East Asia, taro is grown primarily by smallholders either as a sole crop or intercropped with other crops. In Malaysia, taro may be intercropped between rows of coconut, oil palm and fruit trees, and in the Philippines with coffee, cocoa, coconut and fruit trees.
For breeding purposes, taro can be propagated from seed.
Taro can be grown at densities ranging from 4000–49 000 plants/ha. In South-East Asia, densities ranging from 6000–36 000 in rainfed production and 27 000–40 000 in wetlands have been reported. As plant density increases, total yield increases, but size of corm and number of suckers decrease. Spacings may be in the range of 30–100 cm × (30–)60–150 cm. Wider spacing is required if soil fertility or rainfall is low, and spacing must be adjusted for mechanization. Close spacing helps to control weeds and erosion.

Husbandry Weeding is most important during the first 3–5 months after planting, but weeding during the final 2 months before harvest may reduce corm quality. Monthly removal of stolons increases corm yield. After fallow, the first two crops of taro usually do not require additional fertilizers, but on land which has been cropped longer, taro responds well to applied fertilizer, either inorganic or animal manures. Specific fertilizer recommendations based on soil characteristics must be determined for each location. However, a general fertilizer recommendation for taro grown on soil that has been cropped several times is 50–100 kg/ha N (split into 3 applications at 5, 10 and 15 weeks after planting), 50 kg/ha P (applied at planting), and 70 kg/ha K (applied at planting or split into 2 applications at planting and 10 weeks after planting). To avoid decreasing quality, there must be an interval of at least 3 months between the last fertilizer application and harvest.
In areas with below-optimal rainfall, mulching increases yield. Hilling during the growing season and irrigation of rainfed taro during prolonged drought may be practised. Rotation with vegetables, chillies and maize is popular in Malaysia.

Diseases and pests Taro diseases and pests have not been adequately studied in South-East Asia. *Phytophthora* leaf blight and corm rot are more severe under wet conditions and are responsible for declining taro production in Papua New Guinea; fungicides, sanitation and increasing plant spacing can reduce damage. The lethal virus complex, Alomae and Bobone, kills or stunts plants in Papua New Guinea; roguing infected plants helps control. *Pythium* root and corm rot and dasheen mosaic virus are widespread in the Pacific. Resistant cultivars, selecting clean planting materials, crop rotation and fungicides are recommended for controlling *Pythium*.
Aphids and the planthopper *Tarophagus proserpina* damage plants as well as transmit virus diseases. *Agrius convoluli*, *Hippotion celerio* and other hornworms, as well as the cluster caterpillar, *Spodoptera litura*, can seriously defoliate plants; grasshoppers (*Gesonia* spp., *Ocya* sp.) and mites damage leaves, the latter especially during the dry season. *Papuana* beetle and termites (*Coptotermes* spp.) tunnel and feed in corms. 'Mitimiti' caused by the nematode *Hirschmanniella miticausa* is found in Papua New Guinea; control is by cutting planting material with as little corm as possible.

Harvesting Crop duration usually varies from 4–10 months for rainfed taro and 9–12 months for wetland taro. Cool temperatures delay maturity. Harvesting is done by hand.

Yields Reported corm yields from research plots in South-East Asia vary from 2–17 t/ha; 30–60 t/ha have been reported from farms in Johore (Malaysia), and yields of 3–38 t/ha have been reported on subsistence farms in Papua New Guinea, with a national average of about 6 t/ha. However, yields are not well documented throughout the world. Yields for rainfed taro probably average about 5 t/ha, but 12.5–25 t/ha is common on fertile soils. Yields in wetlands are higher and up to 75 t/ha have been reported.

Handling after harvest At ambient temperatures corms begin to spoil 1–2 weeks after harvest, but cool temperatures and high humidity prolong storage. Leaves and stolons are more perishable than corms.

Genetic resources Germplasm collections are maintained at the National University of Malaysia, the Philippine Root Crop Research & Training Center and the Bubia Research Station in Papua New Guinea.

Breeding Worldwide there are only a few taro breeding programmes: University of the South Pacific (Western Samoa), Ministry of Primary Industries (Fiji), Ministry of Agriculture and Lands (Solomon Islands), and Bubia Research Station and Lae University of Technology (Papua New Guinea). Breeding objectives include increased yield, reduced acridity, extended maturity range, appropriate number of suckers, resistance to *Phytophthora*, *Pythium*, Alomae and Bobone and dasheen mosaic virus, improved eating quality and adaptation to lower soil fertility. Improved cultivars can be safely exchanged only as pathogen-tested tissue cultures.

Prospects Further development and expansion will depend on government support for subsistence farming, food crops and diversified agriculture. Increased use by urban populations is dependent on development of low-cost, convenience foods and improved methods of storage and transport.

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J.E. Wilson & J.S. Siemonsma

Curcuma Roxburgh

Asiat. Res. 11: 329 (1810).

ZINGIBERACEAE

$x = 16, 21$; $2n = 42$ (*C. angustifolia*, *C. aromatica*)

Major species and synonyms

- *Curcuma angustifolia* Roxburgh, Asiat. Res. 11: 338 (1810).
- *Curcuma aromatica* Salisb., Parad. Lond. t. 96 (1805–1806), synonym: *C. zedoaria* Roxburgh (1810).
- *Curcuma pierreana* Gagnepain, Bull. Soc. Bot. Fr. 54: 405 (1907).
- *Curcuma xanthorrhiza* Roxburgh – see separate article.
- *Curcuma zedoaria* (Christmann) Roscoe – see separate article.

Vernacular names General: Curcuma (En, Fr). Indonesia: temu. Laos: kachiêw, khminz. Vietnam: ngh[eej].

- *C. angustifolia*: Indian arrowroot, tikur (En). Cambodia: chahuöy, krâchâ:k. Laos: kachiêw dè:ng. Vietnam: ngh[eej] l[as] h[ej]p.
- *C. aromatica*: Wild turmeric, yellow zedoary (En). Safran des Indes (Fr). Laos: khminz khaix, khminz kh'am. Thailand: wan-nangkham (central). Vietnam: ngh[eej] tr[aws]ng, ngh[eej] r[uwf]ng.
- *C. pierreana*: Vietnam: ngh[eej] pierre.

Origin and geographic distribution *Curcuma* is mainly found in the Indo-Malesian region, from India throughout South-East Asia to the southern Pacific, and comprises 40–50 species. Several species have been introduced elsewhere in the tropics and there are numerous cultivars.

- *C. angustifolia* occurs wild and cultivated in the tropical and subtropical Himalaya areas of India, Pakistan, and northern Burma (Myanmar), and also in Laos.
- *C. aromatica* occurs wild and cultivated in India, Sri Lanka and the eastern foothills of the Himalayas. Occasionally, it is cultivated elsewhere (Indo-China, Japan).
- *C. pierreana* occurs wild in Vietnam where it is also cultivated.

Uses The rhizomes and tuberous roots of *Curcuma* species contain starch, which is extracted from certain (perhaps all) species in times of food scarcity. The rhizomes of some species contain pigments which are used as a dye and others have aromatic oils which make them useful as a spice and medicinally. The young shoot and rhizome parts and inflorescences of some species are used as a vegetable. Most species also have ornamental value.

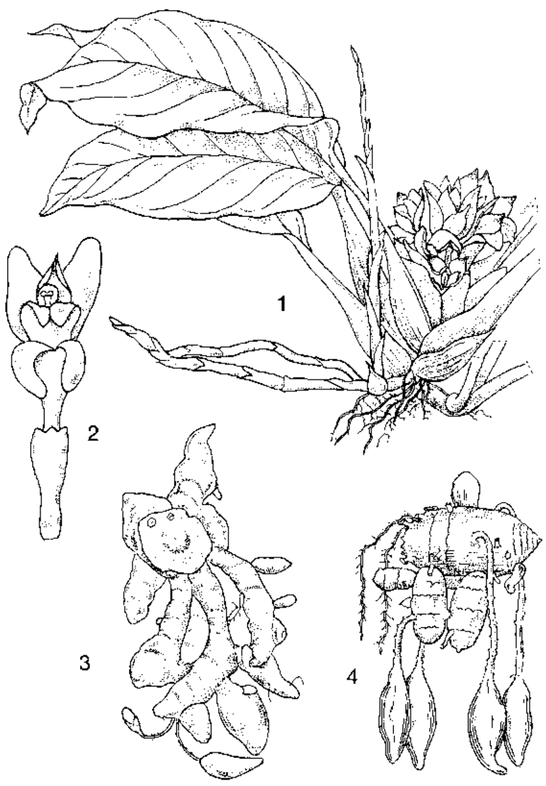
The starch present in the tuberous roots of *C. angustifolia* is considered as good as the starch of the true arrowroot (*Maranta arundinacea* L.) and is used similarly. The starch is easily digestible and very suitable as a food for infants and people with digestive problems. In traditional medicine in India the rhizomes are used to cure bronchitis, asthma, fever, jaundice, leucoderma, and kidney and bladder stones. Sometimes the inflorescence is eaten as a vegetable.

C. aromatica is used as a source of starch, as a dye, cosmetic and drug. The inflorescences are very fragrant and plants in flower are esteemed as ornamentals. The rhizomes are highly aromatic (fresh and dried) and are widely used medicinally against rheumatism.
C. pierreana is used as a source of starch as a substitute for arrowroot.

Production and international trade Most *Curcuma* species are only produced and traded locally. Some are rather important locally, but no statistics are available. Internationally, turmeric (*Curcuma longa* L., synonym *C. domestica* Valeton) is the only extremely important *Curcuma* representative; it is used primarily as a condiment and spice (in curry powder).

Properties Most *Curcuma* species contain starch, dyes and essential oils in their rhizomes and tuberous roots. Fresh rhizomes may contain 10–12% starch and 1–2% essential oils. No specific data are available for the species described here.

Botany Rhizomatous, perennial, erect herbs, usually strongly tillering, up to 2 m tall. The base of each aerial stem consists of an erect ovoid primary tuber ringed with the bases of old scale leaves, bearing when mature several to many horizontal or curved rhizomes, which may again be branched. Roots fleshy, many of them bearing ellipsoidal tubers at their tips. Leafy shoots bearing a group of leaves surrounded by bladeless sheaths forming a pseudostem. Inflorescence spike-like, terminal on a leafy shoot or on a separate shoot from the base of the leafy shoot; peduncle (scape) covered by rather large bladeless sheaths; spike covered with bracts that are joined to each other for about half their length, forming pouches, the free ends usually spreading, each bract subtending a cincinnus of 2–7 flowers; uppermost bracts often larger, differently coloured and sterile (forming a coma); bracteoles thin, open to the base; calyx tubular, split unilaterally, unequally toothed; corolla with a more or less funnel-shaped tube and a 3-lobed limb, the dorsal lobe hooded and ending in a hollow hairy point; staminodes 3, petaloid, the 2 lateral ones folded under the dorsal corolla lobe, the anterior one, called labellum, is the most conspicuous part of the flower, and has a thickened central portion and thinner side-lobes which overlap the lateral staminodes; single fertile stamen, with a short broad filament and a versatile anther which is usually spurred at the base; ovary trilocular with 2 erect glands (stylodes) on top, style linear and held between the anther thecae,



Curcuma pierreana Gagnepain – 1, habit flowering plant; 2, flower.
Curcuma aromatica Salisb. – 3, tuberous rhizome.
Curcuma angustifolia Roxburgh – 4, tuberous rhizome.

stigma expanded. Fruit an ellipsoidal capsule. Seed ellipsoidal, with a lacerate aril of few segments.

- *C. angustifolia*: up to 0.5 m tall; rhizome small, globose, with many oblongoid, pale tubers at the end of the roots; leaves lanceolate, 15–30 cm × 5–7 cm, petiole about 15 cm; inflorescence separate, appearing before the leaves, peduncle 7–15 cm long, spike 7–15 cm × 5 cm with flowers longer than the bracts, bracts green, coma bracts pink, corolla lobes pale yellow, staminodes bright yellow, labellum elliptical, 11 mm × 7 mm.
- *C. aromatica*: up to over 1 m tall; rhizome large, tuberous, cylindrical, 2.5 cm in diameter, root tubers mostly sessile, not at the end of the roots, rhizome and root tubers yellow inside and outside; leaves broadly lanceolate, 40–70 cm × 10–14 cm, pubescent below, petiole up to 70 cm long; inflorescence separate, usually appearing

before the leaves, peduncle 5–8 cm long, spike 15–30 cm × 9 cm with flowers shorter than the bracts, bracts pale green, coma bracts pinkish, corolla lobes pinkish-white, staminodes deep yellow, labellum orbicular.

– *C. pierreana*: up to 20 cm tall; rhizome horizontal, cylindrical, 2 cm in diameter, whitish; leaves lanceolate-ovate, 15–20 cm × 6–8 cm, glabrous, petiole 9–11 cm long; inflorescence separate, appearing after the leaves, sessile, ovoid, 8 cm × 4–5 cm, with flowers longer than the bracts, bracts reddish with pinkish dots, coma bracts absent, corolla lobes white, lateral staminodes white at base, red at top, labellum suborbicular, 11–13 mm in diameter, white with a yellow central stripe.

The taxonomy of *Curcuma* is confusing and needs to be thoroughly revised. All species with tuberous rhizomes are probably used as a source of food in times of scarcity. There are also reports of the following species being used: *C. leucorrhiza* Roxburgh (India, very similar to *C. zedoaria* and *C. aromatica*), *C. montana* Roxburgh (India, related to *C. longa*) and *C. rubescens* Roxburgh (India, related to *C. zedoaria*).

Ecology The ecology of *Curcuma* is not well known. Most species originated or grow in deciduous monsoon forest regions of South and South-East Asia, usually with an annual rainfall of 1000–2000 mm, up to 2000 m altitude in the Himalayan foothills. *Curcuma* grows best on loamy or alluvial, loose, fertile, friable soils and cannot stand waterlogging. In the wild the plants are found in shady sites.

Agronomy *Curcuma* species can be propagated from rhizome parts. If primary rhizome tubers are planted, harvesting can take place after about 10 months, if other parts are used, 2 years are needed.

Clean weeding is recommended. When the leaves start to wither, the rhizomes may be dug up and harvested. Starch can be extracted by macerating the tuberous rhizomes in water and allowing the starch to settle. After several washings with water the starch is dried and is then ready for consumption. In villages, instead of extracting the starch immediately, the rhizome parts are often peeled, sliced and dried and are used when needed or offered for sale in local markets. In general, no specific agronomical practices are known for most species.

Genetic resources and breeding Apart from the *Curcuma* collections present in botanical gardens, no special germplasm collections are known. Breeding programmes are only known for turmeric.

Prospects *Curcuma* deserves much more scientific attention, because of its interesting food, dye, spice, ornamental and medicinal aspects. Germplasm collection is urgently needed, simultaneously with a thorough taxonomic revision. Agronomically, it should be investigated whether large-scale production of promising species is profitable in the humid tropical lowlands of South-East Asia.

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Curcuma xanthorrhiza Roxburgh

Fl. ind. 1: 25 (1820) (*'zanthorrhiza'*).

ZINGIBERACEAE

$2n = 63$ (triploid)

Synonyms *Curcuma zedoaria* Ridley (1899).

Vernacular names Indonesia: temu lawak (Indonesian), koneng gede (Sundanese), temo labak (Madurese). Malaysia: temu lawas, temu raya. Thailand: wan-chakmotluk (central). Vietnam: ngh[eej] v[af]ng, ngh[eej] r[eex] v[af]ng.

Origin and geographic distribution *C. xanthorrhiza* originates from Indonesia (Ambon, Bali, Java) where it still grows wild e.g. in teak forests. It is commonly cultivated in Java and Peninsular Malaysia, occasionally elsewhere (e.g. in India and Thailand).

Uses The deep yellow rhizome has a pungent smell and a bitter taste. Starch can be extracted by grating the rhizomes and kneading the gratings in water above a sieve. This process is repeated for several days and the water above the slurry is repeatedly renewed until it remains colourless when the deposit is pressed. Then the slurry is washed out until the bitterness has gone and most of the pungent smell has disappeared. The resulting starch is used for making various delicacies like pudding and porridge. The starch is said to be of good quality and is easily digestible for infants as well.

In Java, a drink is prepared by cooking dried pieces of rhizome in water and adding sugar. Young growing parts of the stem and rhizome are used as a vegetable raw or cooked, and inflorescences are eaten cooked.

The rhizome is also used to make a yellow dye.

The rhizomes are frequently used in traditional medicine. An infusion or decoction of sliced, grated and sometimes dried rhizomes is used to cure liver diseases, fever, indigestion, rheumatism and to remove gall stones. It is also used as a general tonic, e.g. after childbirth where it is also said to promote the milk flow.

Production and international trade *C. xanthorrhiza* is mainly produced, consumed and traded locally. No recent statistics are available. Between 1934–1938 about 10 t of sliced and dried rhizomes were exported annually from Indonesia to the Netherlands and Germany.

Properties Dry sliced rhizomes contain: water 12%, starch 37–61%, essential oil 7–30%, and curcumin (the yellow colouring principle) 1–4%. The chemical content varies considerably during the development of the rhizomes: initially curcumin and essential oil contents are higher than the starch content; the starch content is highest in well developed rhizomes. The essential oil contains phellandrene, camphor, p-toluyl-methylcarbinol and isoprenemyrcene. Curcumin and isoprenemyrcene are most probably the most characteristic substances of *C. xanthorrhiza*.

Botany Robust, perennial, erect, strongly tillering herb, up to 2 m tall. Rhizome a fleshy complex with an erect ovoid structure (primary tuber) at the base of each aerial stem, ringed with the bases of old scale leaves and when mature bearing numerous lateral rhizomes which are again branched; primary tuber 5–12 cm long, 3–10 cm in diameter, lateral rhizomes much smaller, often without particular shape, clavate or cylindrical, 1.5–10 cm long, 1–2 cm thick, outside yellowish or orange-red-brown turning greyish when older, inside intense orange or orange-red, younger parts paler. Roots numerous, fleshy and terete, up to 30 cm long, at the apex usually abruptly swollen into a globose or ellipsoid tuber up to 5 cm × 2.5 cm. Leaf shoots bearing up to 8 leaves surrounded by

Curcuma xanthorrhiza Roxburgh – 1, habit flowering plant; 2, tuberous rhizome.

bladeless sheaths, the leaf sheaths forming a pseudostem; sheath up to 75 cm long, green; petiole 0–30 cm long, its apex passing gradually into the blade; blade elliptical-oblong or oblong-lanceolate, 25–100 cm × 8–20 cm, dark green above with a more or less intensely reddish-brown central streak 1–2.5 cm wide, light green or sea-green below, glabrous, densely white-dotted. Inflorescence lateral, sprouting from the rhizome next to the leaf shoot, spike-like; peduncle 10–25 cm long, covered by rather large bladeless sheaths; flower spike cylindrical, 15–25 cm long, 10–20 cm in diameter, provided with 15–35 bracts arranged spirally, each containing a flower except the 5–6 upper ones; bracts in their lower half adnate to each other, the basal parts thus forming closed pockets, the free upper parts more or less spreading; the 10–20 upper bracts purplish and longer and narrower than the 10–20 light green lowest bracts; bracteoles small, membranous, surrounding the flowers; flowers in cincinni of 2–7, each cincinnus in the axil of a bract and the flowers about as long as the bracts; calyx small, 1–1.5 cm long; corolla

4–6 cm long, lower half tubular, upper half much widened, light red, 3-lobed with 2 equal anterior lobes and a larger ventricose posterior one; labellum suborbicular, weakly 2-lobed, about 2 cm in diameter, yellowish with a darker yellow longitudinally furrowed central streak; staminodes 2, large and wide, connate with the base of the stamen, yellow-white; filament short and wide, anther thick, at the base with claw-like spurs, white; ovary white, pubescent, 4–5 mm long; style filiform, white, 4 cm long with 4-lobed stigma.
C. xanthorrhiza is closely related to *C. zedoaria* (Christmann) Roscoe, and some authors even consider it to be conspecific with it. The main differences are its pink petals (white in *C. zedoaria*), the deep-orange flesh of the rhizome and root tubers (light yellow in *C. zedoaria*), its larger inflorescence and the reddish-brown central streak only on the upper side of the leaves (both sides in *C. zedoaria*).

Ecology *C. xanthorrhiza* occurs wild in thickets and teak forests of East Java. If prefers slightly shady conditions and demands a moist, fertile soil rich in humus.

Agronomy *C. xanthorrhiza* is propagated from pieces of rhizome, which are preferably planted at the end of the rainy season, in holes 60 cm apart. Planting under light shade is recommended (e.g. under *Paraserianthes falcataria* (L.) Nielsen). Rhizomes start sprouting about 1 week after planting. Clean weeding is recommended. When primary tubers have been planted (requiring much planting material) harvesting is possible after 8–12 months; when lateral rhizome parts have been used it takes about 2 years until harvesting.
Harvesting is carried out in the dry season, when the aboveground parts have died, by digging up the rhizome clump. Yield of fresh rhizomes is about 20 t/ha. The roots and remains of leaves are removed, and the rhizomes are washed, peeled, sliced and dried. Slices 7–8 mm thick are made, dried in one layer at about 50°C, resulting in slices 5–6 mm thick, which should be packed airtight.

Genetic resources and breeding In Indonesia, a germplasm collection of *C. xanthorrhiza* is kept in the Bogor Botanical Gardens. No breeding programmes are known.

Prospects *C. xanthorrhiza* is an important home garden plant in Indonesia and Malaysia. More research is needed to investigate the feasibility of large-scale production and marketing. Many aspects of cultivation and breeding need closer investigation and substantial germplasm collection is needed urgently.

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P.C.M. Jansen

Curcuma zedoaria (Christmann) Roscoe

Trans. Linn. Soc. 8: 354 (1807).
ZINGIBERACEAE
$2n = 63$ (64, 66) (triploid)

Synonyms *Amomum zedoaria* Christmann (1779), *A. latifolium* Lamk (1783), *Curcuma zerumbet* Roxb. (1810). Note: '*zedoaria*' is often erroneously spelled '*zeodaria*'.

Vernacular names Zedoary, kua (En). Zédoaire (Fr). Indonesia: temu putih (Indonesian), koneng tegal (Sundanese). Malaysia: temu kuning, temu lawak, kunchur. Philippines: barak (Tagalog), alimpuyas (Bissaya), tamahilan (Bikol). Burma (Myanmar): thanuwen. Cambodia: prâtiël prèah 'ângkaôl. Laos: khminz khünz. Thailand: khamin-khun (northern), khamin-oi (central). Vietnam: ngh[eej] den, nga tru[aaj]t, ng[ar]i t[is]m.

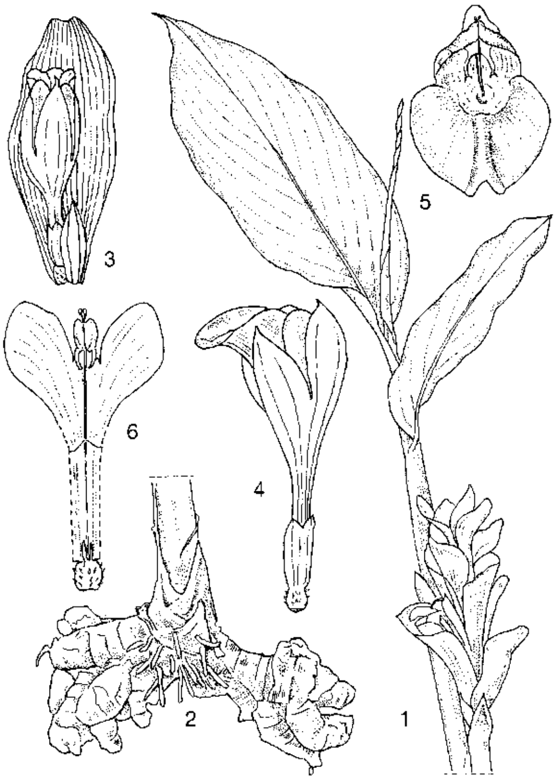
Origin and geographic distribution The origin of *C. zedoaria* is not known exactly, but it is possibly in north-eastern India. It has been cultivated for a very long time throughout South and South-East Asia, China and Taiwan and it easily runs wild in this area, thus occurring wild and cultivated all over. Occasionally, it is cultivated elsewhere (e.g. in Madagascar).

Uses The rhizomes of *C. zedoaria* are the source of 'shoti' starch, which is easily digestible and valued as an article of diet, particularly for infants and people with digestive problems. The heart of young shoots is used as a vegetable (raw or cooked) in Indonesia, where also young rhizome parts (tops) are eaten raw and inflorescences cooked. Leaves are used for flavouring foods in India and Indonesia, and in India the rhizomes are used in perfumery. In traditional medicine the rhizomes are widely used as stimulant, carminative and depurative, the latter especially after childbirth but also to clean and cure ulcers, wounds and other skin disorders. Rhizome parts are chewed against bad breath and decoctions drunk against stomach-ache and colds.

Production and international trade Zedoary is primarily produced and traded locally. Until the Middle Ages the rhizomes were also popular in Europe and were an article of commerce. At present, international trade is negligible but no statistics on local production are available either.

Properties Fresh zedoary rhizomes contain approximately: water 70%, starch 12%, other materials (including essential oil, cellulose) 18%. Per 100 g edible portion 'shoti' starch contains approximately: water 13 g, starch 83 g, ash 1 g, other materials 3 g. The starch grains have an average size of 1.6–4.2 μm and are ellipsoidal or ovoid.
The essential oil present in the rhizomes (1–2%) is light yellow-greenish, smells like ginger oil mixed with camphor; at 30°C it has a specific gravity of 0.9724 and it contains d-α-pinene, d-camphene, cineol, α-camphor, d-borneol, sesquiterpenes, sesquiterpenols and sesquiterpene alcohols.

Botany Robust, perennial, erect, strongly tillering herb, 1(–3) m tall. Rhizome a fleshy complex with an erect broadly ovoid structure (primary tuber) at the base of each aerial stem, ringed with the bases of old scale leaves and when mature bearing numerous lateral rhizomes which are again branched; primary tuber up to 8 cm long, 4–6 cm in diameter, lateral rhizomes usually smaller, up to 10 cm long and 3 cm in diameter, outside grey, inside pale yellow-white to bright yellow. Roots numerous, fleshy and terete, at the apex usually swollen into a subellipsoidal tuber of 2–15 cm × 1–2.5 cm and white inside. Leaf shoots bearing up to 8 leaves, surrounded by bladeless sheaths which form a pseudostem; sheath 40 cm long or longer; petiole 3–12 cm long, its apex passing gradually into the blade; blade elliptical-oblong or oblong-lanceolate, 35–75 cm × 10–20 cm, above dark green with a more or less intensely reddish-brown central streak 1–2.5 cm wide, light green below with a narrower central streak, the streak fading in older leaves. Inflorescence lateral, sprouting from the rhizome next to the leaf shoot, spike-like; peduncle about 22 cm tall, covered with 3 sheaths; flower spike cylindrical,



Curcuma zedoaria (Christmann) Roscoe – 1, leafy and flowering stem; 2, tuberous rhizome; 3, bract with cincinnus; 4, flower in lateral view; 5, flower in front view; 6, stamen and lateral staminodes.

10–16 cm long, 5–12 cm in diameter, provided with 16–30 bracts arranged spirally, each of which contains 4–5 flowers (arranged in a cincinnus) except the 5–6 upper ones; bracts in their lower half adnate to each other, the basal parts thus forming closed pockets, the free upper parts more or less spreading; lowest bracts entirely green, middle ones tipped with a purple spot, uppermost 5 entirely purple with 4 bracts below them streaked white and pale green at the base and purple at the tips; bracteoles small, membranous, surrounding the flowers; flowers as long as the bracts or shorter, 3.5–4.5 cm long; calyx very short, up to 1 cm long; corolla up to 4.5 cm long, lower half tubular, upper half much widened, yellow-white, 3-lobed with 2 equal anterior lobes and a larger ventricose posterior one; labellum broadly elliptical, 2–2.5 cm × 1.5–2 cm, weakly 2-lobed, pale yellow with a darker yellow longitudinally furrowed central streak; staminodes 2, large and wide, connate with the base of the stamen, yellow-white; filament 4.5 mm long and wide, anther white, thick, 6 mm long, at the base with divergent curved spurs 3 mm long; ovary 4–5 mm long, pubescent, 3-locular, style filiform, stigma 4-lobed. Fruit an ovoid capsule, smooth, dehiscing irregularly. Seed ellipsoidal, grey.

Zedoary takes about 2 years to develop fully. It rarely flowers in cultivation, but flowers freely where it runs wild. After flowering the aboveground parts die completely and the plant enters a resting phase which can last a very long time.

C. zedoaria is closely related to *C. xanthorrhiza* Roxburgh, and some authors consider the two to be conspecific. The main differences are: petals white (yellowish-white) in zedoary, pink in *C. xanthorrhiza*; flesh of rhizome and root tubers pale yellow to white in zedoary, deep orange in *C. xanthorrhiza*; the inflorescence of zedoary is smaller and the red-brown central streak on the leaf blade is present on both sides in zedoary, but only on the upperside in *C. xanthorrhiza*.

Ecology Zedoary occurs in a wide range of climatic conditions in tropical and subtropical South and South-East Asia. It prefers areas with an annual rainfall of 900–1250 mm with a pronounced dry season, and is found in shady damp locations, up to 1000 m altitude. It grows on all kinds of soils, but prefers well-drained sandy soils.

Agronomy Zedoary is propagated from pieces of rhizome. In India, it is planted first on well-manured, hand-watered, shaded nursery beds, and sprouted rhizomes are planted out in the field at the beginning of the rainy season, preferably on flat beds at a planting distance of 25–45 cm. The crop is weeded regularly and after planting in the field the crop receives a thick mulch. Application of fertilizers has been recommended: farmyard manure 25 t/ha, sulphate of ammonia 340 kg/ha, superphosphate 450 kg/ha and muriate of potash 450 kg/ha in two doses, respectively 40 days and 6 months after planting.

When primary tubers are planted (requiring much planting material), harvesting is possible after about 10 months; when lateral rhizome parts are used, the required growing period is up to two years. Harvesting may start when the leaves begin to wither. The rhizome clumps are dug up, roots and remains of leaves removed, and washed. Yield is 7.5–12 t/ha. Planting material is separated. The remaining parts are peeled, shredded into a pulp and steeped for 24 hours in 10 times their volume of water, with frequent stirring. The starch slurry is filtered off, repeatedly washed with clean water, centrifuged and dried at 50°C. Yield of starch is about 80%. When dilute sulphuric acid or alkali is used during the washing process, a starch of about 95% purity can be obtained.

Genetic resources and breeding Besides the collections available in botanical gardens, no special germplasm collections of zedoary are known to exist. No breeding programmes are known.

Prospects Zedoary is an important home garden crop in South-East Asia. More research is needed to improve cultivation methods, to breed better cultivars, and to investigate the feasibility of large-scale production and marketing. Yield improvement is necessary before zedoary can become an important industrial crop. Germplasm collection is needed urgently.

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Halijah Ibrahim & P.C.M. Jansen

Cyperus L.

Sp. pl.: 44 (1753); Gen. pl. ed. 5: 26 (1754).

CYPERACEAE

$x = 8, 9$; *C. esculentus*: $2n = 96, 108$; *C. rotundus*: $2n = 96, 108, 152$

Major species and synonyms

- *Cyperus bulbosus* Vahl, Enum. 2: 342 (1806), synonym: *C. jemenicus* (non Rottb.) Clarke (1884).
- *Cyperus esculentus* L., Sp. pl.: 45 (1753).
- *Cyperus rotundus* L., Sp. pl.: 45 (1753), synonym: *Cyperus curvatus* (non Vahl) Llanos (1851).

Vernacular names General: Cyperus, sedge (En). Indonesia: teki. Thailand: haeo. Vietnam: c[os]i.

- *C. bulbosus*: Vietnam: c[os]i c[ur].
- *C. esculentus*. Chufa, yellow nut grass, tiger nut

(En). Amande de terre, souchet sucré (Fr). Cambodia: më:m phlông. Thailand: haeo-thai (central). Vietnam: c[os]i b[oor], c[ur] g[aas]u.
- *C. rotundus*. Purple nut grass (En). Souchet rond (Fr). Indonesia: teki (Indonesian), mota (Madura), karelawai (Sumba). Malaysia: rumput haliya hitam. Philippines: mutha (Tagalog), ahos-ahos (Bisaya), boto-botones (Bikol). Burma (Myanmar): monhnyin-bin. Cambodia: krâva:nh chru:k. Laos: hèwz hmu:. Thailand: haeo-mu (general). Vietnam: c[ur] g[aas]u, h[uw][ow]ng ph[uj].

Origin and geographic distribution *Cyperus* comprises about 600 species, distributed worldwide, but the vast majority occur in the tropics and subtropics. In Malesia, 76 species occur, but most of them have a pantropical or paleotropical distribution.
- *C. bulbosus* occurs in tropical Africa, southern Asia and tropical Australia. In Malesia it is rare and only found in Indonesia on some small islands like Damar Besar, Madura and Timor.
- *C. esculentus* has a very wide distribution from the Mediterranean to southern Africa, from India throughout South-East Asia to Australia and it is abundant in America. In Malesia, it is rare and has only been collected on Java. It is also cultivated for its edible tubers (Mediterranean, Africa, Western Europe, United States) and in some regions it has become an aggressive weed, easily propagating by small tubers and often distributed unintentionally together with other crops. The cultivated form is thought to have originated in the Mediterranean.
- *C. rotundus* is thought to originate in Africa. Now it is widely distributed throughout the warmer parts of the world and it is very common all over South-East Asia.

Uses In general, the genus *Cyperus* is economically unimportant and better known for its weeds than its useful plants. Some species are used for their edible tubers (especially in times of food scarcity), for their edible stems (as vegetable or as forage), for their dried stems (ropes, baskets and other wickerwork), or as ornamentals or for medicine. But several species are best known as weeds in agriculture.

Where *C. bulbosus* is common the young tubers are eaten. *C. esculentus* produces tubers that are eaten raw, cooked, or roasted and ground to a flour which is used in bread-making, in ice-cream, sherbets or drinks, or in the preparation of porridge mixed with a cereal. In Spain, a very popular drink called 'horchata' is prepared from the tubers and is obtained by extracting a milky liquid from thoroughly ground tubers. Oil can be extracted from the tubers, formerly used to make soap. The dried stems are used to make mats and wickerwork. Tubers and aboveground parts also serve as a forage. The plant is also used as a stimulant and as a sedative in Asia and Africa.

The tubers of *C. rotundus* are also edible; it is not cultivated for this purpose like *C. esculentus*, but the tubers are collected from the wild in times of need. Its powdered tubers (usually in decoctions) are widely used medicinally in South-East Asia as a stimulant, diureticum, anthelmintic (in large doses), emmenagogue, galactagogue, sudorific, as mouth-wash against diseases in the mouth, against toothache, stomach-ache and ulcers, as an astringent against diarrhoea and dysentery, and against liver complaints. They are also used as an insect repellent and because of their aroma for perfuming clothing. The roasted tubers have also been used as a substitute for coffee and as an adulterant for cacao.

Production and international trade Only tubers of *C. esculentus* are produced and traded commercially, but not in South-East Asia. All species are considered as weeds that are difficult to eradicate. In particular *C. rotundus* and the weedy forms of *C. esculentus* are considered as belonging to the world's worst weeds. The tubers are only used in times of famine.

Properties Tubers of *C. esculentus* are rich in starch (20–30% on dry weight basis) and oil (20–28%) and are a good source of P and Fe, with small quantities of protein. The oil consists primarily (80%) of unsaturated fatty acids, mainly oleic acid.

Per 100 g edible portion, tubers of *C. rotundus* contain approximately: water 59 g, protein 2.3 g, fat 1.6 g, carbohydrates 20 g, fibre 16 g, ash 0.8 g. The energy value averages 790 kJ per 100 g. The fresh tuber contains about 0.6% essential oil, mostly consisting of sesquiterpenoids (copadiene, epoxy-guiane, rotundone and cyperolone). The petroleum ether extract of the tubers exhibits anti-inflammatory activity against carrageen-induced oedema in albino rats and oestrogenic activity and some spasmolytic action on isolated uterus of guinea pig and rat.

Description Perennial or annual herbs, tufted or with creeping rhizome or stolons. Stem usually erect, triangular in cross-section, usually leafy only at the base. Leaves tristichous, narrowly linear, grass-like, the lower ones often scale-like. Inflorescence terminal, simple to decompound, umbel-

Cyperus rotundus L. – habit of flowering plant with young plantlets.

like or capitate; rays subtended by a leaf-like bract; spikelets more or less compressed, quadrangular to subterete, 1–many-flowered; glumes distichous, usually 2 basal ones empty; flowers bisexual, the uppermost often male or sterile; stamens 3, 2 or 1; style continuous with the ovary, 3- or 2-fid. Fruit a nut, sessile or shortly stipitate, trigonous or lenticular.

- *C. bulbosus*. Perennial with thread-like rhizomes which disappear after having formed tubers. Tuber ovoid to fusiform, 1–1.5 cm long, bulb-like, whitish turning shiny black, coat coriaceous, striate, splitting into some caducous segments. Stem arising from a tuber, slender, (5–)15–30 cm × 0.5–1 mm. Leaves several, often recurved, as long as or longer than the stem, 1–2(–4) mm wide, scaberulous in upper part. Inflorescence simple, often reduced to a spike; involucral bracts (1–)2–3, up to 10 cm long, distinctly separated from each other; spikelet 8–28-flowered, 1–3 cm × 2 mm; rachilla flexuous, broadly winged, persistent; glumes 9–11-veined; stamens 3, stigmas 3. Fruit trigonous, obovoid to ellipsoidal, 1.5 mm × 0.5 mm, black.
- *C. esculentus*. Perennial with very slender, yellowish rhizomes clothed with pale scales; rhizomes often disappearing after having formed tubers; tuber ovoid to globose, about 1 cm in diameter, transversely zoned when young, grey tomentose when ripe. Stem slender, rigid, 10–50 cm × 1–2 mm. Leaves several, somewhat shorter or longer than the stem, 3–6 mm wide. Inflorescence simple or compound, loose to dense, umbel-like; involucral bracts 3–6, the lower 1–2 usually much overtopping the inflorescence; primary rays 3–8, unequal, 3–10(–15) cm long; spikes ovoid, with few to numerous spikelets; spikelet 8–16-flowered, 5–18 mm × 2 mm; rachilla slightly flexuous, broadly winged; glumes distinctly 7-veined over their whole breadth, golden-yellow to pale brown; stamens 3, stigmas 3. Fruit trigonous, obovoid, 1.5 mm × 1 mm.
- *C. rotundus*. Perennial with long, slender, stout, wiry, dark brown rhizomes giving rise to tubers at intervals of 5–25 cm, forming tuber chains that extend to a considerable depth in the soil. Tuber subglobose or ellipsoid, 0.5–2.5 cm long, white and succulent when young, turning fibrous brown-blackish, without grey tomentum, not zoned. Stem slender, 15–30(–75) cm × 1–2 mm. Leaves several, linear, flat, 10–30 cm × 2–6 mm, scabrid on the margins in the upper part. Inflorescence composed of spikes, arranged as a simple or compound umbel, up to 15 cm × 10 cm, usually much smaller; involucral bracts 2–4(–6), up to 30 cm long, as long as or overtopping the inflorescence; primary rays 3–9, very unequal, up to 10 cm long; spikes ovoid, loose to dense; spikelets 10–40(–100)-flowered, 1–3.5 cm × 2 mm; rachilla flexuous, broadly winged; glumes 5–7-veined over one third or one half of either side of the midvein, deep brown; stamens 3, stigmas 3. Fruit trigonous, oblong-obovoid, 1.5 mm × 0.50–0.75 mm, brown to black, rarely maturing.

Growth and development Most *C. rotundus* plants originate from a tuber; seed production is possible but unimportant. The sprouting tuber produces a rhizome which terminates as a green aerial shoot. While emerging from the soil a swelling appears on the rhizome, often near the surface, but up to 20 cm depth, usually called a 'basal bulb'. On the basal bulb roots are formed and rhizomes grow out from it for a distance of 1–30 cm horizontally before the tip turns up to produce a new aerial shoot with another basal bulb, or, alternatively, to form a subterranean tuber from which another rhizome appears at the apical end, thus forming chains of tubers. The basal bulb and aerial shoot population may increase fivefold in the first 4 weeks after a tuber has been planted. It is believed that there are no buds at the nodes of the rhizomes and that no new plants can grow from rhizome fragments. Rhizomes and tubers are white and fleshy when young and some become firmly packed with starch. On aging they darken, harden, and most of the tissue exterior to the endodermis of the rhizomes sloughs off to give a wiry structure resistant to desiccation and decay. Short photoperiods stimulate flowering, and the period from emergence to flowering varies between 3–8 weeks. Short photoperiods might also stimulate tuber formation and it is believed that tubers do not form until flowering begins. Flowers are cross-pollinated, mostly by wind. Although many seeds are formed, viable seeds are rare. Seed germination averages 1–5%. Most tubers are found in the top 15 cm of the soil, and when planted at 90 cm depth, they are unable to grow to the surface. In cultivated areas starch reserves are highest in tubers that are below the disturbed layer, in non-cultivated land in tubers near the soil surface.

The development of *C. esculentus* is practically the same. Flowering, however, is stimulated by photoperiods of 12–14 hours and the viability of the seed produced is much higher than in *C. rotundus*, e.g. above 50%. In the weedy forms seed propagation is much more important.

Other botanical information Some differences exist between the wild weedy forms of *C. esculentus* and the cultivated ones. Cultivated chufa has grey-orange tubers (weedy chufa grey-brown), which are less fibrous and borne on short rhizomes (longer in the weedy forms); shoots arising directly from the tubers are ascending and rarely flower (in weedy chufa they are erect and flower easily), and are sensitive to frost (weedy chufa is frost resistant to a certain degree). It has been correctly proposed to classify the cultivated forms into the cultivar group Chufa.

In *C. rotundus* 2 subspecies are distinguished: subsp. *rotundus* and subsp. *retzii* (Nees) Kük. Subsp. *retzii* (synonym: *C. retzii* Nees) differs from subsp. *rotundus* by its stouter habit (stem 50–75 cm tall), the somewhat broader spikelets (about 2.5 mm wide when ripe) and the paler elliptical-oblong glumes (3.5–4 mm long). It appears in moist locations, sometimes as a weed, but never as a pest; it is often confused with *Cyperus esculentus*, which has glumes with 7–9 prominent veins and ovoid tubers with a grey tomentum. *C. rotundus* can be recognized by its usually dark brown rhizomes, which may produce several tubers in a chain. *C. esculentus* has yellowish rhizomes which end in a single tuber.

Another tuber-bearing species, *C. stoloniferus* Retzius, is also widespread in South-East Asia, growing on coastal sands. It acts as a sandbinder and might, although not reported, provide food in times of food scarcity.

Ecology Most *Cyperus* species are hygrophilous and grow in moist or wet locations at low and medium altitudes, only a few occurring above 1600 m altitude in the tropics.

C. bulbosus grows on dry sandy soils, in Malesia only near the sea.

C. esculentus grows in seasonally wet grassland, in irrigated crops, in damp grassland and along watercourses. It is also quite drought resistant but does not tolerate shade. Optimum average temperatures are 27–30°C, and optimum rainfall varies between 600–1200 mm. Preferred soils are light sandy loams with pH 5.5–6.5, but it grows on any kind of soil provided it is well drained. It is also quite tolerant of saline soils. Short photoperiods of 8–12 hours favour tuber formation, long photoperiods favour other vegetative growth.

C. rotundus is found in cultivated fields, on roadsides, in neglected areas, at the edges of woods, along irrigation canals and streams, all over the world in both hemispheres up to about 50° latitude where cold limits its further expansion. It grows without problems at any elevation, humidity, in almost any soil type, soil moisture and pH, and can survive very high temperatures. Only low temperatures, shade, and soils with high salt content can limit its growth, and the tubers can remain dormant for a long time to carry the plant through the most extreme conditions of heat, drought, flooding or lack of aeration.

Agronomy *C. esculentus* cv. group Chufa is propagated by tubers which are first soaked in water for 2–3 days before being planted. Freshly harvested tubers may show a dormancy period, which can be broken by a cold treatment (e.g. in temperate climates by overwintering). Planting distance varies, usually in rows 60–90 cm apart, at 10–15 cm intervals, 2.5–4 cm deep, at wider spacings usually with 2 tubers per hole. A spacing of 15 cm in 75–90 cm distant rows requires 35–45 kg tubers per ha as planting material. Farmyard manure and NPK (6:6:8, up to 1000 kg/ha) is recommended in Spain.

No serious diseases and pests are known. In the

United States negrobug (*Corimelaena pilicaria*) punctures the tubers; sometimes harm is done by root-knot nematodes (*Meloidogyne* spp.). The tubers reach maturity in 3–4 months; they are harvested manually or mechanically at the end of the dry season when the plants begin to wither. Average yields of tubers on sandy soils range from 800–900 kg/ha; under optimum conditions 8–14 t/ha can be obtained. Harvested tubers are cleaned, washed, and dried before being graded and stored in thin layers under shelter.
C. rotundus may produce up to 40 t subterraneous plant material per ha per year. It is a serious weed of rice, sugar cane, maize and vegetables in South-East Asia. It has been reported as a host plant for *Rhizoctonia* disease and for root-knot nematodes (*Meloidogyne* spp.). Digging up all rhizome parts and/or the planting of crops that cause several years of continuous shade can eradicate it. Biological control methods have not yet been successful, but promising results have been obtained with the rust *Puccinia canaliculata* for the weedy forms of *C. esculentus*.

Genetic resources and breeding No germplasm collections and breeding programmes are known.

Prospects Compared to the efforts to eradicate *Cyperus* weeds in cultivated land, the cultivation of *C. esculentus* cv. group Chufa is of no importance. It is expected that in South-East Asia *Cyperus* will primarily remain a weed problem for which effective herbicides and biological control methods still have to be found.

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Cyrtosperma merkusii (Hassk.) Schott

Oesterr. Bot. Wochenbl. 7: 61 (1857).
ARACEAE
$2n = 26$

Synonyms *Cyrtosperma lasioides* Griffith (1851), *C. edule* Schott ex Seem. (1861, '*edulis*'), *C. chamissonis* (Schott) Merrill (1914).

Vernacular names Giant swamp taro, swamp taro (En). Malaysia: geli-geli, keladi pari, birah hutan. Philippines: palauan (Bisaya), palau (Bisaya), galiang (Bikol). Thailand: kli (Malay-Pattani). Melanesia: kakake (Solomon Islands). Vietnam: h[aj]t cong.

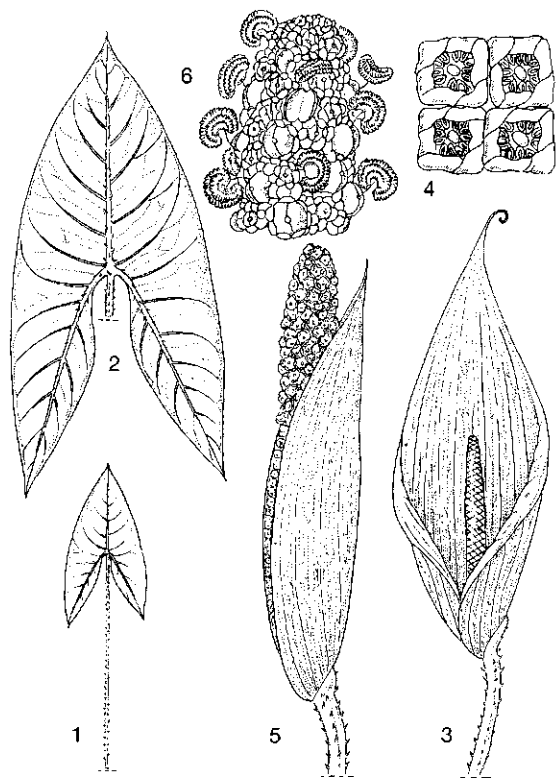
Origin and geographic distribution The origin of *C. merkusii* is not known, possibly in western Malesia or in Melanesia (Solomon Islands). It is now distributed wild and cultivated from Peninsular Malaysia, throughout Malesia to Oceania, but it is absent in Sulawesi, the Moluccas and mainland Papua New Guinea. It has certainly been introduced in Micronesia and Polynesia and is now a major staple food on many islands. In Sumatra and Java it is rare, in Malaysia, Singapore, Brunei and the Philippines it is quite common.

Uses The starchy, underground tubers of *C. merkusii* are edible after thorough cooking. They are peeled, cut into sections and boiled, steamed or baked and also sometimes grated or crushed and mixed with other foods such as coconut milk. Young cooked leaves are used as a vegetable. The leaves are also used as packing material (e.g. for food), as mulch and sometimes medicinally. The fibrous outer layer of the petiole can be peeled off and used in fine grades of mat weaving. In the Philippines, a decoction of the spadix is used medicinally as an emmenagogue and ecbolic. Because of its large size, *C. merkusii* also has ornamental value and in certain parts of Micronesia it is a highly valued prestige plant. In the Gilbert Islands, for example, pulling up an old plant to offer the large tuber to a guest is considered as the greatest honour one can pay another.

Production and international trade In worldwide terms, *C. merkusii* is a minor crop, produced and traded only locally by smallholders, and no statistics are available. Where it grows in South-East Asia, it is primarily considered as an emergency or famine food although in some regions in the Philippines it is still a main staple food. In the past it played an important role in man's adaptation to inhospitable Pacific island environments. At present, it is the dominant aroid crop in Micronesia. In Polynesia and Melanesia, *Colocasia esculenta* (L.) Schott is the major aroid crop and *Cyrtosperma merkusii* kept in reserve as emergency food when taro and other crops have failed.

Properties Per 100 g edible portion, tubers of *C. merkusii* contain approximately: water 63–68 g, protein 0.8–0.9 g, fat 0.1–0.2 g, carbohydrates 29–34 g, fibre 1.5 g, ash 1 g, P 28–55 mg, Ca 330–570 mg, Fe 1 mg, thiamin 0.03–0.05 mg, riboflavin 0.07–0.10 mg, niacin 0.9–1.2 mg, ascorbic acid 0.1–3 mg. The energy value ranges between 500–550 kJ/100 g. In the Philippines, the starch content of the tubers ranges between 7–23% and the starch grains are rounded to angular-rounded, (4–)11(–18) μm in size. The tubers and leaves may also contain irritating calcium oxalate raphides and some hydrocyanic acid, both of which can be removed or made inactive by cooking.

Description Robust to gigantic herb, up to 4 m tall, growing solitarily or in clumps. Rhizome short and slender to tuberous and very large, cylindrical, up to 2 m long and 0.6 m in diameter, sometimes globose, weighing up to 70 kg or even more, producing few to many suckers. Leaves several (6–8), sagittate, rarely hastate; petiole terete, 0.4–3 m long, up to 10 cm in diameter, usually heavily to very heavily armed with stout, conical, straight or upturned spines towards the base, but unarmed in some cultivated forms, with a prominent solid pulvinus at the apex and inside with longitudinal air ducts; blade 0.3–1.3 m × 0.8 m, sometimes armed abaxially, held horizontally to vertically with the posterior lobes down; posterior lobes usually somewhat longer than the anterior one; primary venation of the anterior lobe curvinerved in small lobes to pinnate in large lobes. Inflorescence solitary on a peduncle which is similar to but usually shorter than the petiole; spathe thick and fleshy, very variable in size, colour and shape, 2.5–30 cm long, white, yellow, green or purple, erect to deflexed to rolled back; spadix 2–24 cm long, as long as or more than half the length of the spathe, sessile or stipitate; flowers bisexual, hexamerous; ovary unilocular, (1–)2-



Cyrtosperma merkusii (Hassk.) Schott – 1, habit of leaf; 2, leaf blade with part of petiole; 3, inflorescence; 4, flowers; 5, infructescence; 6, part of infructescence with fruits and seeds.

ovulate, receptive stigma wet; stamens exserted from the tepals at male anthesis. Fruit a berry, reddish-orange, sessile, 1(–2)-seeded. Seed campylotropous, almost circular in profile to shallowly kidney-shaped, 5–11 mm long, brown, with about 3 raised, warty, longitudinal crests or sparsely and more or less irregularly warty and faintly crested.

Growth and development *C. merkusii* is a slow grower and its tubers continue to increase in size and maintain their edibility for many years. Usually tubers are harvested when 3–6 years old, with a minimum of 1 and a maximum of 10 years. Older tubers begin to harden and become increasingly woody and fibrous until completely inedible. Although faster-growing cultivars also exist, their tubers are not considered to be as tasty as those from slow-growing types and the quick growers appear to be more susceptible to adverse conditions. In general, a tuber is considered mature when flowering starts.

Other botanical information The genus *Cyrtosperma* Griffith comprises 11 species, all except *C. merkusii*, confined to New Guinea and surrounding islands. *C. johnstonii* (W. Bull) N.E. Brown is only known from cultivation, mainly as a gigantic ornamental, possibly also producing edible tubers but information on this is scarce. Morphologically, *C. merkusii* is quite variable, which is also expressed by the various existing names for it in taxonomic literature. The poise of the spathe appears to be affected by its size relative to that of the spadix. When the spathe is relatively small, its base is stretched during expansion of the inflorescence and the spathe is deflected. When it is relatively large the spathe is held erect. Cultivated forms tend to be less spiny than wild forms, some types are even unarmed; they usually also have less but larger seeds which are less marked. Locally, many cultivars are informally recognized, differing in leaf shape, colour and spininess, and in the size of the tubers. There are no registered cultivars of the cultivated forms and there is no formal classification into cultivar groups.

Ecology *C. merkusii* is a tropical species, occurring between latitudes 18°N (Mariana Islands) and 20°S (Cook Islands), in lowland swamp forests, open swamps or in man-made swamp pits. It requires high temperatures, and suffers chilling injury and does not tolerate temperatures below 4°C. It mostly grows at sea-level in swamps, but can be grown under year-round high rainfall as a rainfed crop up to 150 m altitude. Ideal growing conditions are natural swamplands rich in humus, about 0.5–2 m deep with slow-flowing irrigation water. *C. merkusii* is a very hardy plant, tolerating or withstanding drought (on atolls often because of the porosity of the soil), salt seawater sprays, brackish water and hurricanes or storms much better than most other aroid crops.

Propagation and planting Young side shoots (suckers) and the top of the main tuber (cuttings comprising the upper 3–5 cm top of the tuber and the lower 30–50 cm of the petioles) are used as planting material. The choice is mostly a matter of local custom, but larger pieces are usually considered stronger and more vigorous. These propagules can be planted in moist or flooded soil, which is kept loose around the base of the plant so as to ensure a nicely shaped tuber. In the Gilbert Islands, in places where natural soil depth is shallow, baskets are woven around the base of the plants and filled with soil and manure as the plants grow. These plants produce large tubers if allowed to grow for several years. On atolls in the Pacific, where the soil is shallow, consisting of sand or partially decomposed coral, people dig pits or trenches down through the coral to the fresh groundwater level, and fill them with a mixture of soil, sand and green manure compost to create a suitable growing medium. Over the years, these man-made pits develop a soil of sorts in which, when supplemented with further vegetative mulches, crop residues and garbage, *C. merkusii* and *Colocasia esculenta* are grown. *C. merkusii* can be planted year-round, provided satisfactory growing conditions prevail. Planting depth varies, but 10–15 cm is fairly standard. Growing conditions and plant size greatly influence the spacings that are used. *C. merkusii* is a large plant and requires a large area, e.g. up to 1.2 m × 1.2 m in Palau and 1–3 m apart in the Philippines.

Husbandry Little is known of the nutritional needs of *C. merkusii* but the plant responds readily to compost and organic mulch. Because *C. merkusii* requires 3–6 years to mature, 2–3 crops of *Colocasia esculenta* are often intercropped while *C. merkusii* is growing.

Diseases and pests No serious disease and pest problems are known and *C. merkusii* is most probably more resistant than *Colocasia esculenta*. Dasheen mosaic virus (DMV) on the leaves and *Pythium* tuber rot are diseases that have been reported to cause some losses. On some islands (e.g. Mortlock Islands) rats cause serious crop losses.

Harvesting Generally, cultivars are considered ready for harvesting when flowering starts; harvesting, however, occurs whenever the food is needed because the tubers can remain in the soil without loss of quality for about 10 years.

Yield Individual tubers vary greatly in size, from an average of 2 kg in Truk and 4.5 kg in Yap, to as much as 20–50 kg or more for the giant types. The largest recorded tuber weighed about 180 kg and was grown on Ponape Island. With moderate soil fertility, annual tuber yield averages 10 t/ha, but up to 35 t/ha has been obtained in the Philippines.

Handling after harvest If left with the top portion, harvested tubers can be stored well under cool conditions for at least 1 month. Sometimes tubers are peeled, sliced and dried in the sun; the dried parts can be stored for several months.

Genetic resources There are no germplasm collections. The collection of germplasm is highly recommended now that many forms are endangered. Natural seed set in *Cyrtosperma* is common and farmers have been known to make selections. Unfortunately, it is difficult to store *Cyrtosperma* seed, since it tends to be recalcitrant and must be planted soon after harvest.

Breeding There are no breeding programmes. Breeding *Cyrtosperma* cultivars with early maturity, low acridity, increased salt and water stress tolerance could contribute significantly to increasing production on the atolls in the Pacific. This is particularly challenging because the resources on those islands are very limited and *Cyrtosperma* seems well adapted to their environment.

Prospects *C. merkusii* is an interesting crop which has received too little scientific attention. Its ability to produce food under conditions where other crops fail (drought, floods, fresh and brackish water swamps) makes it a very useful plant in Oceania. For the regions in South-East Asia where it is not yet known, it is promising for marginal lowland areas as well, and deserves much more attention.

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F.A. Evangelio

Dioscorea L.

Sp. pl.: 1032 (1753); Gen. pl. ed. 5: 456 (1754).

DIOSCOREACEAE

x = 10 (Old World), x = 9 (New World); $2n$ = 40, 60, 80, 100 (*D. bulbifera*); $2n$ = 40, 80 (*D. pentaphylla*)

Major species and synonyms

- *Dioscorea alata* L. – see separate article.
- *Dioscorea bulbifera* L., Sp. pl.: 1033 (1753), synonyms: *D. sativa* Thunb. (1784) et auct., non L. (1753), *D. crispata* Roxb. (1832), *D. heterophylla* Roxb. (1832).
- *Dioscorea esculenta* (Lour.) Burkill – see separate article.
- *Dioscorea hispida* Dennst. – see separate article.
- *Dioscorea nummularia* Lamk, Encycl. méth. 3: 231 (1789), synonyms: *D. glabra* Koorders (1898), non Roxb. (1832), *D. seemannii* Prain & Burkill (1914), *D. palauensis* R. Knuth (1924).
- *Dioscorea pentaphylla* L., Sp. pl.: 1032 (1753), synonyms: *D. triphylla* L. (1753), *D. kleiniana* Kunth (1850).
- Other *Dioscorea* species – see chapter on minor species yielding non-seed carbohydrates.

Vernacular names General: Yam (En). Igname (Fr). Indonesia: uwi (Javanese), huwi (Sundanese). Malaysia: ubi. Papua New Guinea: yam. Philippines: yam, ubi. Cambodia: dâmlô:ng. Laos: man. Thailand: man. Vietnam: c[ur] n[aa]u, c[ur] t[uwf].

- *D. bulbifera*. Aerial yam, potato yam, bulbil-bearing yam (En). Igname bulbifère (Fr). Indonesia: huwi buah (Sundanese), jebubug basu (Javanese), singal (Timor). Malaysia: ubi atas, ubi china, ubi kestali. Papua New Guinea: lapma (Yatmei). Philippines: ubi-ubingan (Tagalog), aribukbuk (Ilokano), pulugan (Bikol). Cambodia: dâmlô:ng dü:hs, dâmlô:ng sdâm préi. Laos: man pauz (general), hwà 'i: mu:z (northern). Thailand: wan-prachim (central), hampao (northern), man-soen (Nakhon Si Thammaraf). Vietnam: c[ur] d[aj]i, khoai ch[oof]i, khoai d[as]i.
- *D. nummularia*. Indonesia: huwi upas (Sundanese), uwi in tuwa (Sulawesi), tatopo (Halmahera), singgo (Kem, Irian Jaya). Papua New Guinea: boku. Philippines: pakit (Tagalog), baen di ipay an napagatan (Ifugao). Vietnam: t[uwf] tr[of]n, c[ur] t[uwf] tr[of]n.
- *D. pentaphylla*. Sand yam, fibrous yam, ginger yam (En). Indonesia: ubi pasir, huwi sawut, huwi jahe. Malaysia: ubi pasir, jabet, ubi katak. Philippines: lima-lima (Tagalog), sapang (Bisaya), kasi (Igorot). Cambodia: dâmlô:ng tük. Laos: hwà 'i: mu:z (general), hwà 'è:ng mu: (northern). Thailand: man-makmu (Chiang Mai), man-khankhao (Suphan Buri), man-sue (Nakhon Si Thammarat). Vietnam: c[ur] v[awf]n.

Origin and geographic distribution *Dioscorea* probably originated in the Far East but spread in early times in the Old and New World. It then evolved independently, as no overlap occurs. Only one species is naturally common to the continents of Africa and Asia. About 600 species are known, mainly occurring in the tropics and subtropics, and about 60 species are gathered or cultivated for their edible tubers. In South-East

Asia about 60 species occur, about 20 of which produce edible tubers or bulbils.

- *D. bulbifera*. The most prolific and widespread of all *Dioscorea* spp., occurring from the Atlantic coast of Africa to the remotest islands of the Pacific. It is the only major edible yam native to two continents. It occurs wild and is cultivated all over South-East Asia.
- *D. nummularia*. A common wild and cultivated yam in eastern Malesia (Philippines, Sabah, northern Sulawesi, northern Moluccas, northern New Guinea) extending to Pacific islands as far as Tahiti.
- *D. pentaphylla*. Wild and cultivated, distributed from upper India and southern China throughout South-East Asia to the remoter islands of the Pacific.

The most important cultivated species in other continents are *D. cayenensis* Lamk (yellow Guinea yam) and *D. rotundata* Poiret (white Guinea yam) in West Africa, *D. trifida* L. (cush-cush yam) in tropical America, and *D. batatas* Decaisne (Chinese yam, syn. *D. opposita* Thunb.) in subtropical eastern Asia. The most widely used wild species in times of food scarcity in Africa is *D. dumetorum* (Kunth) Pax (African bitter or cluster yam), which also occurs in cultivation.

Uses Yams are collected or cultivated for their edible tubers, providing a staple carbohydrate food in many tropical countries. In some cases yam plants also produce edible bulbils in the axils of the leaves. As a staple food, yams are most important in West Africa. Normally, the tubers are peeled and eaten boiled, roasted or fried.

Dioscorea species are widely used in traditional medicine. Tubers of some wild species are commercially exploited because of the steroidal sapogenins they contain, from which contraceptives, sex hormones and cortisone are manufactured.

- *D. bulbifera*. The bulbils are especially used for food, but their edibility varies greatly. Bulbils from wild plants are peeled, sliced, washed, boiled for a long time and sometimes still have to be soaked in water to remove toxic substances before they can be eaten. In Java, bulbils from cultivated plants (called 'gedebug', 'katak' or 'katigubug' in Javanese) are edible after peeling and cooking. The cooked bulbils are greenish-yellow, pappy and taste bitter. Old bulbils are the most tasty. Underground tubers, when produced, are also used for food. They are edible in cultivars, but nauseous and poisonous in wild plants. In Peninsular Malaysia, the Semang prepare a dough by grating the tubers and kneading them with lime in a coconut shell. The dough is then wrapped in a plantain leaf and roasted, or buried in the earth and allowed to ferment. The fermented paste will keep for a week. The dough is called 'kleb' when roasted and 'koyi' when fermented. The tubers of wild plants become increasingly unpalatable as the time of new growth approaches. They are bitter and acrid and, when prepared, they are cooked sliced after adding lime and wood ashes. Both bulbils and tubers are occasionally used to produce starch and flour.
- *D. nummularia*. The tubers are used for food and the tough stems are used as cordage. The tubers descend deep into the soil and grow slowly, and are therefore not harvestable until about 3 years after planting. Although it is common in its natural area of distribution, its use for food seems restricted to times of scarcity. The tubers are never poisonous but are unpleasant to eat because of the saponins they contain.
- *D. pentaphylla*. The tubers are used for food, eaten roasted or boiled by themselves, or mixed in vegetable dishes as a flavouring. The cultivated forms (often grown in garden hedges) are tastier than the tubers collected from wild plants, which are often nauseous but non-toxic. Some forms are indicated as priest's yams ('huwi mantri'), princess's yam ('huwi putri') or sacred yam ('huwi dewata') in Java, perhaps referring to a time when the Hindu religion imposed fasts during which inferior food, such as meal from inferior yams, might be eaten.

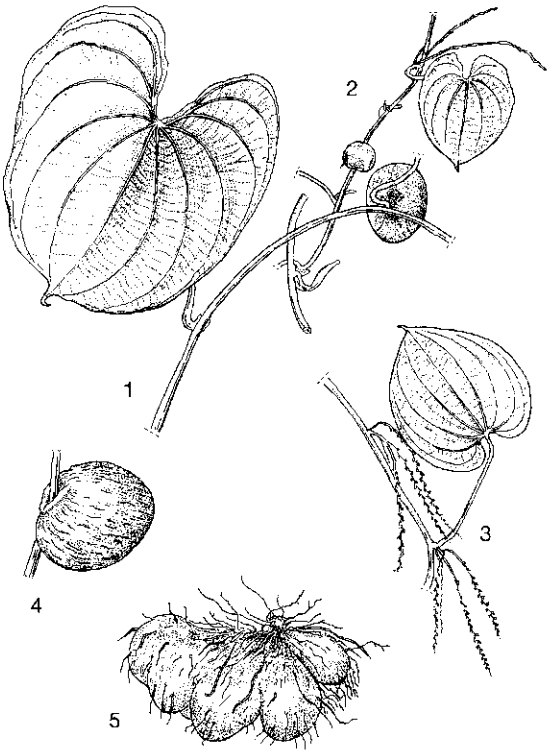
Production and international trade World production of yam is estimated at about 25 million t from about 2.5 million ha. The main producers are West Africa (95%, especially Nigeria and Ivory Coast, with predominantly *D. cayenensis* and *D. rotundata*), the West Indies (1%) and East Africa (1%). Most yam is consumed in the country of production and very small amounts enter international trade. In South-East Asia, *D. bulbifera*, *D. nummularia* and *D. pentaphylla* are cultivated to an appreciable extent. Papua New Guinea and the Philippines are the major producers and consumers.

Properties The approximate composition of yam per 100 g edible portion is: water 65–75 g, protein 1–2.5 g, fat 0.05–0.2 g, carbohydrates (mainly starch) 15–25 g, fibre 0.5–1.5 g, ash 0.7–2 g, ascorbic acid 8–10 mg. The loss on peeling is usually 5–15%. The ascorbic acid is retained during cooking, hence yams contain sufficient vitamin C to be important in nutrition.

Some wild yam species contain toxic alkaloids like dioscorine or dihydrodioscorine, which cause general paralysis of the central nervous system if not removed before eating. Some wild species contain 2–5% sapogenins, the most important of which is diosgenin.

- *D. bulbifera*. Per 100 g edible portion the bulbil contains: water 63–67 g, protein 1.12–1.50 g, fat 0.04 g, carbohydrates 27–33 g, fibre 0.70–0.73 g and ash 1.08–1.51 g. Starch granules are triangular and 5–45 μm in diameter, with a gelatinization temperature of 72–80°C. Starch prepared from the bulbils contains 13.5% moisture, 15.0% amylose, 1.49% protein, 0.29% ash, pH of 4.4, and iodine absorption of 3.9. Viscosity at 95°C is 25 Barbender units, and the gel is not strong.
- *D. nummularia*. Per 100 g edible portion the tuber contains: water 71.9 g, protein 2.0 g, fat 0.06 g, carbohydrates 23.62 g (starch 23.4 g, sugar 0.22 g), fibre 1.84 g and ash 0.95 g. Lysine is the limiting amino acid.
- *D. pentaphylla*. Per 100 g edible portion the tuber contains: water 82.5 g, protein 1.65 g, fat 0.03 g, carbohydrates 14.02 g (starch 13.9 g, sugar 0.12 g), fibre 0.66 g and ash 0.76 g.

Description Dioecious perennial plants, in cultivation usually grown as annuals, with underground rhizome, or more often a woody corm giving off well-defined parenchymatous tubers, sometimes at the end of long stalks; tubers perennial and lignified, or renewed annually as in most edible yams, varying greatly in number, size and form. Roots thick, fleshy and unbranched, or thin, fibrous and branching, sometimes spiny. Stem climbing and twining, 2–12(–40) m long, tough, often woody at the base and winged or with longitudinal ridges; the direction of twining, to the right (dextrorse) with clockwise circumnutation or to the left (sinistrorse) with anticlockwise circumnutation, is constant per species and characteristic of whole sections of the genus. Leaves usually alternate, simple, cordate, acuminate (apex pointing downwards), palmately veined or palmately compound with 3–5 lobes or leaflets pinnately veined; petiole with a pulvinus at each end. Axillary buds often more than one per axil, arranged vertically with the youngest lowest, sometimes developing into a bulbil serving as a storage organ. Inflorescence unisexual, racemose or spike-like; male flowers usually small and green, opening only slightly at anthesis, perianth in 2 whorls of 3 segments, stamens 6, all fertile or 3 staminodal; female flowers usually produced in much smaller numbers, perianth lobes more fleshy, opening more widely at anthesis, ovary 3-locular, style columnar, stigmas 3. Fruit a dehiscent trilocular capsule, 3-winged or strongly angled, 1–3 cm long. Seed flattened, partly or completely winged at its margin.



Dioscorea bulbifera L. – *1, leafy shoot with bulbil; 2, female flowering shoot with bulbil; 3, male flowering shoot; 4, bulbil; 5, tuber.*

- *D. bulbifera*. Tuber produced superficially in the soil, swelling downwards from a rather thick attachment, replaced annually, solitary, globose to pyriform, usually densely covered with rough short roots. Stem twining to the left, climbing up to 6 m tall, usually without hairs, wings or spines. Leaves alternate, simple, broad or long ovate-cordate, up to 20(–32) cm × 20(–32) cm, acuminate; secondary veins conspicuously ladder-like; upper surface shiny, slightly bullate between veins, bluish bloom; petiole half as long to as long as the blade, sometimes winged; auricles usually absent but when present subfoliaceous, partly embracing the stem. Bulbils numerous, usually in leaf axils but sometimes displacing male flowers at the base of flowering axes, small ones usually warty, large ones also smooth or angled, often kidney-shaped, 2.5–5 cm in diameter, flattened, grey to brown, usually weighing 0.5 kg but up to 2 kg; flesh usually pale yellow tinted with violet, when cut, oxidizing to orange, very mucilaginous. Male inflorescence pendulous, 1–4 from the axil of a bract, up to 1 m long with up to 100 flowers; flowers pinky green to white. Female inflorescence pendulous, 1–2 per leaf axil, with about 40 flowers; flowers pediceled, with tepals free. Fruit long and elliptical, 20–22 mm × 8–9 mm, reflexed, winged, shiny brown. Seed winged.

- *D. nummularia*. Tuber spindle-shaped, produced deep in the soil, diameter increasing gradually towards the tip, up to 1 m long and 6 cm in diameter, solitary or sometimes 2 or more; flesh white. Stem twining to the right, cylindrical, usually longer than 3 m, densely spiny at base, less so higher up, glabrous. Leaves opposite or alternate, simple, hastate, up to 11 cm × 9 cm, glabrous, 5-7-veined, red-brown; petiole up to 7 cm long; auricles rounded. Bulbils absent. Male inflorescence 1–4 together, aggregated on downward-pointing leafless branches to 4 cm long with about 50 flowers. Female inflorescence 1–2 together, up to 15 cm long. Fruit red-brown, wings 20 mm × 22 mm.
- *D. pentaphylla*. Tubers elongated and buried deeply, or globose, pyriform or lobed and produced superficially in the soil; flesh white or lemon yellow, sometimes purple flecked. Stem twining to the left, up to 7 mm in diameter, up to 10 m long, usually abundantly prickly in lowest part, glabrescent. Leaves alternate, 3-5-palmately compound, deep rusty red or dirty white pubescent; middle leaflet broadly oblanceolate to obovate, up to 15 cm × 4.5 cm. Bulbils numerous, globose to shortly ellipsoid, brown. Male inflorescence on long leafless branches, bearing 50 flowers each on 3 cm long pedicels. Female inflorescence pendulous, 1–3 together per leaf axil, up to 25 cm long, red pubescent. Fruit blackish, wings up to 20 mm × 6 mm, pubescent.

Growth and development Four phases can be distinguished in a generalized growth cycle of the yam plant (7–9 months form planting to harvesting). In the first phase a profuse root system and a vine develop, the plant depending on nutrients stored in the parent set. In *D. rotundata* this phase lasts about 6 weeks. In the second phase the foliage develops. In *D. rotundata* the canopy is fully formed between weeks 6 and 10 after planting. Root growth continues until week 10, after which root mass remains constant. Vine growth continues until week 13. During the second phase the new plant becomes independent from the parent set. Tuber initiation occurs at week 10–11 and for species that flower, flowering begins approximately at this time. The third phase is characterized by an increase in tuber bulk, which continues until the end of the season. In this phase the fruit also develops. In the fourth phase the shoot senesces and dies back, and the tuber enters a dormant period lasting 2–3 months. The exact duration of each phase varies with the species.

Bulbil production begins when the plant has matured to a certain extent. Bulbils develop in the axils of new leaves and this continues until the end of the season, with old bulbils maturing and dropping off while new ones form closer to the shoot tip. New bulbils arise from the bulbil primordia in the leaf axils. *D. bulbifera* flowers profusely (north of the equator in September, south in May), and produces seed abundantly.

Other botanical information The taxonomy of the genus *Dioscorea* has not stabilized yet because essential information is still missing. Important characteristics are (in order of importance): underground parts, direction of twining, the seeds (wings, colour, shape), the position of the capsules, the shape of the torus of the flower, the degree of segregation of male and female flowers, anatomical features (hairs, glands, etc.).

Most species with edible tubers or bulbils are rather variable. Many cultivars are known.

- For *D. bulbifera* 4 botanical varieties have been distinguished in South-East Asia: var. *bulbifera* (wild plants, tubers and bulbils acrid and nauseous, leaves shortly cordate, the most common variety); var. *heterophylla* (Roxb.) Prain & Burkill (as var. *bulbifera* but with elongated cordate leaves, occurring in Peninsular Malaysia); var. *suavior* Prain & Burkill (cultivated or semi-cultivated plants, tubers and bulbils may be slightly acrid and nauseous, bulbils dark grey-brown, warty, occurring in Java, Madura, Buru, Halmahera, south-eastern New Guinea and the islands eastward); var. *sativa* Prain (as var. *suavior* but with large, smooth, pale yellow bulbils, occurring in Peninsular Malaysia, Singapore, Java, New Guinea, Pacific islands, India ('otaheite potato'), Japan).

Plants from Africa (with small hairs and curiously angled bulbils) have been collectively called var. *anthropophagorum* (Chev.) Prain & Burkill.

Well-known cultivars from *D. bulbifera* include:

'Thuma' (New Caledonia), 'Poison' (Hawaii), 'Smooth Angled' (Puerto Rico).

- *D. nummularia* resembles *D. cayenensis* from West Africa but its tubers are formed deep in the soil.
- *D. pentaphylla* is very variable. In South-East Asia the following varieties have been distinguished: var. *pentaphylla* (the most common, general form, perhaps including 'huwi sawut' from Java with small, cylindrical, unbranched tubers); var. *malaica* Prain & Burkill (more than twice their diameter elongated tubers, abundantly red pubescent, leaflets narrow, middle one 4 times as long as broad, occurring in Peninsular Malaysia, northern Borneo, the Philippines); var. *papuana* Burkill (tubers not elongated, usually lobed, not flattened, covered with roots, large vigorous plants, leaflets to 20 cm long, red pubescent, distal leaves usually simple, flowers large, occurring in New Guinea); var. *javanica* Burkill (as var. *papuana* but plant smaller, leaflets to 10 cm long, flowers smaller, occurring in Java ('huwi jahe'), Sulawesi, Lesser Sunda Islands); var. *palmata* Burkill (tubers flattened, smooth-skinned, leaflets to 20 cm long, silvery pubescent, flowers relatively large, occurring in Timor, the Philippines); var. *sacerdotalis* Burkill (as var. *palmata* but leaflets to 14 cm long and flowers and tubers smaller, occurring in Java ('huwi mantri', 'huwi putri', 'huwi dewata'), Kangean Islands).

Ecology Most yam species are essentially tropical plants, not tolerating any frost. Optimum rainfall is 1500 mm/year or more, well distributed over the growing season. Areas with more than 3–4 dry months per year are unsuitable. Although yam is relatively tolerant of dry conditions for survival, without ample moisture (rainfall or irrigation) tuber production is poor. Optimum average temperatures during growth are 25–30°C. Short days tend to favour tuber formation and high light intensities are favourable. Yams need fertile soils (more than e.g. cassava or sweet potato), rich in organic matter, preferably loamy, and well drained, since they do not tolerate waterlogging.

D. bulbifera will grow well in areas with 1000 mm rainfall per year. It prefers low elevations, but has been found growing in the Himalayas up to 1800 m and in Yunnan to 2700 m altitude.

The ecological requirements of *D. pentaphylla* are mostly like those of *D. bulbifera*.

Propagation and planting *Dioscorea* is usually propagated by tubers. *D. bulbifera* is propagated by bulbils or by tubers. Bulbil dormancy is most pronounced immediately after harvest, and declines steadily with time in storage. The dormancy has been ascribed to batatasins (phenolic compounds) in the outer tissues of the bulbil, and abscissic acid distributed throughout the bulbil. Bulbil sprouting is promoted by exogenous application of benzyl adenine or indole-acetic acid, and inhibited by exogenous application of gibberellic acid. In *D. bulbifera* the planted bulbil sprouts from the end near its previous point of attachment to the parent plant. The larger the bulbil or bulbil piece used for planting, the more robust the resulting plant.

D. nummularia and *D. pentaphylla* are propagated by means of tubers. They are planted on mounds, ridges, or on the flat. Intercropping with other food crops is common.

Husbandry Plants are staked soon after emergence. Weeding is done repeatedly throughout the season. Fertilizer or pesticide use is rare. In general, yam is the first crop in the rotation after fallow.

Diseases and pests Fungal leaf spots afflict most of the species in the field. *D. bulbifera* is moderately susceptible to attack by the yam nematode (*Scutellonema bradys*).

Harvesting In *D. bulbifera* older bulbils mature as new ones are produced towards the apex. Repetitive harvesting is therefore necessary to remove mature bulbils. The main tuber harvest occurs 9–24 months after planting, when the entire plant senesces. For the other species, tubers are harvested from wild or cultivated plants, using manual digging implements. Some plants may be deliberately left to grow for 2–3 years before harvesting. Harvesting is made more difficult in *D. nummularia* by the dense spines at the base of the stem, and the deep location of the tuber in the soil.

Yields The greatest bulbil yields of *D. bulbifera* in trials in Puerto Rico were 19.5 t/ha from cultivar 'Thuma', while the greatest tuber yields were 22.1 t/ha for cultivar 'Poison', which also had the highest combined yield (32.7 t/ha) of tuber plus bulbil.

Genetic resources Yam collections are held by the Malaysian Agricultural Research and Development Institute (MARDI), Serdang, Selangor, Malaysia, and the United States Department of Agriculture (USDA) Agricultural Experiment Station, Mayaguez, Puerto Rico.

Breeding For food production, breeding should aim at achieving a higher harvest index so that more of the dry matter is stored in the economic part (bulbil or tuber), at decreasing the bitter, poisonous or acrid principles (mainly alkaloids, saponins, and phenols), at reducing the time taken to mature, at increasing the ease of harvest (less spininess and shallower tubers), and at increasing overall yield. For diosgenin production, an increased diosgenin content would be a desirable breeding objective.

Prospects For food, *D. bulbifera*, *D. nummularia* and *D. pentaphylla* are certainly minor yams which can hardly compete with the agronomically well-established yams, i.e. *D. alata* and *D. esculenta*. They are even less likely to be able to compete with the African yams (especially *D. rotundata*) on a global scale. Their main role will remain a reserve food in times of scarcity, primarily in subsistence farming systems. For industrial purposes, research should focus on further elucidation of the composition of these tubers and bulbils, and whether any of their contents (e.g. starches, sapogenins) have any particularly advantageous characteristics that will warrant economic exploitation.

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I.C. Onwueme

Dioscorea alata L.

Sp. pl.: 1033 (1753).

DIOSCOREACEAE

$2n = 20, 30, 40, 50, 60, 70, 80$

Synonyms *Dioscorea globosa* Roxb. (1832), *D. purpurea* Roxb. (1832), *D. vulgaris* Miquel (1859).

Vernacular names Greater yam, water yam, ten-months yam (En). Igname de Chine, pacala, igname ailée (Fr). Indonesia: huwi (Sundanese), uwi (Javanese), lame (Sulawesi). Malaysia: ubi kipas, pokok ubi, ubi tiyang. Papua New Guinea: yam tru (Pidgin), nyaing (Yatmei), kolpur (Melba). Philippines: ubi (general), kinampay (Bisaya). Cambodia: dâmlô:ng chiem moan, dâmlô:ng phluk. Laos: man hlièmx. Thailand: man-liam (northern), man-sao (central), man-thu (southern). Vietnam: c[ur] c[as]i, c[ur] m[owx], khoai v[aj]c.

Origin and geographic distribution *D. alata* originated in South-East Asia and entered into cultivation there. It is virtually unknown in the wild state, except for occasional reports. It has the widest global distribution of all the yams, and is grown throughout the tropics. Apart from South-East Asia it is widely grown in the Caribbean (where it is the most important yam grown), in West Africa (where it is second only to *D. rotundata* Poiret), and in Oceania. In South-East Asia, it is the most important species and is grown in virtually all countries of the region, especially in Indonesia, Malaysia, Papua New Guinea, the Philippines, and Vietnam.

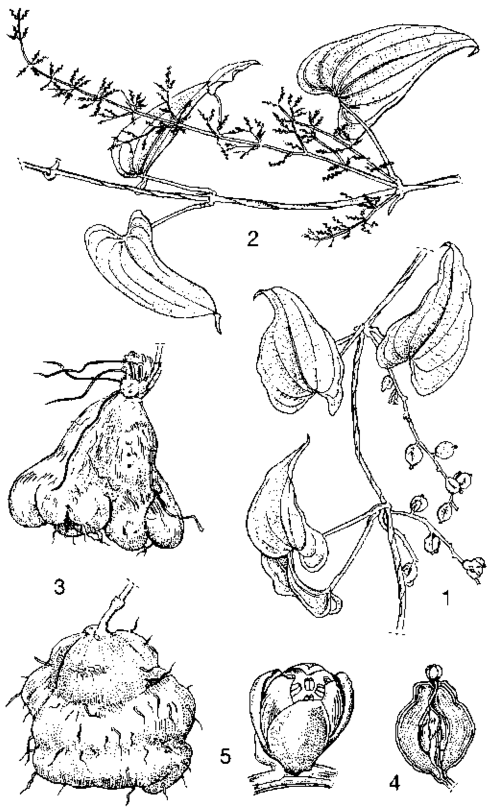
Uses The tubers and larger bulbils of *D. alata* are consumed as a starchy staple, after cooking in various ways. They can be processed into yam flakes or yam flour. Their use as a source of starch is minor. The cultivars with purple flesh are used in the manufacture of ice-cream and other confectioneries. *D. alata* is also used for ceremonial purposes in Papua New Guinea.

Production and international trade Most available production data do not separate the statistics on *D. alata* from those of the other yams. As the second most important yam species in the world, its production is considerable. Most of it is traded and consumed locally in the country of production. There is some export trade in *D. alata* from the Caribbean to North America and Europe.

Properties Tuber texture is looser than that of other edible yams. The approximate composition of the tuber per 100 g edible portion is: water 70 g, protein 1.1–2.8 g, fat 0.1–0.3 g, carbohydrates 28.5 g (starch 28 g, sugars 0.5 g), fibre 0.6–1.4 g, ash

0.7–2.1 g, vitamin A 0.18 mg, vitamin B_1 0.09 mg, vitamin B_2 0.03 mg, and vitamin C 5–28 mg. The starch is mainly amylopectin. The starch grains are relatively large, ellipsoidal, up to 55 µm long, with the hilum located at the narrower end. Gelatinization temperature is 69–88°C, and viscosity 100–200 Barbender units. Unlike most other yams, starch from *D. alata* has a high gel strength. Extracted starch from white-fleshed cultivars has 13.3% moisture, 21% amylose, 0.24% reducing sugars, 0.15% protein, 0.23% ash, pH of 7.3, and iodine absorption of 5.5. Purple-fleshed cultivars yield starch of 13.9% moisture, 21.1% amylose, 0.12% reducing sugars, 0.13% protein, 0.20% ash, pH of 6.9, and iodine absorption of 5.5. The anthocyanins from the purple-fleshed types are cyanidin glycosides. Lysine is the limiting amino acid. Per 100 g dry matter the tuber also contains: oxalate 50 mg, cyanide 1.08 mg, and tannin 75 mg.

Description Dioecious, annual, glabrous herb, climbing up to 10 m. Root system fibrous, shallow, mostly confined to the top 1 m of the soil. Tubers usually single, varying in size and shape, often very large; cylindrical or clavate in shape (often found as deep as 1.5 m) or globose, stout and short, pyriform, often variously lobed or fingered and fasciated or curved; skin brown to black; flesh white, cream or purplish (superficially or throughout). Stem twining to the right, unarmed but sometimes rough or warty at base, quadrangular and usually conspicuously 4-winged, green to purplish. Axillary bulbils abundant but number varies with cultivar. Leaves simple, alternate at the very base, thereafter opposite, subsagittately or subhastately ovate, 10–30 cm × 5–20 cm, acuminate, 5-nerved, bright green or sometimes tinged purplish; petiole up to as long as the blade, sometimes marginally frilled, auriculate at base. Male inflorescence a spike, 1–2 together, aggregated on leafless axillary branches up to 30 cm long, axis sometimes slightly zigzag. Female inflorescence a solitary, axillary spike, up to 60 cm long. Some cultivars do not flower, many remain sterile. Fruit a transversely elliptical, 3-winged capsule, about 2.5 cm × 3.5 cm. Seed orbicular, winged all round.



Dioscorea alata L. – 1, female flowering shoot; 2, male flowering shoot; 3, tuber types; 4, female flower; 5, male flower.

Growth and development As with most other edible yams, the growth and development of *D. alata* falls roughly into 4 phases. The first phase spans from 0–6 weeks after emergence, and is characterized by extensive root and vine growth, but very limited leaf expansion. The second phase, lasting from 6–12 weeks after emergence, is characterized by limited root growth, extensive shoot and leaf growth, and the onset of tuber formation. The third phase, lasting until the end of the season, is characterized by tuber bulking and maturity. Root and shoot growth are very limited in this phase. The total growing period is 8–10 months. In the fourth phase, the shoot senesces and dies back, and the tubers enter a dormant period lasting 2–4 months before sprouting again.

Other botanical information *D. alata* is the most important yam for South-East Asia and is easily recognized by its quadrangular winged stems. The variability of the tubers in form, size, weight, colour and flesh is so great that in every country where it grows and is used, many forms, selections and cultivars exist, all with their own vernacular names.

Because *D. alata* is only known from cultivation, a classification into cultivar groups and cultivars is most suitable, but there is no satisfactory worldwide system. In a study of 235 different cultivars from all over the world, 15 cultivar groups could be distinguished. The greatest variability was present in materials from New Guinea, Indonesia and the Philippines. Relevant groups for South-East Asia include:

- cv. group Purple Compact. Plants with a large content of anthocyanin, especially in the petiole; well developed, ruffled wings; tubers short with coloured flesh and cortex. Principal region: the Philippines. Cultivars include 'Morado', 'Vino Violeta', 'Kinampay'.
- cv. group Primitive Purple. Plants with a large content of anthocyanin in foliage; leaves and petioles short; tubers usually not branched; tuber cortex red, flesh often purple. Principal region: New Guinea. Some cultivars: 'Buster', 'Kiubu', 'Aupik'.
- cv. group Primitive Green. Plants with light green leaves, foliage almost free of anthocyanin; tubers long with prominent neck; cortex and flesh very white, cooking qualities poor. Principal regions: New Guinea, Indonesia. Cultivars include 'Masi', 'Lanswa', 'Suabab'.
- cv. group Compact. Plants with foliage tinged with anthocyanin; tubers short, wide; little coloration of cortex and flesh, very good cooking qualities. Principal regions: New Guinea and the Philippines. Some cultivars: 'Uhbisi', 'Toma', 'Kabusak'.
- cv. group Poor White. Plants with solitary tubers; cortex coloured but flesh whitish; pronounced gradient of colour and texture. Principal regions: New Guinea, India. Cultivars include 'Baron', 'Toa', 'Goarmago'.

Ecology *D. alata* is a plant of the subhumid to humid tropics. An annual rainfall of 1000–1500 mm, distributed over at least 6–7 months, is required for its cultivation. It is mostly a crop of the lowlands, though it occurs at elevations of up to 2500 m in India. Tuberization is promoted by short days (less than 12 h). It tolerates poorer soils than most other cultivated yams. *D. alata* is sensitive to aluminium toxicity in the soil.

Propagation and planting Tuber dormancy lasts for 2–4 months after harvest, but can be broken with ethylene chlorohydrin. Small intact tubers ('seed tubers') or tuber pieces weighing 50–500 g are used for planting on mounds, ridges, or on the flat. Intercropping is the most common practice, with the distance between *D. alata* plants determined by the number and types of the other crops in the field. Where sole cropping is done, rows are 1 m apart, with intra-row spacing of 50–100 cm. In Papua New Guinea, shifting cultivation is a common practice.

Husbandry Plants are usually staked soon after emergence. Unstaked cultivation also occurs, which suppresses weeds better but gives lower yields. Weeding is done 3–4 times during the season, using hand tools. Most production in South-East Asia takes place without irrigation, mechanization or even chemical fertilizer. In general, yam is the first crop in the rotation after fallow.

Diseases and pests Yam anthracnose, caused by several organisms (including *Colletotrichum* spp. and *Glomerella* spp.), is a serious disease which results in blackening and die-back of the leaves. The disease is more severe on *D. alata* than in other edible yams. The best control measure is the use of resistant cultivars such as 'TDA 291' or 'TDA 297' (International Institute for Tropical Agriculture). Phenol content is reportedly higher in resistant cultivars than in susceptible ones. Tuber rots caused by *Fusarium* spp., *Penicillium* spp., and *Rosellinia* spp., all afflict *D. alata* tubers especially in storage. The yam virus complex, of which very little is known, also attacks *D. alata* and depresses yield.

The yam beetle (*Heteroligus* spp.) attacks the tubers, and can be controlled with insecticidal dusts, or by planting as late as possible in the season. Scale insects and mealy bugs may infest the tubers, especially during storage. Nematodes attack the plant, resulting in warty appearance of the tuber. Wild animals, such as pigs and rodents may destroy the crop in some locations.

Harvesting Harvesting occurs 7–10 months after planting. Hand tools are used to dig up the tubers.

Yield Yields range from 8–30 t/ha. Individual tubers usually weigh 5–10 kg, although up to 60 kg have been reported. A yield of 42 t/ha has been reported in Malaysia.

Handling after harvest Although the tubers can be kept quite well (historically a favoured food on ships), they are prone to mechanical damage during and after harvest, and are handled carefully to avoid bruises. They are stored in cool shady conditions, but are subject to chilling injury if stored below 12°C. Tubers can be processed into yam flakes or yam flour, or marketed fresh.

Genetic resources Germplasm collections of *D. alata* are held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, the USDA Agricultural Experiment Station, Mayaguez, Puerto Rico, and the Philippine Root Crops Research & Training Centre, at VISCA, Baybay, Philippines.

Breeding The main breeding objectives are resistance to diseases, especially yam anthracnose and the yam virus complex, higher yields, amenability to mechanization and unstaked cultivation, and better storability.

Prospects *D. alata* is already well established as the most ubiquitous of all edible yams. The prospects remain good for its continued use as food, especially if the high labour requirements to produce it can be substantially reduced.

Literature |1| Alozie, S.O., Nwankiti, A.O. & Oti, E., 1987. Source of resistance in anthracnose blotch disease of water yam (Dioscorea alata) caused by Colletotrichum gloeosporioides Penz. 2. Relationship between phenol content and resistance. Beitrage zur Tropischen Landwirtschaft und Veterinarmedizin 25(1): 55–59. |2| King, G. & Hackett, C., 1986. Tabular description of crops grown in the tropics. 13. Greater yam (Dioscorea alata L.). Technical Memorandum 86(4). Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia. 53 pp. |3| Martin, F.W., 1976. Dioscorea alata. In: Martin, F.W., Sadik, S. & Degras, L. (Editors): Tropical yams and their potential. Part 3. Agriculture Handbook No 495. United States Department of Agriculture (USDA), Washington, D.C., United States. 40 pp. |4| Martin, F.W. & Rhodes, A.M., 1977. Intra-specific classification of Dioscorea alata. Tropical Agriculture (Trinidad) 54: 1–13. |5| Onwueme, I.C., 1978. The tropical tuber crops. Wiley, Chichester, United Kingdom. pp. 3–106. |6| Udoessien, E.I. & Ifon, E.T., 1992. Chemical evaluation of some antinutritional constituents in four species of yam. Tropical Science (UK) 32(2): 115–119.

I.C. Onwueme & Z.N. Ganga

Dioscorea esculenta (Lour.) Burkill

Gard. Bull. Straits Settl. 1: 396 (1917).

DIOSCOREACEAE

$2n = 40, 90, 100$

Synonyms *Dioscorea aculeata* L. (1754, not of Sp. pl., 1753), *Oncus esculentus* Lour. (1790), *Dioscorea tiliifolia* Kunth (1850).

Vernacular names Lesser yam, Chinese yam, Asiatic yam (En). Igname des blancs, igname de Chine (Fr). Indonesia: ubi aung (West Java), ubi gembili (East Java), kombili (Ambon). Malaysia: ubi torak, kembili, kemarung. Papua New Guinea: mami (Pidgin), taitu (Motu), kalak (Yatmei), diba (Hanuabada). Philippines: tongo (Tagalog), aneg (Ibanag), baribaran (Bikol). Cambodia: dâmlô:ng sya. Laos: hwà katha:d, man 'o:nz. Thailand: man-musua (central), man-chuak (northern). Vietnam: c[ur] t[uwf], khoai t[uwf], t[uwf] gai.

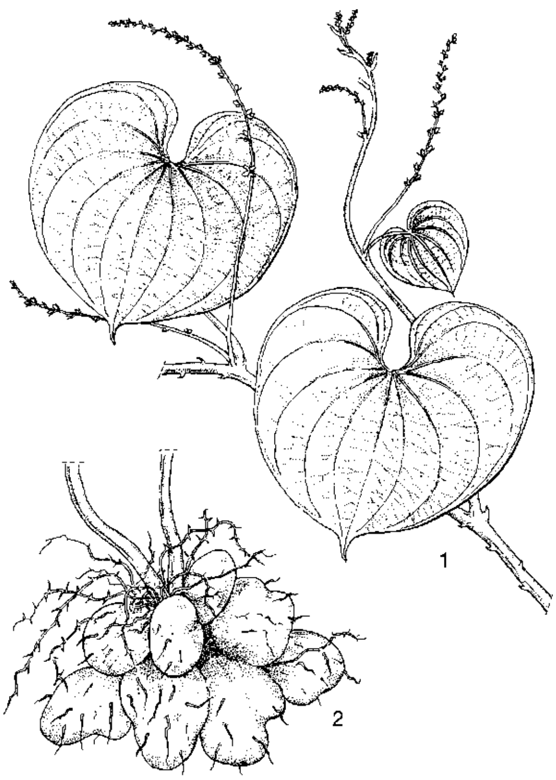
Origin and geographic distribution *D. esculenta* is native to Thailand and Indo-China, and may have originated there. It also grows wild in northern India, Burma (Myanmar) and New Guinea, but it is not known whether these are escapes from ancient cultivation or real relicts of its natural distribution area. Within South-East Asia the main direction of prehistoric spread has been out of the continent of Asia through the Philippines, thence south and south-east and ultimately towards the south-west. After 1500 it spread throughout the tropics. At present its cultivation is most important in South-East Asia (especially in New Guinea), Oceania, the Caribbean and China.

Uses The tubers are eaten as a starchy staple, after cooking or roasting, and their taste is sweet and pleasant. Flour and starch are also extracted. Starch grains are small, and more easily digested than those of other yams. *D. esculenta* is therefore used in special diets for persons with alimentary disorders. Grated raw tubers are applied medicinally as a poultice on swellings, especially on the throat.

Production and international trade No separate production statistics are available for *D. esculenta*. Production and trade is mainly local and very little of this yam enters into international trade. In South-East Asia, *D. esculenta* comes second in importance after *D. alata* L.

Properties The proximate composition of the tuber per 100 g edible portion is: water 70–80 g, protein 1.3–2.1 g, fat 0.1–0.3 g, carbohydrates 26–36 g (starch 25 g, sugars 1–11 g), fibre 0.2–1.5 g, ash 0.5–1.2 g, vitamin A 0.017 mg, vitamin B_1 0.08 mg, vitamin B_2 0.02 mg, and vitamin C 20.3 mg. The starch is mainly amylopectin, and the starch grains are small (0.5–2.0 μm) and angular, with a gelatinization temperature of 69.5–80.5°C. The sugar content is higher than for most other yams, and this gives it a sweet taste. Tubers of some Philippine cultivars reportedly contain up to 0.7% diosgenin. Lysine is the limiting amino acid.

Description A herbaceous, pubescent, often prickly, climbing annual. Roots thorny in wild plants, often thornless in cultivated plants, fibrous, mostly confined to the top 1 m of the soil. Tubers 4–20 per plant, thrust downwards from a corm, on stolons 5–50 cm long; mature tubers



Dioscorea esculenta (Lour.) Burkill – 1, male flowering shoot; 2, cluster of tubers.

shortly cylindrical, sometimes lobed, 8–20 cm × 2–5 cm; skin brown or grey-brown, thin, often rough with indurated bases of rootlets; flesh white. Stem terete, twining to the left, prickly at the base and less so upwards. Bulbils absent. Leaves alternate, simple, cordate, 10–15 cm × 10–17 cm, acuminate, 9–13-nerved, secondary veins regular but not conspicuously ladder-like; petiole 1–1.5 times as long as the blade, often with 2 prominent spines at the base. Inflorescence unisexual; male inflorescence solitary in distal leaf axils, usually carrying one flower at a time along the axis but up to 70 or more in total; female inflorescence on downcurved spike-like racemes, solitary from upper leaf axils, up to 40 cm long. Fruit (very rare) a reflexed capsule, 27 mm × 12 mm. Seed winged all round.

Growth and development Because of limited tuber dormancy, the planted tuber sprouts readily, and roots then proliferate. The vine then grows vigorously, and at 2–4 months after planting, underground stolons are produced. The tips of the stolons eventually give rise to the tubers. Mycorrhizal associations aid in nutrient absorption. Flowering is rare in cultivars, but in Papua New Guinea male flowers commonly occur. The plant senesces after 6–10 months.

Other botanical information Wild plants of *D. esculenta* usually have more vigorous foliage, larger leaves, longer stolons, more fibrous tubers and more thorny shoots and roots than cultivated plants. In the literature 2 botanical varieties are distinguished: var. *spinosa* (Roxb.) Prain & Burkill for plants well provided with thorny roots, and var. *fasciculata* (Roxb.) Prain & Burkill for plants with few thorny roots. The type specimen of *D. esculenta* is too poor to determine which variety should become var. *esculenta*. It would be more useful to classify the cultivated plants into cultivar groups and cultivars. South-East Asian cultivars include 'Asakua', 'Mart', 'Saikidi', and 'Kuali' from Papua New Guinea.

Ecology The natural habitat for *D. esculenta* is the humid and subhumid tropics. The plant does best where there is well-distributed rainfall of 875–1750 mm/year. Those parts of South-East Asia without a dry monsoon are rather too humid for it. The average minimum temperature for good growth is 22.7°C. Temperatures of 35°C and above reduce sprouting of the planted set. The plant is essentially a lowland crop, but grows successfully at an altitude of 900 m in the Himalayas. The maximum elevation for *D. esculenta* cultivation in Papua New Guinea is 900 m. Tuber formation is promoted by short-day conditions. Light, well-drained soils of pH 5.5–6.5 are best.

Propagation and planting Small whole tubers are used as planting material. The tubers have a very short dormancy period. They are planted on mounds (e.g. in Papua New Guinea), ridges, or on the flat. Intercropping with other food crops is common, with variable spacing between *D. esculenta* plants. For sole cropping, spacing is 100 cm × 50 cm.

Husbandry Plants are usually, but not always, staked soon after emergence. Manual weeding 2–3 times in the season is necessary. Herbicidal weed control, using atrazine and paraquat, is also practised.

Diseases and pests Leaf spots and leaf necrosis are caused by *Cercospora* spp. and *Glomerella* spp. The yam beetle (*Heteroligus* spp.) attacks the tubers, and can be controlled with insecticidal dusts, or by planting as late as possible in the season. The yam scale (*Aspidiella hartii*) and mealy bugs may infest the tubers, especially during storage. Nematodes, especially the root-knot nematode (*Meloidogyne* spp.) and the yam nematode (*Scutellonema bradys*) attack the growing plant and cause wartiness of the harvested tubers. Wild animals, such as pigs and rodents may destroy the crop in some locations.

Harvesting The crop matures in 6–10 months (8–9 months in Malaysia) when the vines turn yellow and begin to senesce. Harvesting should not be delayed, since if left in the soil the tubers soon begin to sprout because of their short dormancy period. The tubers do not lie deep in the soil, so simple hand tools are used to lift them.

Yield The following yields have been reported: 24.6 t/ha in Malaysia, 20–30 t/ha in the Philippines, 70 t/ha in Irian Jaya, 10–20 t/ha in Papua New Guinea. Tubers may weigh 0.1–3 kg.

Handling after harvest In commercial production, the tubers are graded in the field, and packed for the market in well-ventilated boxes. They are not packed in sacks because of the greater risk of bruising and rotting. Because the skin of the tuber is thin, tubers are easily bruised and storage is difficult.

Genetic resources Germplasm is maintained at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, and the United States Department of Agriculture (USDA) Agricultural Experiment Station, Mayaguez, Puerto Rico. In South-East Asia, some lines are kept at the Laloki Experiment Station in Papua New Guinea.

Breeding Breeding is difficult because female flowering is very rare and fruiting even more so. The main breeding objectives are resistance to diseases, higher yields, amenability to production with reduced labour, and greater storability.

Prospects *D. esculenta* is well established as a staple in South-East Asia and elsewhere. The prospects remain good that it will retain this position. Research priorities are breeding of improved cultivars and improvement of cultural practices.

Literature |**1**| Bourke, R.M., 1982. Root crops in Papua New Guinea In: Bourke, R.M. & Kesavan, V. (Editors): Proceedings 2nd Papua New Guinea Root Crops Conference, Part 1. Department of Primary Industry, Port Moresby, Papua New Guinea. pp. 51–63. |**2**| King, G. & Hackett, C., 1986. Tabular descriptions of crops grown in the tropics. 14. Lesser yam (Dioscorea esculenta L.). Technical Memorandum 86(15). Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia. 52 pp. |**3**| Martin, F.W., 1974. Dioscorea esculenta. In: Martin, F.W., Sadik, S. & Degras, L. (Editors): Tropical yams and their potential. Part 1. Agriculture Handbook No 457. United States Department of Agriculture (USDA), Washington, D.C., United States. 18 pp. |**4**| Onwueme, I.C., 1978. The tropical tuber crops. Wiley, Chichester, United Kingdom. pp. 3–106.

I.C. Onwueme

Dioscorea hispida Dennst.

Schlüss. Hort. Malab.: 15 (1818).

DIOSCOREACEAE

$2n = 40$

Synonyms *Dioscorea triphylla* L. (1754, not of Sp. pl., 1753), *D. hirsuta* Dennst. (1818), *D. daemona* Roxb. (1832).

Vernacular names Asiatic bitter yam, intoxicating yam (En). Indonesia: gadung (general), sikapa (Bali, Sulawesi), ondo (Ambon). Malaysia: ubi arak, gadongan, gadong mabok. Philippines: nami (Tagalog), gayos (Bisaya), karot (Ilokano). Burma (Myanmar): kywe. Cambodia: dâmlô:ng k'duöch (western). Laos: hwà ko:y (northern). Thailand: kloi (central), kloi-nok (northern), kloi-huanieo (Nakhon Ratchasima). Vietnam: c[ur] n[ee].

Origin and geographic distribution *D. hispida* occurs naturally from India and southern China, through South-East Asia to New Guinea. There is no appreciable distribution or cultivation outside this area. Even in South-East Asia the plant is scarcely cultivated, so its spread is practically confined to its area of natural occurrence.

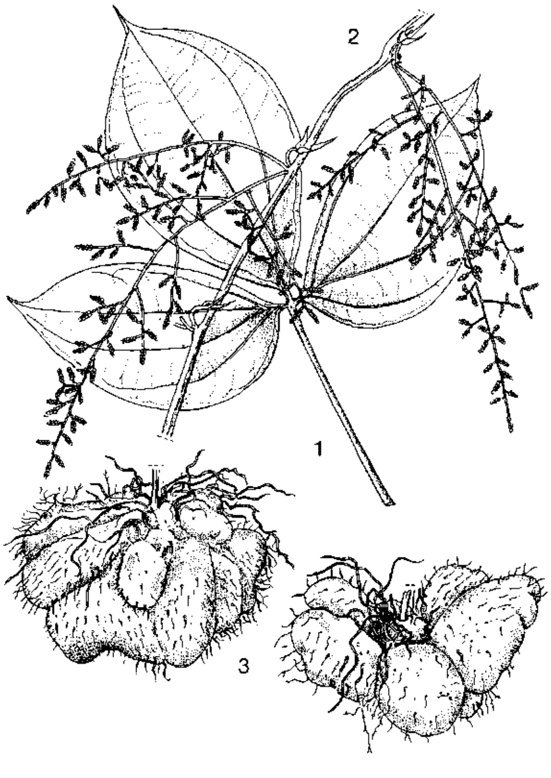
Uses The tuber of *D. hispida* is the chief famine food of tropical Asia, as is *D. dumetorum* (Kunth) Pax for Africa. The tuber is poisonous because of a high content of the alkaloid dioscorine. Its preparation for food requires much time and skill and includes slicing, washing the fresh or boiled tuber in several changes of salt water, or in running water, and a final check on whether all poison has been removed. Starch extracted from the tubers can be used for culinary or industrial purposes, notably the manufacture of glucose.

The poison in the tubers is often extracted and used as bait for animals or other devious purposes. It is also used for eliminating fish from shrimp pond cultures. The pounded tubers are sometimes used externally as an antiseptic, and a decoction is drunk to alleviate chronic rheumatism.

Production and international trade Most of the *D. hispida* used is gathered from the wild in times of food scarcity, and there are hardly any production statistics. Virtually all that is harvested is used and traded locally, with little or none entering into international trade.

Properties The approximate composition of the tuber per 100 g edible portion is: water 78 g, protein 1.81 g, fat 1.6 g, carbohydrates 18 g, fibre 0.9 g, and ash 0.7 g. On a dry weight basis, the tuber also contains 0.2–0.7% diosgenin and 0.044% dioscorine; these poisons can cause paralysis of the central nervous system. Commercial starch extracted from the tubers contains 88.34% starch, 5.28% protein, 5.33% fibre, 0.23% fat, and 0.66% ash. Some tubers from India have been found to contain ovoid, non-stratified starch grains with a longitudinal diameter of 35–40 μm, and a gelatinization temperature of 85°C. Unlike cassava or potato starches, its viscosity does not decline appreciably after prolonged heating. Its amylose content has been reported as 10.24%.

Description Climbing herb with a fibrous root system. Tubers renewed annually from a superficial corm, from which they grow as lobes, in outline globose, sometimes slightly elongated, pale yellow to light grey; flesh white to lemon-yellow. Stem twining to the left, firm, 9 mm or more in diameter, usually prickly, drying bright yellowish, glabrescent. Bulbils absent. Leaves trifoliolate, herbaceous to chartaceous, pubescent; middle leaflet oblong-elliptical (rarely obovate or tripartite), up to 30 cm × 28 cm, acuminate; lateral leaflets inequilateral, the outer half 3-nerved; petiole usually longer than the middle leaflet, usually with small prickles on the back; petiolules up to 1 cm long. Male inflorescence spike-like, on leafless branches, 2–3-compounded, up to 50 cm long, with closely packed or spaced sessile flowers, fertile stamens 6. Female inflorescence solitary from upper leaf axils, pendulous, with flowers spaced. Fruit a large woody capsule, honey-coloured, 3-winged, facing upwards; wings 40–60 mm × 10–12 mm, margin sometimes freed in dehiscence. Seed winged.



Dioscorea hispida Dennst. – 1, leaf; 2, male flowering shoot; 3, clusters of tubers.

Growth and development Presumably, *D. hispida* follows a similar pattern of growth and development as other yams, i.e. emergence from the planted tuber and early root development are followed by extensive shoot growth, then tuber differentiation, bulking, and maturity. The crop is ready for harvest after 12 months.

Other botanical information *D. hispida* is quite variable and 4 botanical varieties are distinguished:

- var. *hispida*: vigorous plants with long male inflorescences; flowers spaced; hairs honey-coloured; capsules truncate or retuse at apex; universal in South-East Asia.
- var. *mollissima* (Blume) Prain & Burkill: like var. *hispida* but hairs white and denser; from Burma (Myanmar) to Java, in similar localities to where var. *hispida* grows.
- var. *scaphoides* Prain & Burkill: less vigorous than var. *hispida* with much smaller, acute capsules; in Thailand.
- var. *dalmona* (Roxb.) Prain & Burkill: male spike dense, terminal flowering part less than twice as long as thick; foliage herbaceous; from India to Burma (Myanmar) and perhaps scattered elsewhere.

Ecology *D. hispida* occurs mostly in rain-forest areas. It is found mainly at lower elevations in the Philippines, but has been found growing at altitudes of up to 1200 m in the Himalayas.

Agronomy *D. hispida* perennates in the wild by means of the tuber. It is also propagated in cultivation by means of the tuber. As with other yams, best yields are obtained if planted on mounds or ridges. In cultivation, the crop is usually staked. Weeding is done at regular intervals, but the use of fertilizers is rare. No serious diseases and pests are known, only minor leaf spots have been reported. Harvesting occurs from wild stands, or from cultivated plants that are 12 months or older. Manual harvesting with the aid of a fork or digging stick is the usual practice. Individual tubers weigh 5–16 kg, but may be fused together into irregular clusters weighing up to 35 kg. Yields of up to 20 t/ha are obtainable. It has been suggested that the preparation of flour or starch from the tubers should proceed as follows: washing of the tubers, pulping, treating with lime water containing potassium permanganate, and final separation.

Genetic resources and breeding Germplasm collections are available in Malaysia (Malaysian Agricultural Research and Development Institute (MARDI), Serdang) and in Puerto Rico (Mayaguez Institute of Tropical Agriculture (MITA), Mayaguez). For food, it would be desirable to breed for reduced alkaloid content so that the tubers can be consumed without elaborate detoxification procedures. Breeding for a higher starch content would also be useful both for food and industrial purposes.

Prospects The present use for food of *D. hispida* continues to be hampered by the poisonous nature of the tubers, and the easier availability of other yams. Use for commercial starch extraction is limited because of the low starch content, the low intensity of cultivation/production, and the very wide area over which the production is scattered. Commercial extraction and use of dioscorine and diosgenin in the tuber is at present not economically feasible. *D. hispida* holds promise as a source of genetic material for various breeding programmes.

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I.C. Onwueme

Eleocharis dulcis (Burm.f.) Trinius ex Henschel

Vita Rumphii: 186 (1833).

CYPERACEAE

$2n = 64$

Synonyms *Eleocharis plantaginea* Roemer & Schultes (1817), *E. tuberosa* Roemer & Schultes (1824), *Heleocharis plantaginoidea* W.F. Wight (1905).

Vernacular names Chinese water chestnut (En). Indonesia: teki (Indonesian), peperetan (Javanese), babawangan (Sundanese). Malaysia: tike. Philippines: apulid (Tagalog, Bikol), pagappo (Ibanag), buslig (Bisaya, Ilokano). Cambodia: mëm phlông. Thailand: haeo (general), haeo-chin (central). Vietnam: m[ax] th[afl]y, n[aw]n ng[oj]t, n[aw]ng.

Origin and geographic distribution Chinese water chestnut is a widespread variable species of the Old World tropics, distributed from tropical West Africa and Madagascar through India eastwards to south-eastern China, Japan, South-East Asia, northern Australia, Micronesia and Melanesia.

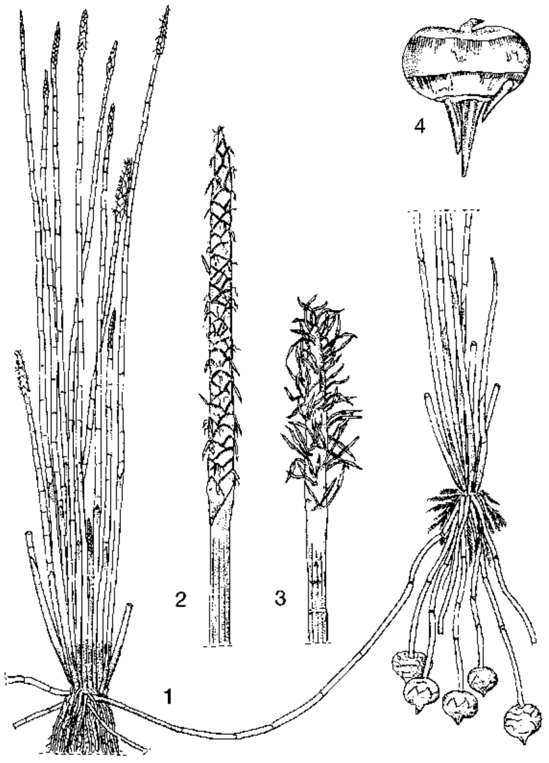
Uses Chinese water chestnut (tuber or corm) is used as a vegetable both raw or cooked in numerous local dishes such as omelets, soups, salads, meat and fish dishes, and even in sweet dishes in China, Indo-China, Thailand and other parts of South-East Asia. The larger corms are widely eaten raw as a substitute for fresh fruits. The smaller corms are used principally for making starch. In Indonesia and the Philippines, the corms are usually made into chips ('emping teki'). Stems are used for making sleeping mats (Sumatra, Sulawesi) and skirts (Papua New Guinea). They are also used as cattle feed or as mulch. The juice expressed from the corms contains antibiotic 'puchiin', which is effective against *Staphylococcus aureus*, *Escherichia coli*, and *Aerobacter aerogenes*.

Production and international trade Chinese water chestnut is a locally important crop in most countries in South-East Asia, India, China, Hong Kong, Taiwan, Hawaii and the southern United States. No statistics are available on production and trade.

Properties Data on the nutritive value of corms from different regions show wide variation. Per 100 g edible portion the peeled corms contain: water 77.3–78.3 g, protein 1.4–1.5 g, fat 0.15–0.20 g, carbohydrates: starch 7–19 g, reducing sugar 1.94 g, sucrose 6.35 g, fibre 0.8–0.9 g, ash 1.1–1.2 g, Ca 4.0 mg, P 65 mg, Fe 0.6 mg and vitamin C 4.0 mg.

The energy value is 328 kJ per 100 g. Starch grains are round, regular or irregular, up to 27 μm long.

Description A perennial, rhizomatous, semi-aquatic herb, often grown as an annual crop. Rhizome short with elongated stolons, each one often terminating in a zoned, depressed globose, brownish to blackish corm, 1–4 cm in diameter. Stem erect, terete, tufted, 40–200 cm tall, 3–10 mm in diameter, longitudinally striate, distinctly transversely septate, the intersepta 5–12 mm long, hollow, smooth, greyish to glossy dark green. Leaves reduced to some bladeless basal sheaths, 3–20 cm long, membranous, oblique or truncate at the apex, reddish brown to purple. Inflorescence a single, terminal, many-flowered spikelet, cylindrical, 1.5–6.0 cm × 3–6 mm, as thick as or somewhat thicker than the stem, apex obtuse to acute; glumes numerous, oblong, 4.0–6.5 mm × 1.7–3.2 mm, densely imbricate; flowers bisexual, with perianth of 6–8, filiform, unequal, white to brown bristles; stamens 3, anthers linear, 2–3 mm long; style 7–8 mm long, 2–3-fid, the enlarged base persistent in fruit. Fruit an obovoid nut (achene), 1.5–2.2 mm × 1.2–1.8 mm, shiny yellow to brown.



Eleocharis dulcis (Burm.f.) Trinius ex Henschel – 1, habit; 2, young spikelet; 3, old spikelet; 4, corm.

Growth and development About 6–8 weeks after corms have been planted they develop short subterranean rhizomes which start producing a number of daughter plants close to the mother stem, resulting in a clump. Because the plant does not develop normal leaves, the photosynthetic activity takes place in the numerous stems. When stems protrude about 15 cm above the surface of the water, they start forming inflorescences at their tips. Shortly after flowering, plants start producing corms at the end of about 12.5 cm long stolons which grow downwards into the mud at an angle of 45° to the surface of the mud. About 7–8 months after planting, the new corms are mature and the stems turn brown and eventually die.

Other botanical information *E. dulcis* is extremely polymorphic, widely distributed and also extensively cultivated. The wild forms usually produce only very small, almost black corms up to 1 cm in diameter. The cultivated forms have more robust stems and larger, sweeter, purplish to brownish corms, up to 4 cm in diameter and about 2.5 cm long.

In Japan the cultivated form has been classified as var. *tuberosa* (Roxb.) T. Koyama but classification into cultivar groups and cultivars would be more appropriate.

In the literature *Eleocharis* can sometimes be found as *Heleocharis*.

Ecology Chinese water chestnut occurs in open places both in salt or brackish and in fresh water swamps, often forming pure stands surrounding the open water, from sea-level up to 1350 m altitude and as far as 40°N latitude in China. A long warm growing season with at least 220 frost-free days is needed for plant growth. Corms will only sprout at soil temperatures above 14°C. The field should be kept inundated for at least 6 months. Preferred soils are rich clay or muck soils with a pH of 6.9–7.3. Chinese water chestnut can be grown successfully in slightly more acid soils provided that these are limed.

Propagation and planting Chinese water chestnut can be propagated by corms and by seed. For planting material, corms are dug out, dried in the shade for 2–3 days, then soaked in clean water for 2 days and planted in a nursery bed, 2–3 cm apart under light shade. When the young sprouts are 5–15 cm tall they are transplanted to a second nursery bed in rows 50 cm apart. The media used in the nursery beds could be rice husk charcoal, saw dust, or cocopeat and sand in a 1 : 1 ratio. Young plants can be transplanted to the permanent field when they are 3–5-stemmed or 15–20 cm tall. Spacing is rectangular at 50–100 cm × 50–100 cm or triangular at 45–60 cm × 45 cm. After planting, the field is flooded for 24 hours and then allowed to drain naturally.

Husbandry As soon as the top growth reaches 20–30 cm height, the field must be kept permanently flooded and the water level at 10–12.5 cm until harvest. A pre-emergence herbicide is recommended at 7 days after transplanting to the field; regular hand weeding is also needed for about 1 month until the ground between plants is covered. Heavy applications of fertilizers are common in commercial production of Chinese water chestnut. In the United States, a high grade complete fertilizer at the total rate of 2.5 t/ha is recommended. In Thailand, the following practices are followed: 150–160 kg/ha of NPK 16-20-0 or 20-20-0 are applied 20 days after transplanting, 150–160 kg/ha of NPK 13-13-21 are applied when the plants begin to produce short lateral rhizomes with secondary plantlets, and 300–320 kg/ha of NPK 9-24-24 are applied when new corms are being formed.

Diseases and pests Diseases and pests are common but rarely serious on Chinese water chestnut. Fusarium wilt and stem blight have been reported from China. In the United States, plants grown on acid soils (pH 5.5) are subject to attack by a stem fungus (*Cylindrosporium* sp.). In Thailand, diseases common in rice are also found on Chinese water chestnut, including foot rot, stem spot, downy mildew, yellow orange leaf virus and stem blight.
The billbug (*Calendra cariosa*), the stem nematode (*Ditylenchus* sp.), and the awl nematode (*Dolichodorus heterocephalus*) are reported to attack the crop. In the Philippines, it is sometimes attacked by a grasshopper (*Ailopus tamalus*). Common insect pests on Chinese water chestnut in Thailand are brown planthopper, whitebacked planthopper, green leafhopper and stem borers. Rodents, especially rats, can cause considerable losses at harvest.

Harvesting Harvesting normally takes place at 7–9 months after transplanting to the field or after the stems have turned brown or been killed by frost. Usually, irrigation is stopped at least 3–4 weeks before harvest so that the field dries out. Harvesting may be delayed, since the corms do not deteriorate in the soil if they are not subjected to severe frost. In the United States, harvesting is carried out mechanically by a small plough and a rake. In China, two methods of harvesting are used for different cultivars. For the larger corm type, the water is drained off the field before harvest to permit the field to dry. At times it is flooded again and then allowed to dry a second time. This is believed to raise the sugar content of the corms. For the smaller corm type, harvesting is done without any prior draining of the water; the farmer wades in knee-deep mud and stoops over to claw out the corms by hand.

Yield Average annual corm yield varies considerably from place to place: 20–40 t/ha in China, 28 t/ha in the United States, and 25–38 t/ha in Thailand.

Handling after harvest Harvested corms are washed and dried in the shade before marketing. They can be kept satisfactorily up to 6 months at temperatures between −1°C and 4°C in moisture-proof, but not airtight containers. They will start sprouting if stored at 14°C or higher.
For commercial processing, dry corms are peeled and then processed similarly to potatoes. They can be canned or deepfrozen (at −18°C and kept for 12 months). In China, a simple method of starch extraction is practised. The corms are washed, crushed and the starchy mass transferred into a fine bamboo basket which is placed on a filter cloth and hung over a fire. Water is passed through the basket and the contents stirred for 15 minutes. The starchy water is collected and after standing for 5 hours, the starch has separated out and can be dried in the sun.

Genetic resources and breeding At present, no germplasm collections or breeding programmes of Chinese water chestnut are known to exist. However, there is ample opportunity for breeders to improve both quantity and quality due to the enormous variation throughout the range of distribution.

Prospects Chinese water chestnut is one of the most popular vegetables among the Chinese around the globe and also among the people in South and South-East Asia and Oceania. In view of such a large number of consumers, there is quite a potential to develop the crop and to promote it for the international market. It is also one of the few crops that can be grown under aquatic condition like rice, but with better returns. It could be an interesting cash crop in places where the return from rice is low.

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Y. Paisooksantivatana

Helianthus tuberosus L.

Sp. pl.: 905 (1753).
COMPOSITAE
$2n = 102$

Vernacular names Jerusalem artichoke (En). Topinambour, navet de Jérusalem (Fr). Thailand: thantawan-hua (Bangkok). Vietnam: qu[yf] d[oj]i.

Origin and geographic distribution Jerusalem artichoke originates from America. Wild relatives are found in the eastern parts of North America. The cultivated types may have developed in southern Canada, from where they were dispersed to western Europe early in the 17th Century. Soon they were spread over many of the temperate parts of the northern hemisphere. In the tropics, including South-East Asia, it is only occasionally cultivated.

Uses The most important part is the edible tuber, which may serve in vegetable dishes. Certain parts of France and Germany used to grow *H. tuberosus* for alcohol production, but this has been superseded by cheaper raw materials. Since the 1980s, there has been a revival of research on the industrial processing of *H. tuberosus* for fuel and chemicals. Pigs, chickens and rabbits relish the raw tubers. The fresh foliage may serve as a forage, mainly for horses, mules and ruminants. The withered, almost leafless aboveground material of mature plants is hardly nutritious and can be used for litter or fuel. If the foliage is harvested or grazed in an early stage, the nutritive value will be good but the production of tubers will suffer. The green foliage is not especially liked by animals because it is rough-haired and stalky, but it will be rejected only if more tasty feed is available. Early-flowering cultivars are popular as ornamentals.

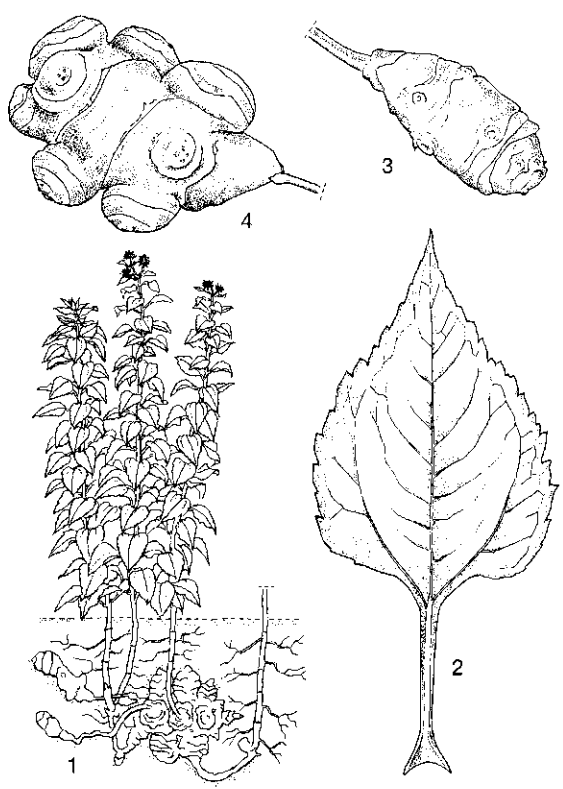
Production and international trade Although *H. tuberosus* has several advantages over Irish potato (*Solanum tuberosum* L.) such as non-toxic foliage, sturdy erect stems, lower susceptibility to fungal diseases, and frost-tolerant tubers, it has never reached widespread commercial acceptance.

Properties The boiled tubers, somewhat soggy, have a sweetish taste found pleasant by some, wearisome by most, and even foul by a few people. Thus, no more than a few consumers appreciate the tubers as an occasional vegetable. The main constituent in the dry matter is inulin, a chain-like polysaccharide of fructose units, each chain with one terminal glucose unit. In water it forms a viscous non-particulate 'solution', qualities which are useful for providing body to drinks.

The tubers have a nutritive value similar to that of other tubers, although in spite of its high degree of dispersion the inulin is digested very slowly and passes through the small intestine. It is then hydrolysed in the colon by bacterial action, thereby keeping the colon microflora in a healthy state. The similarity with the functioning of fibre has led to the term 'dietary fibre'. It may explain the wholesomeness experienced by some consumers, notably diabetics, who have used *H. tuberosus* in their diet. This is certainly not attributable to some content of insulin in the tubers, as has sometimes been thought. The resemblance of both names (inulin and insulin) may have led to this erroneous belief.

Typical composition figures of the tubers per 100 g fresh material are: water 79.6 g, protein 1.5 g, fat 0.2 g, extractable N-free matter 16.9 g, fibre 0.7 g, ash 1.1 g. The starch equivalent is 16.4. With regard to feed, the composition of 100 g fresh foliage is: water 80 g, protein 2.0 g, extractable N-free matter 13.1 g, fibre 2.2 g, ash 2.7 g. The starch equivalent is 16.2.

Description Robust, erect, perennial herb, in cultivation usually grown as an annual, up to 3 m tall, scarcely to moderately branched in upper half of stem, hirsute in most aboveground parts. Roots adventitious (in plants not grown from seed), fibrous, spreading deeply. Tubers formed by thickening of short and stout or long and slender underground stolons, ellipsoid to globose, 2–8(–15) cm × 3–6 cm, whitish, yellow, red or purple, with small scale leaves and axillary buds. Leaves opposite or in whorls of 3 in lower plant part, in upper part alternate, simple; petiole 2–4 cm long, winged above; blade ovate to ovate-lanceolate, 10–20 cm long, base tapering into petiole, margin irregularly serrate, apex acute, veins prominent with 3 main veins. Inflorescence a head, 4–8 cm in diameter, few together in a leafy panicle 8–20 cm long; involucral bracts in several rows, lanceolate, long acuminate, subequal, 15–17 mm × 4 mm, cili-



Helianthus tuberosus L. – 1, habit; 2, leaf; 3, young tuber; 4, tuber with swollen eye regions.

ate, blackish outside; receptacle flat, 1.5–2 cm in diameter; outer ray florets sterile, with golden-yellow, ligulate corolla, elliptical to oblong, 2.5–4.5 cm × 1 cm; disc florets bisexual, with tubular bright yellow corolla, 6–7 mm long; sterile bracts pale, 8–9 mm long, with greenish-yellow apex; stamens 5; style slender, with 2-lobed stigma. Fruit an achene, oblongoid, 5–7 mm long, flattened at the sides, brownish with dark stripes, thinly hairy.

Growth and development Nearly all documented experience with *H. tuberosus* is from areas between latitudes 30–50°N. This means that estimation of the potential of *H. tuberosus* for South-East Asia is based on extrapolation of data from elsewhere. Tuber formation starts with a drastic drop (dormancy) of the elongation rate near the stolon apex. If this rate drops to zero, the tuber will be pear-shaped, tapering backwards. If dormancy is less deep, the top end of the tuber will be oval. If the lateral eyebuds on the developing tuber retain or regain some elongation activity, very irregular tuber shapes will arise. The dormancy behaviour of the different buds and their interaction depend on the cultivar, but are also influenced by soil temperature and texture. Short stolons and early tuber initiation lead to an unwieldy, tightly-packed bunch of tubers. Long stolons and late initiation cause a very loose pattern of tubers wide apart that easily become lost at lifting.

Normally, fruits (seeds) are rarely formed. Under reduced light intensity or cold conditions, no flower heads may appear. Usually, a crop reaches maturity in 3–6 months.

Near the equator, the shorter daylength causes foliage growth to stop earlier and tuber initiation to start sooner, resulting in smaller plants. Moreover, temperatures are more even, so that cool or cold periods in the juvenile and closing phases of the production cycle are absent. Therefore, leaf area reaches full size sooner, but leaves senesce earlier. Also underground functions such as tuber growth, translocation of assimilates from the foliage to the tubers, and mineral uptake are faster near the equator. As a result, two consecutive crops may be produced per year.

Other botanical information *H. tuberosus* varies considerably in time to flowering, form and colour of the tubers, leaf form and hairiness. Well-known cultivars include 'Fuseau' (tubers purple, smooth, easy to peel), 'New White' (tubers white), 'Boston' (tubers red), and 'Dwarf Sunray' (plants relatively small).

Ecology Most *H. tuberosus* cultivars respond to short days with earlier tuber and flowerbud initiation. The growing season needs at least 125 frost-free days, preferably with average temperatures of 18–26°C and an evenly distributed rainfall of up to 1250 mm. It is tolerant of drought and survives short periods of flooding. Tubers are frost resistant, in the soil as well as in storage. In the tropics, *H. tuberosus* is preferably grown at 300–750 m altitude, but in India it is cultivated up to 3600 m. The soil should preferably not be too heavy, and should be well drained and friable in order to facilitate harvesting of the tubers.

Propagation and planting A tuber weight class of 50–60 g is suitable for seed tubers. They need a very cool (storage) period to overcome dormancy and uneven sprouting. In the warm areas of South-East Asia too few fully adapted cultivars are available, and therefore imported seed tubers must be used. It may be advisable to grow them in the pilot stage in cooler parts at altitudes from 800–1400 m. If successful, one could extend to lower areas. Optimal spacing is 8–12 plants per

m^2, but closer spacing should be practised where harvesting is envisaged before ripeness or where weed competition is expected to be excessive.

Husbandry If the growth cycle of *H. tuberosus* proceeds under a daylength shorter than in the region of origin, one should grow types known to be leafy (low harvest index) and known to have loose, widely separated tubers in the region of origin. These undesirable traits will be undone by the reduced growth and faster development under the prevailing short-day conditions. Hand weeding is advisable in the early growth stage, followed by interrow hoeing lightly on the surface so as not to damage roots and stolons. If unavoidable, a herbicide can be used. Once the plants have formed a closed canopy, further weed growth will be suppressed since *H. tuberosus* is a strong competitor; intercropping seldom succeeds, for the same reason. It responds favourably to fertilization and irrigation, but it is tolerant of suboptimal supply of nutrients.

Diseases and pests Expanding the acreage of *H. tuberosus* in South-East Asia will cause an increase of disease and pest damage to the crop. Most of the parasites of *H. tuberosus* belong to the types with a wide range of hosts: *Pseudomonas syringae*, *Fusarium*, *Sclerotinia*, *Puccinia* and *Botrytis*. These will cause more damage if *H. tuberosus* remains for years as a perennial in the same field.

Harvesting Normally, tubers are ready for harvesting when the leaves begin to wither. For home consumption they can be lifted manually with a fork when required, because they store very well in the field. Tubers less than 2 cm in diameter tend to be left on the ground; if hand-harvested, they are easily overlooked and during mechanical harvesting, they are lost by the sieve.

Yield In temperate climates a normal tuber yield is 30 t/ha per year (tuber dry matter 6 t/ha). Yield expectations for South-East Asia can only be guessed. Assuming 120 days of closed and productive canopy with a daily dry matter gain of 120 kg/ha, total dry matter would amount to 14 t. During this period, tuber growth might proceed during 80 days, taking 75% of the daily gain, resulting in a final 7.2 t/ha of dry matter in the tubers. If weeds, parasites and harvesting losses take 30%, about 5 t/ha of tuber dry matter would remain.

Handling after harvest The skin of the tubers is tender and moisture is readily lost. Plastic sheets can be used during transport and storage to protect them from drying out. Tubers can be stored for 2–5 months at 0°C and 90–95% relative humidity.

Genetic resources Germplasm is maintained in a number of research institutions in North America and Europe.

Breeding Breeding should concentrate on improving some of the weaknesses of the tuber, i.e. aim for better taste, sturdier skin and improved keeping quality. Moreover, leaf longevity should be improved, the harvest index should be raised and damage by local parasites reduced or eliminated. If industrial processing is contemplated, a higher inulin content is advantageous.

Prospects Prospects for *H. tuberosus* are not bright. Several attempts in northern countries have petered out. Other plants are preferred for the production of inulin. Yet, a genetic breakthrough or a specific regional set of farming conditions might give it a better place.

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G.J. Vervelde

Ipomoea batatas (L.) Lamk

Tabl. encycl. 1: 465 (1793).

CONVOLVULACEAE

$2n = 90$ (hexaploid)

Synonyms *Convolvulus batatas* L. (1753), *C. edulis* Thunb. (1784), *Batatas edulis* (Thunb.) Choisy (1833).

Vernacular names Sweet potato (En). Patate douce (Fr). Indonesia: ubi jalar (general), ketela rambat (Javanese), huwi boled (Sundanese). Malaysia: ubi keladi, ubi keladek. Papua New Guinea: kaukau (Pidgin), kaema (Motu). Philippines: kamote, kamuti. Burma (Myanmar): myonk-ni. Cambodia: dâmlô:ng chvië. Laos: man kè:w. Thailand: man-thet. Vietnam: khoai lang.

Origin and geographic distribution It is generally accepted that sweet potato originated from Central America or the northern part of South America. This acceptance is based on archaeological finds, the distribution patterns of wild species, and variation in cultivated clones.
Three lines of dispersion from the centre of origin to other regions have been postulated based on linguistic evidence:
- the 'kumara' line: prehistoric transfer from the northern part of South America to eastern Polynesia;
- the 'batatas' line: introduction to Africa and Asia through Europe from the first voyage of Columbus;
- the 'kamote' line: direct transfer from Mexico to the Philippines via Hawaii and Guam in the 16th Century.

Sweet potato, now an established crop, is widely grown in tropical, subtropical and warm temperate regions.

Uses Storage roots of sweet potato are used mainly for human consumption (70–100%) in most tropical countries. Small portions are used as feed (10–30%); negligible amounts are used for industrial purposes (5–10%). In temperate Asia, 30–35% is produced for industrial purposes, mainly for starch and alcohol.
Human consumption of sweet potato in tropical Asia is in the form of dessert, snacks or supplementary food, while it serves as a staple food on the island of New Guinea and some Oceanian countries. Young shoots are often consumed as a green vegetable.

Production and international trade The world sweet potato cultivation area peaked at 15 million ha with a total production of over 130 million t in the early 1970s. There has been a significant reduction in the world production area, to 9.4 million ha with 124 million t output in 1994. Asia's production, amounting to 118 million t, accounts for 92% of the world's total production. China is the main producer with 109 million t, about 85% of the world's total production. Other Asian countries with a significant production are: Indonesia (2 million t), Vietnam (2 million t), Japan (1.3 million t) and India (1.2 million t). Sweet potato is usually domestically consumed and not commonly exported.

Properties Nutritional quality and chemical composition of storage roots are genetically determined, but vary widely in response to various environmental and cultural conditions. Freshly harvested storage root consists of 16–40% dry matter of which 75–90% is carbohydrate. The carbohydrates consist mainly of starch (60–80% of dry matter), sugars (4–30% of dry matter) and small amounts of cellulose, hemicellulose and pectins. Sucrose is most commonly found in fresh storage roots. There are also small amounts of glucose and fructose. Maltose increases in cooking due to the activation of β-amylase. The crude protein ranges from 1.3% to more than 10% on a dry weight basis. The energy value averages 479 kJ/100 g.
The range of β-carotene (pro-vitamin A) is 0–22 mg/100 g on a fresh weight basis. Orange-fleshed cultivars are rich in β-carotene. Vitamin C content is high in sweet potato, ranging from 20–50 mg per 100 g on a fresh weight basis.
Sweet potato greens contain on average per 100 g fresh weight: vitamin A 5580 IU, vitamin B_2 0.32 mg, Fe 4 mg and protein 2.7 g.

Description A perennial herbaceous plant. Root system with fibrous, adventitious roots and

Ipomoea batatas (L.) Lamk – 1, flowering branch; 2, storage roots.

enlarged roots, derived from secondary thickening of some adventitious roots, serving as storage organ, variable in shape, size, number, skin colour (white, yellow, brown, red, purple) and flesh colour (white, yellow, orange, purple). Stems prostrate or ascending, or occasionally twining, 1–8 m long, much branched from several nodes. Leaves arranged spirally with a phyllotaxy of 2/5, simple, lacking stipules; petiole 5–30 cm long, with 2 small nectaries at the base, grooved above; lamina usually ovate, 4–15 cm × 4–12 cm, entire, angular or palmately lobed. Flowers axillary, solitary or in cymes; pedicel 3–18 cm long; calyx 5-lobed; corolla funnel-shaped, white or lavender with purple throat; stamens 5, of unequal length, attached near the base of the corolla; ovary surrounded by lobed orange nectary, stigma 2-lobed, white or pale purple. Fruit a 5–8 mm long capsule with 1–4 seeds. Seed about 3 mm long, black, usually with very hard testa.

Growth and development Sweet potato is normally grown as an annual. Planted cuttings, which are usually taken from the tip of the vine, start to form adventitious roots from the soil-covered nodes at the base of axillary buds in about 2 days. The adventitious roots form a fibrous root system. New stems also arise from the nodes of the cutting. The stems also form adventitious roots at the nodes when in contact with soil. Storage roots (3–12 per plant) develop in the top 30 cm of the soil by secondary thickening of some of the adventitious roots, both from the original cuttings and from creeping stems.

Approximate duration of sweet potato growth is 3–7 months, depending on cultivar and environment. Growth occurs in three distinct phases:

- an initial phase in which the fibrous roots grow extensively with only moderate growth of the vines;
- an intermediate phase in which the vines grow extensively with a considerable increase in leaf area, and the storage roots are initiated;
- a final phase in which bulking of the storage roots occurs, with little further growth of the vines and fibrous roots, with total leaf area being constant and thereafter declining.

The storage root produces sprouts readily from the vascular cambium region, almost always at the stalk end of freshly harvested storage roots, but sprouts can also arise from the middle and distal parts of aged storage roots.

There are wide differences in flowering habit. Many breeding programmes induce non-flowering plants to flower by grafting onto free-flowering cultivars or onto other *Ipomoea* species.

Sweet potato is self-incompatible characterized as a sporophytic, multiallelic system. More than 16 cross-incompatibility groups in the crop have been reported. Knowledge of the incompatibility system in a wild diploid makes it possible to interpret the incompatibility; a duplication or possibly triplication of the self-incompatibility explains the cross-incompatibility of sweet potato. Hybridization between genotypes belonging to the same group is mostly hindered. Natural cross-pollination is carried out by hymenopterous insects, particularly bees. The flower opens before dawn and is receptive up to only about 11 a.m.; thus, there is a large chance that any given flower may fail to be pollinated.

The seeds germinate very irregularly due to the hard testa, but germination can be improved by scarification. Scarified seeds germinate in 1–2 days. Germination is epigeal.

Other botanical information The genus *Ipomoea* L. section *Batatas* (Choisy) Griseb. contains 12 species which have chromosome numbers based on a multiple of $x = 15$. Within the genus, *I. batatas* (hexaploid) is the only known species with sizable storage roots. There are numerous sweet potato landraces in tropical and subtropical areas, mostly farmers' selections in populations, resulting from natural hybridization and spontaneous mutation. Many improved cultivars have evolved through systematic breeding programmes.

Ecology Sweet potato is grown between latitudes 48°N and 40°S. At the equator it is grown at altitudes ranging from sea-level to 3000 m. Its growth is maximum at temperatures above 25°C; when temperatures fall below 12°C or exceed 35°C, growth is retarded. Dry matter production increases with increasing soil temperature from 20–30°C, but declines above 30°C. It is a quantitative short-day plant in terms of flowering response.

Sweet potato is a sun-loving crop; however, it can tolerate a 30–50% reduction of full solar radiation. Light saturation of single leaf photosynthesis occurs at around 800 $\mu E/m^2$ per second; light intensity required for saturation in the canopy increases with increasing leaf area index. Optimum leaf area index in the field is 3–4 at solar radiation of 380 $gcal/cm^2$ per day. The photosynthetic rate of the canopy in the field is highest between 10 a.m. and 2 p.m.

Sweet potato grows best with a well-distributed annual rainfall of 600–1600 mm during the growing season. Dry weather favours the formation and development of storage roots. Soil moisture at 60–70% of field capacity is favourable for the initial phase, 70–80% for the intermediate phase, and 60% for the final phase. Sweet potato is relatively drought tolerant, mainly because of its capacity for regeneration and root penetration. However, it cannot withstand long periods of drought; the yield is considerably reduced if drought occurs about the time of storage root initiation.

The crop can be grown on a wide range of soil types, but a well-drained, sandy loam with a clayey subsoil is considered ideal. It cannot stand waterlogging and is usually grown on mounds or ridges. Poor aeration or an oxygen concentration of less than 10% in the soil in the initial phase increases the degree of lignification of stele cells and suppresses the primary cambium activity, resulting in young roots developing into fibrous roots. At the final phase, it restrains the secondary cambium activity, favouring vine development at the expense of the storage roots. Flooding shortly before harvest may result in storage roots rotting in the soil or during subsequent storage. The best bulk density of the soil is 1.3–1.5 g/ml. Higher bulk densities tend to reduce storage root formation, resulting in reduced yields or poorly shaped storage roots. The optimum soil pH for sweet potato is 5.6–6.6, but it grows well even in soils with a relatively low pH, e.g. 4.2. It is sensitive to alkaline or saline soils; maximum soil salinity without yield loss (threshold) is about 1.5 dS/m.

Propagation and planting In the tropics, sweet potato is propagated vegetatively from vine cuttings, but slips or sprouts obtained as cuttings from storage roots are sometimes used. Vine cuttings are generally taken about 30 cm from the tip, but sometimes from the middle portion as well. In areas where the plant cannot grow all year round, sprouts from storage roots of the previous crop are used as planting material. Direct propagation from storage roots is uneconomic and gives poor yields. Propagation by seed is possible but is used only for breeding purposes.

If there is no critical dry season, sweet potato can be planted at any time. In regions with a critical dry season, planting early in the rainy season is the best. It is usually planted towards the end of the rainy season if this is long and very wet. Land preparation varies from planting on level ground in less intensive systems, to ploughing, harrowing and ridging in more intensive systems. Planting on ridges is recommended. Cultivation on mounds, with several cuttings on each mound, is practised in the tropics, e.g. in the highlands of New Guinea. The mounds vary in shape and may be up to 1.5 m high in extremely wet areas.

Vine cuttings are inserted into the soil horizontally or at an angle, with 3–4 nodes covered by soil. The cuttings are planted manually in most parts of the tropics. The optimum plant density depends on local conditions and practices; however, sweet potato readily compensates to some extent for a low plant density. Number and mean weight of storage roots and the yield per plant decrease with increasing plant density. Normally, vine cuttings are planted 25–30 cm apart in rows with 60–100 cm between rows; the total yield may be expected to be highest at 40 000–50 000 plants per ha.

Husbandry Weed infestation during the first two months of growth poses a problem in stand development, and requires adequate control to ensure high yield. Thereafter, vigorous growth of the vines results in rapid and effective coverage of the ground and smothers weeds. In the tropics, manual weeding is generally practised, but herbicides are sometimes used in large-scale production.

Sweet potato responds well to fertilizer, particularly if the land has been continuously cropped. However, fertilizer is seldom applied in the tropics. Type and application rate of fertilizer depend on soil type, environment and cultivar. It is estimated that 70 kg N, 20 kg P and 110 kg K are removed from the soil by a sweet potato crop yielding about 15 t/ha of storage roots. Sweet potato plants develop deficiency symptoms when the nutrient levels in the tissues (stems and leaves) fall below 2.5% N, 0.12% P, 0.75% K, 0.16% Mg, 0.2% Ca and 0.08% S. Manure may also be incorporated to improve soil fertility. This is a common practice in smallholdings and traditional agriculture. Sweet potato is used in a wide variety of cropping systems around the world. Rotating sweet potato with other crops such as rice, legumes and maize is desirable to control diseases, pests and weeds in the following crop.

Diseases and pests In South-East Asia and some Pacific islands, scab caused by *Sphaceloma batatas* (perfect state: *Elsinoe batatas*) is the most prevalent disease in sweet potato, followed by Fusarium wilt (*Fusarium oxysporum*) and witches' broom (caused by mycoplasma-like organisms). Soil rot (*Streptomyces ipomoea*), black rot (*Ceratocystis fimbriata*), Java black rot (*Diplodia tubericola*), scurf (*Monilochaetes infuscans*), root-knot nematode (*Meloidogyne* spp.) and some virus diseases also occur in sweet potato, but their distribution and importance vary with the region. The use of disease-free planting material and crop rotation are the most reliable means of controlling these diseases and pests. Some cultivars are resistant to scab, Fusarium wilt, witches' broom, black rot and root-knot nematode.

Among the 300 insect and mite species that feed on sweet potato in the tropics and subtropics, only sweet potato weevil (*Cylas formicarius*) and vine borer (*Omphisa anastomosalis*) cause damage and yield loss over wide areas in South-East Asia and Oceania. The sweet-potato weevil is the most destructive insect pest in the tropics and subtropics. No resistant source is available. Integrated pest management for this insect is recommended, consisting of the following measures: crop rotation, eradication of *Ipomoea* weeds, use of clean planting material, deep planting, regular hilling to fill soil cracks around plants, and the use of sex pheromone which is effective to trap male weevils.

Harvesting The harvesting period of sweet potato storage roots is not clearly defined; it varies with cultivar, cultural practices and climate. In South-East Asia, sweet potato is generally harvested 3–4 months after planting. In the Philippines, early-maturing cultivars are harvested 70–80 days after planting, late-maturing ones after 120–150 days. In New Guinea, sweet potato is harvested after 5–6 months in the lowlands, 6–8 months in the highlands and 8–12 months or more in the highest mountainous areas. 'Progressive harvesting' (piecemeal harvesting) is common practice in tropical countries where sweet potatoes are grown for home consumption. It is generally recommended to harvest within four months to prevent weevil damage. In the tropics, manual harvesting using simple implements such as a stick, spade or hoe is practised. Mechanical harvesting is done only in large-scale production areas where the terrain is suitable for machinery; a variety of ploughs, either animal- or tractor-drawn, are used.

Yield Average yield of storage roots throughout the world in 1994 was 13 t/ha. The average yield in Asia was 16 t/ha; it varied from 2–22 t/ha. The yield potential of sweet potato is high. However, various abiotic and biotic stresses in the tropics prevent the full expression of this potential.

Handling after harvest Post-harvest handling procedures differ greatly between temperate and tropical regions. In temperate regions, sweet potatoes are harvested and handled mechanically, often causing damage to the storage roots. In these areas, harvested storage roots are normally cured for 4–7 days at temperatures of 29–35°C with a relative humidity of 85–90% in specially heated storage sheds which must be well ventilated. This treatment promotes the formation of wound cork and the production of phenolics on damaged surfaces, thereby preventing excessive water loss and pathogenic infection. Once the curing procedure is complete, storage roots are stored at 13°C with a relative humidity of 80–90%. Under these conditions, storage roots can be kept for 12 months or longer, depending on the cultivar.

In tropical countries, root storage is difficult because of rotting, weevil damage, and sprouting. Most growers use methods such as progressive harvesting or growing early- and late-maturing cultivars, to avoid the problem of storage. The roots are usually consumed within a few days of harvest. For transport to the market, roots are packed into sacks, boxes or crates soon after harvest. The roots may remain viable for up to a week; however, the quality deteriorates rapidly after a few days. Storage in pits or mounds is often practised but, even then, storage life extends only to 1–2 months.

Genetic resources Continuous vegetative propagation and diversity in the utilization throughout time contributed to the immense amount of genetic variability that exists in sweet potato. In the Asia and Pacific area alone, there exist an estimated 12 000 landraces. The International Potato Center (CIP) in Peru held a total of 6500 accessions in 1994. However, many of them could be duplicates.

Breeding CIP is focusing its breeding programme on the improvement of quality and insect resistance within a strategic approach that involves global collaboration with the national agricultural research systems. Well-established research programmes with defined breeding objectives have also been carried out in China, Japan and Taiwan. In the Philippines and Indonesia, breeding activities are also in progress.

Utilization of sweet potato, preferred types, and production constraints vary with region, and breeding goals should reflect the needs of each region. In Asia and Oceania, biotic constraints such as scab and weevils, and abiotic ones such as drought, excess moisture and low soil fertility deserve consideration in genetic improvement programmes. In addition, early maturity, eating quality (flavour, taste and texture), nutritional value, high yield, uniformity and storability are important characteristics which require improvement.

The value of utilizing wild relatives has been demonstrated in several cases, e.g. the Japanese commercial cultivar 'Minamiyutaka' has been derived through controlled genetic introgression from the hexaploid *Ipomoea trifida* (Kunth) G. Don. However, wild germplasm cannot yet be utilized effectively because of the differences in ploidy levels, and the inability of wild species to form storage roots. The efficient utilization of wild relatives requires further information on heterosis effects and specific traits which do not occur in the cultivated sweet potato.

Prospects Sweet potato has a great yield potential, high nutritional value, and can survive in a wide range of environments. Great potential exists for using sweet potato for human consumption, animal feed, and industrial processing in Asia and many other tropical regions.

Besides improvement of the important basic characteristics, development of new traits may lead to new applications, e.g. the use of non-sweet sweet potato (lacking β-amylase) for staple and processing, and the elimination of trypsin inhibitor for better digestibility as feed. In addition, management practices, post-harvest handling, and processing technology should receive due attention.

Conventional breeding methods will remain the mainstay of improving sweet potato. However, the efficiency of the sweet potato breeding programme can be improved through the introduction of appropriate biotechnological tools. In particular, techniques such as restriction fragment length polymorphisms (RFLP) and randomly amplified polymorphic DNA (RAPD) are increasingly being adopted for genome characterization, and to detect markers that are closely linked to genes of strategic interest. Furthermore, transformation with recombinant DNA in conjunction with gene expression technology is being used in the development of virus- and weevil-resistant sweet potatoes.

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Manihot esculenta Crantz

Inst. rei herb. 1: 177 (1766).
EUPHORBIACEAE
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Vernacular names Cassava, tapioca, Brazilian arrowroot (En). Manioc (Fr). Indonesia: ubi kayu, singkong, ketela pohon. Malaysia: ubi kayu, ubi benggala, ubi belanda. Papua New Guinea: mandioca, cassava. Philippines: kamoting-kahoy (Tagalog, Bisaya), balangay (Bisaya), kasaba (Ilokano). Burma (Myanmar): palaw-pinan-u-pin. Cambodia: dâmlô:ng chhë:. Laos: man tônz. Thailand: man-sampalang (general), man-samrong (central), man-mai (southern). Vietnam: s[aws]n, khoai m[if].

Origin and geographic distribution Cassava is indigenous to tropical America, as are all species (98–200) of the genus *Manihot* Miller. It is not known in a wild state and the origin of cassava as a crop is unknown. It is thought to have first been cultivated in north-eastern Brazil (related wild species are very abundant there) but Mexico and Central America are also mentioned as centres of domestication. Cassava was certainly already cultivated in many parts of tropical America in the first millennium BC, and its initial cultivation is thought to be considerably more ancient. In the post-Columbian Era, the cassava plant spread from the American continent. It is known to have been introduced early on in several Asian countries by the Portuguese. It was probably introduced around 1810 in Indonesia. Spanish explorers and traders from Mexico are thought to have introduced it in the Philippines. Initially, its adoption was slow in all countries of South-East Asia. In Java, cassava cultivation had spread little by 1880. Good export prospects for cassava starch and dried storage roots, failures of rice and maize crops causing famine during several years, and promotional campaigns in favour of cassava organized by the colonial Dutch government were the main reasons for the rapid expansion of cassava cultivation in Indonesia at the beginning of the 20th Century.

It is now a prominent crop in South-East Asia, particularly in Indonesia and Thailand.

Uses Of the world production of cassava, 65% is used directly for human consumption, 20% for animal feed and the remaining 15% for starch and industrial uses. For human consumption, the storage roots are peeled and chopped and then boiled, steamed, fried or roasted, directly or after drying or fermenting.

In South-East Asia, the use differs considerably between different countries. In Thailand, local use for human consumption is unimportant. Ninety-five per cent is exported, mainly for animal feed in European countries. The remainder is for local human consumption and industrial uses. In Indonesia, 60% of production is used for direct human consumption, 25% fresh and 35% after drying; 25% is used for starch production, most of which is for human food as kerupuk, cookies and other snacks. The remaining 15% is exported. In Malaysia, the starch industry uses about 90% of all cassava produced. The remaining 10% is used for animal feed. Only a very small proportion of local production is used directly for human consumption in Malaysia. The cassava produced in the Philippines is split equally between human consumption, animal consumption and starch production. In China, cassava is presently used mainly for industrial processing. Starch and monosodium glutamate are the traditional industrial products. With the improvement of cassava industrial technology, other products such as alcohol and starch-based sweeteners, e.g. glucose and fructose, have become more important. In Vietnam, the use of cassava for human consumption (actually 80% of the production) is decreasing because of the improvement of the rice supply. Presently about 10% of cassava production is processed into starch, the remaining 10% is for animal consumption. Throughout the region cassava leaves are used for human or animal consumption.

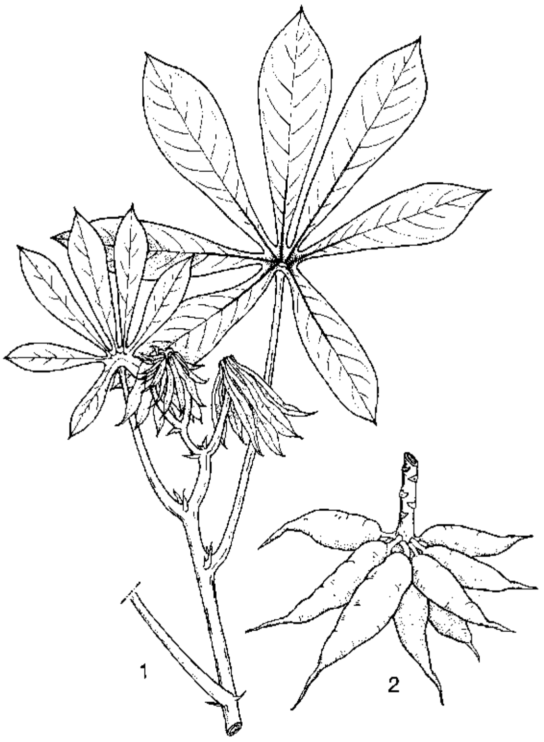
Production and international trade Production of fresh storage roots from cassava in Asia is 50 million t per year, which represents about one third of world production. The main producers are Thailand with 21 million t and Indonesia with 16 million t. Indonesia has been the leading producer for many years. The very rapid increase in Thailand is striking: from about 2 million t in 1964 to 20 million t in 1984. The export of cassava to Europe started at the beginning of the 1960s, serving as a component of animal feed, initially as meal, later as chips and since about 1969 as pellets. In the last decade, with a brief depression in 1986 and a peak in 1989, the yearly production in Thailand has been about 20 million t.

Other Asian countries with a significant cassava production are India (5.3 million t), China (3.4 million t), Vietnam (2.6 million t) and the Philippines (1.8 million t). Production in Asian countries was more or less stable between 1983–1993, which means a per capita decline.

Properties The edible portion of fresh storage roots represents 80–90% of the total storage root weight. Its average composition per 100 g is: water 62 g, protein 1.0 g, fat 0.3 g, carbohydrates (mainly starch) 35 g, and minerals 1.0 g. The energy value amounts to 600 kJ/100 g. The contents of protein, fat, most vitamins and minerals are low. Only the vitamin C content is of importance. The protein of cassava storage roots is especially deficient in sulphur-bearing essential amino acids. The dry matter content of the roots varies from 30–40%. The protein content of fresh cassava leaves is up to 7%. The leaves also contain reasonable amounts of carotene and vitamin C.

Cassava roots can contain dangerous amounts of cyanogenic glucosides. The glucoside content (as HCN) in the central part of fresh storage roots varies from 10–490 mg/kg. Small amounts are tolerable, but a person should not consume more than 1 mg HCN per kg body weight per day. Glucoside content is also influenced by ecological conditions and mineral supply. High content of nitrogen and low content of potassium in the soil increase the glucoside content. The first rains after a dry season may also cause a large increase in glucoside. If the cells of storage roots are crushed, glucosides and the enzyme linamarase make contact and the HCN is produced. This is the key to methods of getting rid of HCN. The volatile HCN should be allowed to escape. Boiling is not always a guarantee that the product is safe, as the HCN can be trapped in the starchy paste. Grating and slowly drying the resulting product is effective. Though consumers in villages usually know how to prepare a safe product, accidents still occur, especially with children. Cassava leaves also contain considerable amounts of cyanogenic glucosides, but no accidents have been reported in relation to their consumption. It is advisable, however, to cut the leaves into pieces before cooking and to throw away the cooking water.

Description A perennial, monoecious, cultivated shrub, up to 4 m tall, all parts containing white latex and varying concentrations of a cyanogenic glucoside. Seedling forming a taproot with generally slender secondary roots; adventitious roots arising from stem cuttings, very variable in shape, size, position and number, usually 5–10(–20) per plant, usually tapering but also long and slender, cylindrical to globose, up to 100 cm × 15 cm, serving as storage organ of starch in the parenchymatous cells of the white, yellowish or reddish pith; storage roots white, brownish or reddish, becoming lignified with age. Stem woody, unbranched to variously branched, predominantly brownish or greyish, usually with prominent leaf scars. Leaves arranged spirally with phyllotaxis 2/5, petiolate, simple; petiole 5–30 cm long, attached basally to the blade or slightly peltate; blade entire to 3–10-partite to near the base; lobes oblong, obovate, linear or lanceolate, 4–20 cm × 1–6 cm, entire, acuminate. Inflorescence a lax terminal raceme, 3–10 cm long; flowers unisexual with 5 united sepals and no petals, the pistillate flowers are basal and open first, the staminate flowers are apical; male flower with pedicel 4–6 mm long, calyx about 1 cm long, divided to or beyond the middle, yellowish, stamens 10 in two whorls; female flower with pedicel 0.5–2.5 cm long, calyx up to 1.3 cm long, stigmas 3, thick, warty-lobed, ovary 3-carpeled. Fruit a 6-winged subglobose capsule, 1–1.5 cm in diameter, with up to 3 ellipsoid seeds, 12 mm long, carunculate, variously marked or plain.



Manihot esculenta Crantz – 1, young branch with leaves; 2, storage roots.

Growth and development All commercial crops are grown from stem cuttings. Planted cuttings start to root from the soil-covered nodes, at the base of the axillary buds and the stipule scars, some 5 days after planting. Sprouting starts about 10 days after planting. At that time, callus can also be observed at the base of the cutting, from which a large number of adventitious roots emerge. Two to four months after planting, storage roots start to develop by secondary thickening of a number of the adventitious roots. In tropical regions, an almost constant proportion of dry matter production is stored in the roots once secondary thickening has started. This proportion depends on cultivar and ecological conditions.

The number of shoots per planted cutting depends on the length and orientation of the cuttings: the longer the cutting, and the more horizontally it is planted, the greater the number of shoots. New leaves are formed continuously, but the rate decreases with time. Older leaves die and fall after 40–200 days. After a certain number of nodes (leaves) has been formed (depending on cultivar and ecological conditions), the growing point becomes reproductive. This entails a number of axillary buds just below the growing point sprouting and developing into similarly sized branches (generally 2–4). Later in the growth period this process may be repeated once or more. However, some cultivars do not branch at all. There is strong evidence that long days stimulate flower initiation in some cultivars. Premature abortion of inflorescences may prevent flowering. Flower initiation, however, results in the stem forking.

In cassava, both cross-pollination and self-pollination occur naturally. Male and female flowers hardly ever open simultaneously in the same raceme; however, female and male flowers on different branches of the same plant commonly open simultaneously. Male sterility is frequent. Cross-incompatibility has not been found. The fruit matures three to five months after fertilization.

Other botanical information There is no satisfactory general botanical classification of cassava below species level. Cassava's pantropical distribution by man and its cultivation since ancient times have resulted in an enormous number of cultivars which, when compared, show continuous variation in every characteristic studied. Many attempts to classify the cultivars formally have failed and usually only have historical or local practical value.

All cassava cultivars contain cyanogenic glucosides (mainly linamarin), which liberate toxic HCN by enzymic breakdown. Glucosides are present in all plant parts. Cultivars used to be divided into two groups on the basis of the glucoside content in the central part of the storage roots: 'sweet' and 'bitter'. This distinction is not justified as all kinds of intermediates occur, and correlation between the glucoside content and the taste is far from straightforward.

Ecology Distribution of cassava is worldwide in regions between 30°N and 30°S. In equatorial areas, cassava can be grown up to 1500 m altitude. At the more extreme latitudes the growth period is limited because of the occurrence of periods of frost, which result in an immediate die-off of the plant. The optimum temperature range is 20–30°C. Specific cultivars are necessary for successful cultivation at an average temperature of 20°C.

Cassava is grown in regions with 500–6000 mm of rainfall per year. Optimum annual rainfall is 1000–1500 mm, without distinct dry periods. Once established, cassava can resist severe drought. With prolonged periods of drought, cassava plants shed their leaves but resume growth after the rains start, making it a suitable crop in areas with uncertain rainfall distribution. Because of its drought resistance, in many regions cassava is planted as a reserve crop against famine in dry years. This practice has often been the reason for its introduction in a certain area. Good drainage is essential for cassava; the crop does not tolerate waterlogging.

A linear relationship has been observed between the amount of absorbed incoming radiation and growth, thus high irradiance is preferred.

Cassava is grown on soils with very different physical and chemical characteristics. Best growth and yield are obtained on very fertile sandy loams. It is able to produce reasonable yields on severely depleted or even eroded soils where other crops fail. Gravelly or stony soils causing problems with root penetration are unsuitable, as are heavy clay or other poorly drained soils. Cassava growth and yield are reduced drastically on saline soils with an electrical conductivity of more than 50 mS/m and on alkaline soils with a pH above 8.0. The optimum pH is between 5.5 and 7.5, but cultivars are available that tolerate a pH as low as 4.6 or as high as 8.0. Reasonably salt-tolerant cultivars have also been selected. Cassava is tolerant of high levels of exchangeable aluminium and available manganese.

Propagation and planting In commercial production, cassava is propagated exclusively from stem cuttings. Propagation from storage roots is impossible as the roots have no buds. Propagation by seed is possible but is only practised in breeding. Cuttings, well lignified, 20–30 cm long and 20–25 mm in diameter, preferably from the middle of the stems of plants 8–14 months old, are most suitable. Healthy material should be taken and should be dipped in fungicide and insecticide before planting.

The interval between cutting stems and planting should be as short as possible (not more than a couple of days). Whole stems can be stored in shady places for 3 months.

In Asia, cassava is usually planted vertically. The drier the soil the bigger the part of the stem placed in the soil. Under very dry conditions, cuttings should be planted at an angle and covered for the larger part with soil. There is no clear relation between planting angle and yield. Horizontal planting leads to a large number of thin stems, which may cause lodging. Cuttings should not be planted upside down, as this drastically reduces yield.

Soil preparation varies from practically zero under shifting cultivation to ploughing, harrowing and possibly ridging in more intensive cropping systems. Planting on ridges is recommended, especially for areas with rainfall of more than 1200 mm per year. Ridging may not give higher yield, but harvesting is easier and soil erosion may be reduced, especially by contoured ridges. Plant density is 10 000–15 000 plants per ha in sole cropping. In intercropping, densities are usually lower. Cassava for home consumption is often planted in mixtures with crops such as maize, groundnuts, other grain legumes, coconuts or bananas. Sole cropping is the common method for large-scale production.

Planting is usually at the beginning of the rainy season. It is mostly done by hand, though large-scale planting may be mechanized. Cuttings are then planted horizontally.

In Java, a special grafting technique has been developed by Mukibat, a farmer. *Manihot glaziovii* Muell. Arg. ('tree cassava') is used as a scion and ordinary cassava as the rootstock. This method is used by many small farmers in Java, especially for home garden production. Very high yields can be obtained with this method, especially under dry conditions. The reason may be that Mukibat plants have a more extensive root system, allowing greater uptake of water and nutrients. It is a very labour-intensive method and probably not suitable for large-scale production.

Husbandry Weeding is necessary every 3–4 weeks until 2–3 months after planting. Afterwards the canopy may cover the soil and weeding is less necessary. Herbicide use is still limited, though pre-emergence and post-emergence herbicides are increasingly being used where labour is scarce, e.g. in large-scale production.

As yet, fertilizers are little used, though yield declines in the long term if fertilizers are not applied. In fact, use of fertilizers is often not economic because of low and uncertain prices. Moreover, the crop can still produce reasonably well on soils of poor fertility where other crops such as maize do badly. In general, cassava responds well to farmyard manure. Nutrient removal by 1 t of fresh storage roots is N 2.3 kg, P 0.5 kg, K 4.1 kg, and Ca 0.6 kg. Nutrient removal by 1 t of total plant (storage roots, stems and leaves) is N 4.9 kg, P 1.1 kg, K 5.8 kg and Ca 1.8 kg. Stems are often taken from the field and used as firewood. Fertilizer recommendations for cassava are not easy to make. In East Java, good yield responses are obtained with nitrogen fertilizers and more and more farmers are applying small amounts of nitrogen. Critical contents of major elements to prevent deficiencies in the youngest fully expanded leaf blades of cassava plants 2–5 months old are: N 5.0%, P 0.4%, K 1.2%, Ca 0.7% and Mg 0.3%.

Under certain conditions symbiotic fungi of cassava roots (mycorrhiza) can significantly increase phosphate availability.

There is a wide variety of cropping patterns and rotations with cassava. Though rotation with other crops is preferable, cassava is sometimes grown continuously on the same land, especially in dry areas not suitable for other crops (but in Thailand also because of the economic importance of the crop). When grown in bush-fallow systems, cassava is usually planted at the end of the rotation cycle, as it still produces relatively well at lower fertility levels and also allows a smooth transition to the fallow.

Diseases and pests Damage by diseases and pests is relatively moderate in South-East Asia. Cassava bacterial blight (*Xanthomonas* spp.) is present in Asia but no severe damage has been reported. Leaf spot (*Cercospora* spp.) is quite common but there are no clear data about the yield reduction it causes. The major pest in South-East Asia is probably red spider mite (*Tetranychus* spp.). Locally, scale insects can seriously reduce yield.

Harvesting Cassava has no distinct period of harvesting, because the crop is perennial. At harvest the top part of the stem is cut off and then the plant is pulled up or levered out of the ground with a tool. For human consumption, it is usually harvested 9–12 months after planting. It is sometimes harvested earlier if needed for food. When grown for starch production, it may be harvested after 18 months or even later. Optimum harvest period depends on root quality, yield and climatic conditions. Storage roots become too woody if harvesting is delayed.

Yield Average world yield of fresh roots is 10 t/ha. There is much variation between countries; in Asia, yields are higher (on average 13 t/ha) than in other continents. Nevertheless, actual yields on the farm are far below potential yields. Under optimal conditions, a yield of 30 t/ha of dry storage roots, i.e. 90 t/ha of fresh storage roots, is possible. Much depends on climate, soil fertility and the inputs. Annual yields of fresh roots of 30–40 t/ha are not difficult to achieve. But, as cassava is often grown on poorly fertile soils with low inputs, such yields are quite rare in practice.

Leaves can be taken from plants grown for roots or from plants specially cultivated for their leaves. If the leaves of a crop intended for root production are harvested, there is a reduction in the storage root yield. If cassava is grown specially for its leaves the first harvest can be 50–70 days after planting; yields of 20 000 kg/ha per year have been reported.

Handling after harvest Once harvested, cassava must be consumed or processed within a couple of days. Physiological changes cause blue or brown vascular streaking in the roots, just below the peel, already 2 days after harvest. In addition, a microbial deterioration normally starts after the onset of physiological deterioration but often within a week after harvest. First symptoms are blue

or brown streaks throughout the root. Spoilage is fastest in damaged roots.
For danger of toxicity on consumption directly after harvest, see under Properties.
Some progress has been made with storage of fresh roots. One method is to pack fresh, undamaged roots in moist sawdust in boxes; it can be used for marketing roots in urban areas. Storage for up to two months is possible. Microbiological deterioration, however, still occurs. Another method of storing cassava is to dry pieces of roots, called 'gaplek' in Indonesia. These chips should be dried quickly to avoid deterioration. Sun-drying is quite common. The shape of the chips is important for quick drying, a cube 1 cm across is recommended. For commercial production, as in Thailand, chips are dried on concrete floors. Afterwards they are converted into pellets, which are denser than chips and easier to transport. In small-scale drying on the farm, cassava chips are often dried on woven bamboo mats.
Cassava can also be stored as flour. For this purpose, roots are peeled, grated, squeezed, and then slowly roasted and dried. This product is called 'farinha de mandioca' in Brazil and 'gari' in West Africa. Cassava starch is usually prepared in special factories. Roots are washed, crushed and further processed. The starch is usually separated by centrifuging.

Genetic resources In South-East Asia, only limited cassava germplasm banks occur, e.g. in Thailand 250 germplasm accessions have been registered, in Indonesia 208, in the Philippines 338, and in China 72. The largest cassava germplasm bank is at CIAT (Centro Internacional de Agricultura Tropical) in Colombia, containing about 3000 accessions from large parts of Central and South America.

Breeding Breeding of cassava started seriously in Indonesia in about 1908, largely with genotypes imported directly from South America. The most extensive breeding programmes are at CIAT in Cali, Colombia and at IITA (International Institute of Tropical Agriculture) in Ibadan, Nigeria.
In 1983, a Thai-CIAT cassava breeding programme was established in Thailand with the dual function of developing cultivars for Thailand and generating promising breeding material for other Asian programmes. Transfer of selected clones and seed (from crosses) from Thailand to other cassava breeding programmes in Asia has recently been initiated. In Thailand, five cultivars have been released so far: Rayong 1, 2, 3, 60 and 90. Breeding in Thailand is especially oriented towards higher yielding ability, higher storage root dry matter content and early harvestability, compared to the traditional cultivars. This breeding programme has stimulated the release of new cultivars in other Asian countries too. Local breeding in Indonesia has resulted in the release of Andira 1, 2 and 4, the latter in 1986. As a result of cooperation with the Thai-CIAT breeding programme some new clones will be released in the near future. New cultivars, some of them CIAT-introduced materials, have also been released recently in the Philippines.
Additional objectives of the breeding programme are low glucoside content, broad adaptation to various soil and climatic conditions, good eating quality and resistance to the main diseases and pests.

Prospects Because of population growth, cassava production for human consumption, especially in Africa, is steadily increasing. In Asia, however, production remained rather stable during the last decade. It appears that if average income in society increases, the relative importance of cassave for human consumption decreases. Cassava may become more important as a feedstuff if the use of storage roots in local animal feed receives more attention. Production in Thailand and Indonesia for the feedstuff market of western Europe is expected to remain quite important.

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H.J. Veltkamp & G.H. de Bruijn

Maranta arundinacea L.

Sp. pl.: 2 (1753).
MARANTACEAE
$2n = 48$

Synonyms *Maranta sylvatica* Roscoe ex J.E. Smith (1819).

Vernacular names Arrowroot, West Indian arrowroot, St Vincent arrowroot (En). Arrowroot des Antilles, herbe aux flèches, arruruz (Fr). Indonesia: garut (Indonesian), angkrik (Javanese), larut (Sundanese). Malaysia: ararut, ubi garut, berolu. Philippines: aroru (Tagalog), aru-aru (Tagalog), sagu (Bikol). Cambodia: saku:. Laos: sa:kh'u:. Thailand: sakhu (central). Vietnam: ho[af]ng tinh, c[ur] dong, hu[yf]nh tinh.

Origin and geographic distribution The exact origin of arrowroot is not known but it is indigenous in Central America (including the Caribbean area) and northern South America with exclaves in western Ecuador and in some of the interior Guiana savannas. Nowadays, it can be found in cultivation throughout the tropics, but is important only in the West Indies (Bahamas, Antilles, especially St Vincent island). In South-East Asia, it can be found cultivated everywhere, mainly as a home garden crop.

Uses Arrowroot is mainly cultivated for the valuable starch that can be extracted from the rhizomes. The starch is very easy to digest and is often used as a thickener in all kinds of foods, dressings, soups, sauces, candies, cookies, and desserts like puddings and ice-creams. Industrially, processed rhizome pulp is applied in the manufacturing of paper, cardboard, cushions and wallboards and the starch as basic ingredient of powders, glues and soap. Whole rhizomes can be eaten boiled or roasted when they are not yet fibrous. Medicinally, the pulp of fresh rhizomes is used in poultices to cure wounds and ulcers and the starch, prepared with water or milk, is used to cure stomach problems (e.g. against poisoning) and diarrhoea, or to prepare easily digestible food for patients with stomach or intestine problems. The rhizomes are also a good substitute for maize in broiler rations and the fibrous debris after starch extraction is used as feed and manure. Arrowroot cultivars with strikingly coloured leaves (e.g. brown-purple) are also popular as ornamentals. Leaves are used for wrapping.

Production and international trade Commercial production of arrowroot starch started in the middle of the 19th Century in the West Indies, with St Vincent as the principal producer for the United States, Canada and Europe. Annual production fluctuated from 1000–2000 t until 1940, to 4500 t after the Second World War, and to 1500–3000 t at present. Outside the Caribbean, including in South-East Asia, arrowroot products are mainly produced and traded locally on a very small scale.

Properties The chemical composition of fresh arrowroot rhizomes per 100 g is approximately: water 69–72 g, protein 1–2.2 g, fat 0.1 g, starch 19.4–21.7 g, fibre 0.6–1.3 g, and ash 1.3–1.4 g. The starch grains are ovoid or flattened ovoid and 15–70 μm long. Arrowroot starch contains about 20% of amylose and contains a high percentage of K. It has a high viscosity which it retains at higher temperatures, in contrast with the fall in viscosity of, for example, cassava and sago starch at higher temperatures. The dried residue remaining after starch extraction contains approximately: water 12%, fibre 14% and starch 50–64%. In modern factories most of this starch can be extracted by steam grinding.

Description Perennial, erect herb, 0.5–1.5 m tall, shallow-rooted, with rhizomes penetrating more deeply into the soil. Rhizomes fleshy, cylindrical, 5–40 cm × 2–5 cm, white or reddish, covered with overlapping, persistent or deciduous, brownish-white scale leaves. Stem thin, usually much forked towards the apex. Leaves radical and cauline, distichous; petiole terete, sheathing at the base, with a thickened, glabrous to sparsely hairy pulvinus at the apex, in upper leaves petiole often absent; blade ovate-oblong, 10–30 cm × 3–10 cm, rounded to truncate at base, acute acuminate at top, largest in basal leaves, glabrous or more usually hirsute, green or sometimes variously

Maranta arundinacea L. – 1, habit; 2, flowering shoot.

streaked white or brownish-purple, with prominent midrib and numerous pinnately arranged, fine, closely spaced parallel veins. Inflorescence paniculate, terminal, often branched, each branch subtended by a deciduous bract and ending in a stalked flower pair; peduncle of flower pair thin, up to 4 cm long; pedicel of one flower of the pair 7–15 mm long, the other one 0–3 mm; flowers bisexual, zygomorphic, about 2 cm long, with 3 green, free, persistent, lanceolate sepals 12–16(–18) mm long, and a white, 3-lobed, tubular, early caducous corolla; androecium in 2 whorls, attached to the corolla; outer whorl consisting of 2 petaloid staminodes, about 1 cm long; inner whorl about half as long, consisting of 1 fertile stamen, a large fleshy staminode and a smaller hooded staminode; fertile stamen with a 1-celled half anther joined to a petaloid appendage; pistil 1, with a 1-celled, 1-ovuled, inferior ovary, style adnate to corolla tube, stigma 3-lobed and enclosed by hooded staminode. Fruit oblongoid, about 7 mm long, berry-like, leathery, brown, glabrous to hairy. Seed 3-sided, scabrous, pinkish, with yellow, 2-lobed, basal aril.

Growth and development After the tip of a rhizome has been planted, a shoot arises in 1–3 weeks. The new plant establishes by forming adventitious roots within 6–7 days. In the next phase more leaves and a stem develop aboveground and more roots and new rhizome material develop underground. Some of the new rhizomes become specialized storage rhizomes, others start suckering, a process which is not well understood. It appears that storage rhizomes are not found throughout the growing season but are initiated only after the plant has reached a certain stage of development. There is some kind of relation with the deciduous growth habit in which the plants die back to the rhizome in the dry season. Under optimum conditions the plant grows continuously, producing suckers and rhizomes; old leaves wither, fleshy rhizomes deteriorate or develop new plants when not harvested. Flowering starts 3–6 months after planting and flowers open in the evening. Arrowroot is predominantly autogamous according to some authors, obligately allogamous according to others; the flowers seem devised for cross-pollination by insects. Fruit development is rather abundant with about one fruit per 4 flowers, but seed viability is poor. A crop matures and can be harvested 8–12 months (depending mainly on environmental factors) after planting. Starch content reaches a maximum in the rhizomes about 12 months after planting, but then they are more fibrous and the starch is more difficult to extract. When storage rhizomes are left in the soil for more than 12 months, the starch is gradually converted into sugar. Arrowroot is mostly grown as an annual crop, but it could be grown as a perennial.

Other botanical information There are several cultivars of arrowroot. In St Vincent the 2 main ones with white rhizomes are 'Creole' and 'Banana'; a cultivar with reddish rhizomes is known from Dominica. 'Creole' is grown particularly by smallholders, and has widely dispersed, deeply penetrating, long, thin rhizomes (on poor soil often too thin). They can be stored for up to 7 days before processing without serious deterioration. 'Banana' has shorter, thicker, less fibrous rhizomes, growing in clusters just below the soil surface. They are easier to harvest and process, are higher yielding, more suitable for mechanical harvesting and mainly grown on estates, but they should be processed within 2 days after harvest. It is not known which cultivars are grown in South-East Asia.

The genus *Maranta* L. comprises about 23 species, mainly occurring in tropical America and none being indigenous to South-East Asia. The species related to *M. arundinacea* have been classified into subgenus *Maranta*. In particular, *M. amplifolia* K. Schumann, *M. linearis* L. Andersson and *M. incrassata* L. Andersson also develop starch-storing rhizomes. *M. amplifolia* is very closely related to *M. arundinacea*, and is sometimes even united with it. It is a more robust plant with glabrous leaves, sepals 16–20 mm long, obligate allogamous and fruiting very rarely. *M. linearis* differs from *M. arundinacea*, especially in its linear or very narrowly oblong leaf blades, smaller inflorescences and shorter sepals. *M. incrassata* is a small plant up to 1 m tall with ovate leaf blades and simple inflorescences.
In the literature, the name arrowroot is also used for various other crops: Queensland arrowroot (*Canna indica* L.), Indian arrowroot (*Curcuma angustifolia* Roxburgh), Brazilian arrowroot or cassava (*Manihot esculenta* Crantz), and East Indian arrowroot (*Tacca leontopetaloides* (L.) O. Kuntze).

Ecology In the wild, *M. arundinacea* grows primarily in the understorey of tropical deciduous or semi-deciduous forest near temporary pools and brooklets, sometimes however, also in dry pine forest. It grows best under warm humid conditions, preferring temperatures of 25–30°C and requiring an annual average rainfall of 1500–2000 mm or more, but with 1–2 dry months. Arrowroot tolerates up to 50% shading without notable yield reduction, and survives waterlogging and saturated soil conditions but does not produce storage rhizomes under such circumstances. It prefers lowland conditions, but can be cultivated up to 1000 m altitude. Arrowroot can be grown on many soil types but thrives on rich, loose, sandy loams with pH of 5–8 (e.g. the volcanic soils of St Vincent are perfectly suited for arrowroot).

Propagation and planting Arrowroot is propagated vegetatively from rhizome apices ('bits') about 2–4 nodes long and not too thin; about 3 t are required to plant 1 ha. No special land preparation is needed besides the usual ploughing and harrowing. The bits are planted 5–7.5 cm deep and about 30 cm apart, preferably at the beginning of the rainy season. Bits can be stored for some months before being planted in the field. Suckers 30 cm tall can also be used, but they should be planted immediately after cutting. Planting distance depends on the mode of cropping, e.g. when intercropped with annual crops row distance is wider and plant distance closer (e.g. 75 cm × 15–20 cm); square planting patterns (20–50 cm) are more appropriate in sole cropping with hand-weeding and poor soil conditions. Because arrowroot tolerates shade quite well, it can be grown successfully under perennial tree crops (e.g. coconut, fruit trees). Propagation by seed is rare.

Husbandry Usually, a field with arrowroot needs 3–4 weedings, effected manually or mechanically. Young plantings are especially susceptible to weed competition. Recommended fertilizer levels per ha are 350–650 kg ammoniumsulphate, 300 kg superphosphate and 300 kg KCl. The entire quantity of P and K can be applied at planting time, N is applied at intervals. Per t harvested rhizomes, about 16 kg N, 5 kg P and 36 kg K are withdrawn from the soil, and this should be compensated for by a balanced fertilization programme. When the crop starts flowering, the inflorescences should be removed to achieve a maximum nutrient flow to the storage rhizomes. Crop rotation is recommended for nutrient and pest management, at least every 5–6 years. Pieces of rhizome left in the soil after harvest often pose a weed problem in subsequent crops because they are difficult to eradicate.

Diseases and pests Arrowroot does not have any serious diseases or pests. Under poor drainage conditions, burning disease, caused by *Rosellinia bunodes*, may cause losses. On poor soils, arrowroot may produce so-called 'cigar roots', i.e. long thin fibrous rhizomes, containing little starch; this can be prevented by applying more fertilizer. In India, the banded leaf blight disease, caused by *Pellicularia filamentosa*, sometimes infects the crop; spraying with Bordeaux mixture is effective. Sometimes the arrowroot leaf roller (*Calpodes ethlius*) causes defoliation and, consequently, starch losses; it is usually controlled by arsenicum-based sprays.

Harvesting Rhizomes mature in 8–12 months and can be harvested when the leaves turn yellow and stems start to lodge. Harvesting can be done manually using a fork or by ploughing carefully. One person can harvest about 450 kg rhizomes per day by hand. Weeds and aboveground parts are usually buried to provide organic matter, and 'bits' are separated from the harvested rhizomes to serve as new planting material. Harvesting should be done before the next rainy season otherwise the rhizomes will start sprouting.

Yield Rhizome yield varies considerably, ranging from 7–47 t/ha. The amount of starch obtained is 16–18% of the fresh weight of the rhizomes. The highest reported rhizome yield of 47 t/ha was obtained with a spacing of 50 cm × 30 cm and an NPK 60-60-60 fertilizer application.

Handling after harvest To extract the starch, mature rhizomes are cleaned, washed, grated and crushed, and the remaining pulp is washed over sieves until all fibres have been removed. The starch is allowed to settle or is separated by centrifuging, then is dried, pulverized, graded and packed. Grading of starch is based on e.g. colour (should be white), purity, moisture content, pH and viscosity. Large quantities of clean fresh water are essential when processing the rhizomes. In St Vincent, usually only ordered quantities are harvested and processed immediately, to minimize deterioration.

Genetic resources A germplasm collection of arrowroot is held in St Vincent. In South-East Asia, 35 accessions of arrowroot are available at the Philippine Root Crops Research and Training Centre, Visayas State College of Agriculture, Leyte.

Breeding In St Vincent, a breeding programme for arrowroot is in progress aiming at the development of cultivars with higher starch yields. Because of low seed setting and poor germination it is difficult to breed arrowroot.

Prospects The prospects for arrowroot are promising because of its high yield potential, high quality starch and multiple uses. To survive competition with other starch-producing crops, the efficiency of starch extraction should be improved and the utilization of debris optimized. In South-East Asia, the feasibility of large-scale production in areas with a short dry season should be investigated.

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F.G. Villamayor Jr & J. Jukema

Metroxylon Rottboell

Nye Saml. K. Danske Vidensk. Selsk. Skrift. 2: 527 (1783).

PALMAE

$x = 13$

Major species and synonyms

- *Metroxylon sagu* Rottboell – see separate article.
- *Metroxylon amicarum* (H.A. Wendland) Beccari, Ann. Royal Bot. Gard. Calc. 12(2): 187 (1918), synonyms: *Sagus amicarum* H.A. Wendland (1878), *Coelococcus carolinensis* Dingler (1887), *C. carolinense* Beccari (1913).
- *Metroxylon salomonense* (Warburg) Beccari, Denkschr. K. Akad. Wiss. M. Nat. Kl. (Rechinger ed.), Wien, 84: 60 (1913), synonyms: *Coelococcus salomonensis* Warburg (1896), *Metroxylon bougainvillense* Beccari (1913).
- *Metroxylon warburgii* (Heim) Beccari, Ann. Royal Bot. Gard. Calc. 12(2): 182 (1918), synonyms: *Coelococcus warburgii* Heim (1904), ? [*Metroxylon upoluense* Beccari (1918)].
- *Metroxylon vitiense* (H.A. Wendland) Beccari, Ann. Royal Bot. Gard. Calc. 12(2): 185 (1918), synonyms: *Coelococcus vitiensis* H.A. Wendland (1862), *Sagus vitiensis* H.A. Wendland (1865–1868).

Vernacular names General: Metroxylon (En, Fr).

- *M. amicarum*: Caroline ivory-nut palm, Polynesian ivory-nut palm (En). Micronesia: osh (Pohnpei), rupung (Truk).
- *M. salomonense*: Solomons' sago palm, ivory-nut palm, hebe-nut palm (En). Papua New Guinea: bia. Solomon Islands: koko, sao.
- *M. warburgii*: Fiji: ota, oat (Rotuma). Western Samoa: niu (o)lotuma. Vanuatu: natangora, tenebee.
- *M. vitiense*: Fiji: songa, soqo, sogo.

Origin and geographic distribution The origin of *Metroxylon* is disputed: Moluccan, Moluccan and New Guinean, or Melanesian. It only occurs in South-East Asia and several island groups of Micronesia and Melanesia. The distribution areas of the five species in this genus within this area are neighbouring but hardly overlap. *M. sagu* is the most widespread and naturalized throughout

South-East Asia. The other four occur from the Federated States of Micronesia and the Bismarck Archipelago north of New Guinea to Western Samoa far to the east of it.

- *M. amicarum* is found in the Federated States of Micronesia (native in Pohnpei and Truk, probably planted in Nukuoro, and in Kusaie), and cultivated in the Philippines and in Guam.
- *M. salomonense* grows in Papua New Guinea (north-eastern New Guinea, Bismarck Archipelago, Bougainville Island), throughout the Solomon Islands (e.g. Guadalcanal, Santa Cruz Islands), and in Vanuatu (probably imported).
- *M. warburgii* is found in Vanuatu (indigenous), in West Samoa, and in the Fijian depency Rotuma, while its occurrence on Tikopia in Solomon Islands is uncertain.
- *M. vitiense* only occurs in Fiji (e.g. on Viti Levu, Vanua Levu, and Ovalau).

Uses The main useful products from *Metroxylon* palms are starch from the pith of the trunks, roof thatch from leaflets, and vegetable ivory from the hard endosperm of seeds.

The four more easterly occurring *Metroxylon* species have always been used far less for starch than *M. sagu*, and since the 1950s their use has died out in most places where they occur. There are no reports of the starch in *M. amicarum* trunks being exploited. At present, Rotuma (Fiji) is the easternmost point where starch is produced from these species, i.e. *M. warburgii*.

Metroxylon thatch is widely preferred to *Nypa* and *Cocos* thatch in many parts of South-East Asia and the Pacific where these palms are available together.

Vegetable ivory is derived not only from the corozo nuts (*Phytelephas macrocarpa* Ruiz & Pavon) of Ecuador and Peru, but also from the fruits of *Metroxylon* species. The most usual source used to be *M. salomonense*, with much smaller amounts coming from *M. amicarum* and even less from the fruits of *M. warburgii* and *M. vitiense*. Buttons were the main objects manufactured, though chessmen, umbrella handles and other ornaments were also made. The demand for vegetable ivory has dwindled since the introduction of plastics.

Other uses and main site-specific uses are:

- *M. salomonense*. There are recent reports of the use of starch extracted from the pith in East Futuna, Anuta, Tikopia and Kolombangara in the western Solomons, and from the Santa Cruz Islands. Unprocessed pith from the trunk is fed to domestic pigs. Building material from the leaves is the most important use (the universal thatch provider). Starch from the trunk is collected and processed throughout Bougainville Island (Papua New Guinea). Fronds are used for thatching throughout the islands of Bougainville and Buka. The plant is an item of the nursery trade in ornamental plants in northern Queensland, Australia.
- *M. warburgii*. In Vanuatu (New Hebrides), the people only know of the tradition of extracting and using the starch from this palm as food. Nowadays they value *M. warburgii* solely for its leaves and trunks, which they use to build houses. In Rotuma (Fiji), starch extracted from the trunk is used to thicken soups and stews, to starch clothing, and is cooked (e.g. baked or fried after being wetted and wrapped in a banana leaf); the midribs of leaflets are used to make brooms; immature fruits are eaten raw after the pericarp has been removed. In western Samoa the practice of using starch from this palm has almost been forgotten.
- *M. vitiense*. In Fiji, starch from the trunk is only occasionally extracted; leaves used to be, and indeed still are, applied in thatching.
- *Metroxylon* spp. On Tikopia (Santa Cruz Islands in the Solomons), an undocumented *Metroxylon* species ('rakau ota') – probably *M. warburgii*, but possibly *M. salomonense* – is used: its trunk for starch, its leaflets for thatch, and its petioles to make rafts. The starch is used in times of scarcity, but it is also regarded as a delicacy (a food particularly for infants and the elderly). It is often used as an emollient to mix with other foods to give them bulk, flavour, and smoothness.

In Bougainville Island (Papua New Guinea), an undocumented *Metroxylon* species – *M. salomonense* or *M. sagu* – is regularly used for starch; sago beetle grubs are also collected from this palm, and burnt petioles were an important source of salt until the 1950s.

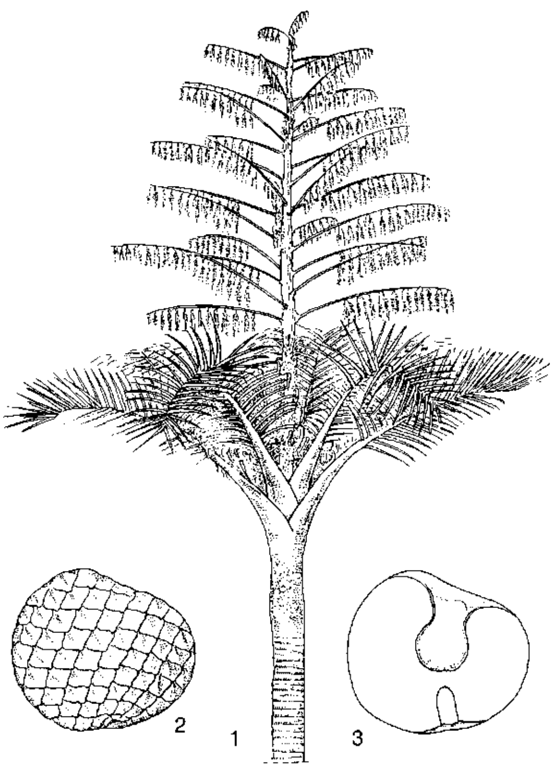
Production and international trade

- *M. amicarum*. During the German and Japanese occupation, fruits were harvested, dried, and exported as vegetable ivory under the name of Tahiti nuts, Polynesian ivory nuts, or Südsee Steinnüsse, for use in the manufacture of buttons. This species is native to the Caroline group, and it is from those islands, and especially from Pohnpei, that seeds were exported to Germany. Vegetable ivory is no longer an item of commercial importance.
- *M. salomonense*. In the Solomon Islands, fruits used to be gathered and sold as a source of veg-

etable ivory to traders for export for button manufacture, under the names ivory nut and 'hebe nut' (pidgin English). The export of this commodity from the (formerly British) Solomon Islands fell steadily from 1570 t, worth £ 23 400 in 1925, to only £ 3600 from half this quantity in 1935, when the price was only £ 5 per t. The latest figures are for 1955, when only 19.5 t worth £ 525 were exported.

Properties In Rotuma (Fiji), leaflets of *M. warburgii* ('rau ota') are regarded as superior to those of coconut for thatching, and last 5–10 years. Midribs of leaflets of this species provide the material for a broom called 'taufere'; these brooms are considered to be more durable than those constructed from coconut leaflets and are used for sweeping outdoors. Rotumans much prefer the taste of the starch from this palm ('mar ota') than the taste of starch prepared from cassava, East Indian arrowroot (*Tacca leontopetaloides* (L.) O. Kuntze), or sweet potato. Older Rotumans are said to enjoy 'mar ota' particularly, but it is rarely prepared nowadays because it is more difficult to process than cassava starch.

Description Robust to massive, solitary or clustered, armed or unarmed, hapaxanthic or pleonanthic, polygamous tree palms. Stem erect, cylindrical, up to 20 m tall, usually partly obscured by remaining leaf bases, bearing circular leaf scars on the nodes, the internodes sometimes having usually spine-like adventitious roots; cortex hard, pith soft and rich in starch. Leaves large, pinnately compound, erect, spreading or sometimes horizontal, marcescent or sometimes neatly abscising; sheath clasping the stem, splitting opposite the petiole, covered with caducous indumentum, smooth or having semicircular transverse ridges bearing series of more or less conspicuous spines; petiole well developed, largest in tillers, armed or unarmed like the sheath, rounded abaxially, deeply grooved adaxially in the proximal part; rachis like the petiole but angled adaxially; leaflets numerous, single-fold, linear, acuminate, straight to drooping, arranged regularly or in clusters, usually armed with inconspicuous short spines along the margin and main vein, green and shiny, slightly paler beneath. Inflorescence a panicle, branched to 2 or 3 orders, interfoliar (axillary) in pleonanthic species, in hapaxanthic species suprafoliar (terminal) and aggregated into a compound, multibracteate inflorescence with branches equivalent to axillary inflorescences, each subtended by a reduced leaf or bract and sometimes emerging through a split in its mid-line; peduncle very short; rachis much longer than peduncle; bracts armed or unarmed; rachillae catkin-like, robust, cylindrical, with a short stalk-like portion and a dense spiral of imbricate, membranous bracts, each enclosing a pair of flowers (dyad), one male and one bisexual; male flowers open before the somewhat flatter bisexual ones; calyx 3-lobed, corolla twice the length of the calyx, 3-lobed; stamens 6, filaments united at base, forming a tube around the ovary in bisexual flowers; pollen grains elliptical, dicolpate; in bisexual flowers pistil tricarpellate, triovulate, style conical with 3 stigmatic angles. Fruit drupe-like, subglobose, usually large and containing 1 seed; exocarp covered in neat vertical rows of shiny yellowish to brown, reflexed, imbricate, rhomboidal scales; mesocarp rather thick, corky or spongy; endocarp not differentiated. Seed globose, deeply invaginated apically, sarcotesta thin to thick fleshy; endosperm homogeneous, hard, bony; germination adjacent-ligular, eophyll bifid or pinnate.



Metroxylon salomonense (Warburg) Beccari – 1, habit flowering tree; 2, fruit; 3, seed (longitudinal section).

– *M. amicarum*. Solitary, pleonanthic; stem 6–8 (–20) m tall, 30–40 cm in diameter, brown-corky, pith fibrous, upper part often with stubs of old inflorescences; leaves 5–6 m long, spiny, about 85 pinnae on each side of the strong woody rachis, petiole 25 cm long, sheath 90 cm long and closed in its lower 30 cm, median pinnae 110 cm × 10 cm; inflorescence interfoliar, axillary, up to 125 cm long with about 12 primary (first-order) branches, the lower ones each with 6 rachillae 10–14 cm long (rachillae here second-order branches); fruit 7–11(–13) cm long, 8–9.5(–12) cm wide, covered with 24–28 rows of brown-red scales, bearing a prominent tubercle at apex.

- *M. salomonense*. Solitary, hapaxanthic; stem 9–20 m tall, up to 55 cm in diameter; leaves 9–11 m long, bearing spines in transverse series; inflorescence suprafoliar, first-order branches erecto-patent, 3–4 m long, second-order branches spreading, rachillae (here third-order branches) pendulous and about 20 cm long; fruit 5.5–6.5 cm long, 7–9 cm wide, with 24–27 rows of yellowish scales, depressed at base and apex.
- *M. warburgii*. Solitary, hapaxanthic; stem 6–7 m tall, up to 30 cm in diameter; leaves up to 3 m long, bearing spines in transverse ridges or series; inflorescence suprafoliar, branched to 3 orders, all branches erecto-patent, first order branches 1–1.5 m long; flowers large, corolla up to 1 cm long; fruit inversely pear-shaped, (4–)7–12 cm long, (3.5–)6–9 cm wide, with 24 rows of red-brown scales; seed in upper, wider part.
- *M. vitiense*. Solitary, hapaxanthic; stem 5–10 (–15) m tall, up to 50 cm in diameter; leaves up to 5 m long, with brown spines, leaflets in one plane, petiole short (long in seedling leaves); inflorescence suprafoliar, first-order branches erecto-patent, 2–2.5 m long, second-order branches pendulous, 20 cm long, each with 8–9 rachillae (third-order branches); fruit conical, 7 cm long, 5 cm wide, with 27–28 rows of yellow-brown scales.

Growth and development All *Metroxylon* palms accumulate starch in the pith of their trunks. The starch in *M. amicarum* is not exploited by people, probably because its pleonanthic habit prevents starch accumulating in sufficient quantity.

The stout trunks of the hapaxathic *Metroxylon* species take about 15 to 20 years to reach the flowering stage.

- *M. salomonense*. When cultivated for its leaves for house thatching, the 'pruning' effect of harvesting seems to retard tree development; flowering and fruiting are delayed.
- *M. warburgii*. A 13-year-old non-flowering specimen, growing on a rich, well drained loam in Papeari on the south-east side of Tahiti (annual rainfall 2500 mm, 22–32°C), started developing a trunk when 9 years old, had an overall height of 10 m and a trunk height of 2 m, bearing 35 leaves and 21 leaf scars.

Other botanical information The genus *Metroxylon* is divided into two sections: *Metroxylon* (clustering palms with fruits covered with 18 vertical rows of scales), comprising only *M. sagu*, and section *Coelococcus* (solitary palms with fruits covered with (22–)24–28 vertical rows of scales), comprising the other 4 species. This division based on fruit characters is not in accordance with the division based on the two pollen types occurring in *Metroxylon*.

When more information is available on the length and abundance of spines, the other *Metroxylon* species could possibly be subdivided similarly to *M. sagu*.

In the Santa Cruz Islands (Solomon Islands), two types of *M. salomonense* are recognized: a large type up to 10 m tall at maturity, with wide leaflets and large flattened globose fruits, and a smaller type with obviously narrower leaflets and smaller pointed fruits. Both types are said to breed true from seed.

Ecology *Metroxylon* palms usually occur in lowland swamps, but occasionally also on hillsides.

- *M. amicarum*. Thrives inland on hill slopes, and in dry conditions.
- *M. salomonense*. Is often cultivated well away from swampy areas, sometimes on high ridges.
- *M. vitiense*. On Viti Levu Island (Fiji) it is very abundant on lowland gley soil, and occurs occasionally in dryland forest. In one of the major wetland sites, the Vunimoli wetlands, there are almost pure stands on the wet gley soils on the colluvium and alluvium in the valleys upstream of the coastal plain. This is the only extensive wetland forest (262 ha) in Fiji and includes most of the *M. vitiense* population. On wet gley soils, *M. vitiense* forms a distinctive vegetation type. It also occurs on adjacent hillsides in association with a variety of trees.

Propagation and planting Unlike *M. sagu*, which is propagated almost exclusively from basal offshoots, the other *Metroxylon* species can only be propagated from seed. *M. salomonense* is normally propagated by sowing in situ, but sometimes germinated seed is transplanted.

Husbandry Although *M. salomonense* may once have been planted for exploitation on Bougainville Island (Papua New Guinea) and the Solomon Islands, no information is available on husbandry.

Diseases and pests The cane weevil borer, *Rhabdoscelus obscurus*, is gaining importance as a pest in *M. salomonense* in northern Queensland where this palm is grown as an ornamental. Larvae mine in the leaf bases and adjoining trunk tissue, killing young palms and making older ones unmarketable.

Harvesting
- *M. salomonense*. For its – now obsolete – use as vegetable ivory, the fallen fruits used to be gathered and brought to trading centres.
- *M. warburgii*. Trees just about to start flowering are preferred for the production of starch in Rotuma (a dependency of Fiji), because they have a maximum of available starch. A tree's suitability is tested by plunging a machete into the trunk: the ideal tree is hard outside and very soft inside; a hard inner trunk indicates that the palm does not have much starch. After selection the tree is felled close to the ground and the trunk split longitudinally with a single well-placed blow of an axe. A halved coconut shell, sharpened along the edge, is used to scrape out the tissue in the inner part of the trunk. A person straddling the trunk, holds the shell firmly in both hands, and pulls it towards him. The trunk gratings are piled up and put into a sack or basket for transport and processing.

Handling after harvest
- *M. salomonense*. Seed for export as vegetable ivory has to be dried sufficiently, because fresh seed contains up to 50% moisture. Incompletely dried seed is a useless product for trade.
- *M. warburgii*. In Rotuma, for the production of starch, the grated pith from the trunk is put into a clean fabric bag (which used to be made from the textile-like base of coconut fronds or fibres from banana petioles). The bag is then placed in a container of water, and the starch is wrung out. After wringing, new gratings are placed in the bag. The water in the container soon becomes cloudy with the starch. After wringing the gratings, the cloudy water is covered with leaves (to exclude flies or other undesirable particles), the starch is allowed to settle for approximately 10 minutes, and is then decanted. The starch is dried in the sun, and in this form may either be stored for future use, or used immediately.

Genetic resources and breeding No germplasm collections or breeding programmes are known to exist for the *Metroxylon* species considered here.

Prospects As starch plants, *Metroxylon* species other than *M. sagu* are not very productive, and cannot be readily propagated vegetatively. The effort needed to produce food from these palms compares unfavourably with other ways of procuring food energy. They are, however, useful as emergency food; during the life cycle of the once-flowering species, harvestable quantities of starch remain stored in the live trunk for several years.

Their importance as providers of thatch will slowly decline as more durable building materials take over.

The role of vegetable ivory in manufacturing has since long been taken over by synthetic products. Vegetable ivory from *Metroxylon* species may play a modest role in local tourist industries as a material for carving souvenirs.

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D.L. Schuiling

Metroxylon sagu Rottboell

Nye Saml. K. Danske Vidensk. Selsk. Skrift. 2: 527–528 (1783).

PALMAE

$2n = 26$

Synonyms *Metroxylon rumphii* Mart. (1845) with many varieties, designated by Beccari (1918); *M. squarrosum* Becc. (1918) with many varieties.

Vernacular names True sago palm, sago palm (En). Sagoutier (Fr). Indonesia: pohon sagu (general), pohon rumbia (general), kirai (Sundanese), lapia (Ambonese). Malaysia: rumbia (general), balau (Melanau, Sarawak). Papua New Guinea: sak-sak (Pidgin). Philippines: lumbiya. Burma (Myanmar): tha-gu-bin. Cambodia: chraè saku:. Laos: sa:kh'u: tônz. Thailand: sakhu. Vietnam: sagu.

Note: In the Indonesian-Malay language region, the word 'sagu' denotes the edible starch from the pith of any palm and each of these palms may be called 'pohon sagu' (sago tree). 'Pohon rumbia' designates one of them, namely the 'true' sago palm dealt with here, but the name is not commonly used.

Origin and geographic distribution The sago palm probably originates from New Guinea and the Moluccas but has only recently been dispersed for research beyond South-East Asia and the nearby Pacific islands. In Indonesia, the palm is now found in parts of Sulawesi, Kalimantan, Sumatra and West Java, as well as on many smaller islands with a non-seasonal climate, notably the Riau Islands, Nias and the Mentawai Islands. In Malaysia, the palm grows in Sabah, Sarawak and on the Peninsula. Some are found in Brunei and in the Philippines (Mindanao). There are large areas of sago palm in Papua New Guinea. There is also a small area in southern Thailand. Sago palm is found at least as far east as the Solomon Islands and probably the Santa Cruz Islands (species have not been identified with certainty).

The world's largest contiguous sago palm swamps and forests are found in New Guinea, totalling a roughly estimated 5–6 million ha, with 4–5 million ha on the Indonesian part of the island.

Uses The starch stored in the trunk is a staple food, notably in New Guinea. Usually, wet starch is boiled, fried or roasted, alone or mixed with other foodstuffs, resulting in products of different keeping quality. In Indonesia and Malaysia, the starch is used industrially in the manufacture of cakes and cookies, noodles and kerupuk (crisps), and in the United States for custard powders. Non-food uses include sizing pastes for paper and textiles, and extender in adhesive for plywood. It is a very suitable raw material for further industrial processing, e.g. into high-fructose syrup and ethanol.

The palm has many secondary uses. Whole young trunks, pith and pith refuse are given to animals. The 'bark' of the trunk is used as timber or as fuel. Walls, ceilings and fences can be constructed from the petioles ('gaba-gaba'); the fibrous outer layer of the petioles is used for cordage and to weave mats. The leaflets produce one of the best ataps (roof thatch) available, the main use of the palm in West Java. Young leaflets are made into baskets for the transport and storage of fresh (wet) starch. The growing point of the palm with its surrounding tissues may be eaten raw or cooked (palm cabbage).

The larvae of insects feeding on the pith of the trunk, notably weevils of the genus *Rhynchophorus*, are eaten raw, boiled or roasted in most places where sago palm is a staple. A mushroom (*Volvariella volvacea* Fries) which grows on pith refuse is relished in the Moluccas.

Production and international trade Of the total sago palm area of 5–6 million ha, only an estimated 210 000 ha is planted. Planted areas are estimated to be 130 000 ha in Indonesia, 40 000 ha in Malaysia (mainly Sarawak and Sabah), less than 1000 ha in Brunei, 5000 ha in the Philippines, 20 000 ha in Papua New Guinea, 5000 ha in Thailand and 10 000 ha on the Pacific islands. Most sago starch is consumed locally or traded on domestic markets. It accounts for less than 3% of international trade in starches. Some of it is traded as sago pearls: partially gelatinized kernels, 1–2 mm in diameter, obtained by forcing raw starch paste through a sieve and stirring the extruded pieces of paste on a hot-plate until hard and rounded. Sometimes, pearled starches of non-palm origin are erroneously called 'sago pearls' or even just 'sago'.

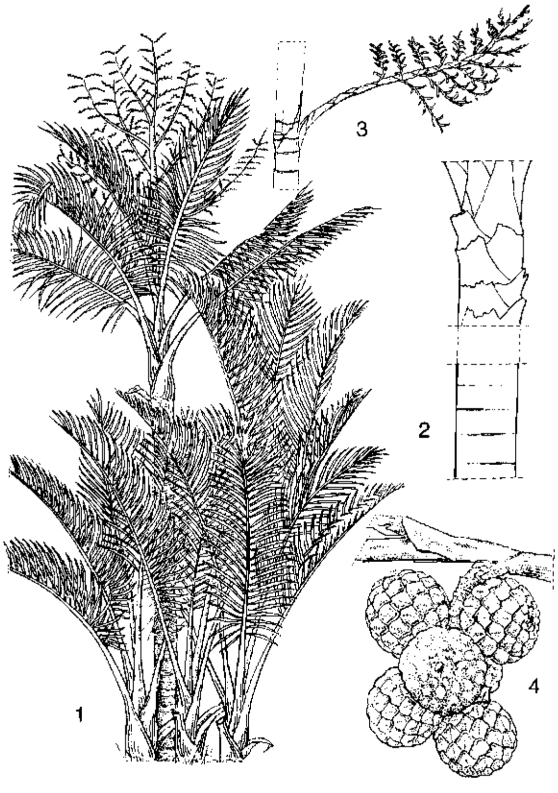
Unambiguous economic statistics are scarce. In 1992, the export of dry sago starch from Sarawak was 45 700 t (value MY$ 31 million). On Bengkalis (Riau Islands), an old centre of sago starch production, 30 mills operated in 1980 with a total output of 6600 t/year of dry starch. In the 1930s, 30 000–40 000 t/year wet starch production from the east coast of Sumatra was exported to Singapore to be refined and re-exported. The once prosperous sago-starch trade through Singapore has declined steadily since the 1950s.

Properties Purified sago starch consists of 27% amylose and 73% amylopectin. Dry starch samples from various parts of Indonesia contained water 10–17%, protein 0.31%, fat 0.11–0.25%, carbohydrates 81–88%, fibre 1.35%, ash 0.15–0.28%. A sago-based diet should be complemented with other foodstuffs to provide essential proteins, minerals and vitamins.

In Sarawak, the dry matter content of the grated whole pith (sample of 6 palms) contained: N 0.15%, P 0.046%, K 0.45%, Ca 0.24%, Mg 0.09% and starch 54%.

Sago weevil larvae from Sarawak and Papua New Guinea, weighing 3–8 g, contained: water 65–75%, protein 3–7%, fat 10–30%.

Description A medium to tall palm tree, flowering once only, andromonoecious, forming basal suckers. Roots spongy but with a tough central fibro-vascular strand, not extending to great depth (80–100 cm in peat soil); pneumatophores (air roots) present. Trunk 30–60 cm in diameter, 7–20(–25) m tall, lower part ringed with leaf scars, upper part covered with semi-persistent leaf sheaths; epidermis thin, very sclerenchymatous, surrounding the fibrous bark, 5–10 mm thick; under the bark an extremely hard layer of sclerenchymatous fibre bundles, up to 1 cm thick surrounds the parenchymatous pith. Leaves 18–24 in vigorous trunked palms, simply pinnate, 5–7 m long (sometimes up to twice as long); petiole very robust, widening at its base into a stem-clasping sheath; sheath and petiole unarmed or armed to various degrees with needle-like spines, up to 22 cm long, arranged in transverse combs; leaflets up to 200 per leaf, 50–160 cm × 3–6(–9) cm, often with small spines along the margins and on the midrib and sometimes with an apical, filiform appendage, margins usually valvate and reflexed. Inflorescence apparently a terminal panicle, 3–5(–7.5) m high and wide; first-order branches (10–)15–30, straight to curving upward, morphologically constituting separate lateral inflorescences arranged spirally on the main stem in the axils of reduced leaves or bracts with a phyllotaxy of 5/13, rigidly and distichously branched to the third order; the flower-bearing third-order branches spadix-like, rust-coloured when young, darker and more red from densely packed bulging flower buds later; flowers in pairs arranged spirally, each pair consisting of one male and one hermaphrodite flower, but up to half of the buds, usually most of them male, may abort before they reach anthesis; bracts of the first to the third order smooth to spinulescent outside; flowers 3-merous with 6 stamens. Fruit a depressed-globose to obconical drupe, 3.0–5.0(–7.0) cm in diameter, covered with 18(–19) vertical rows of scales, rhomboid, pointing downwards, greenish-yellow, turning straw-coloured towards or after fruit fall; scale layer lined inside with a white spongy layer. Seed subglobose, about 3 cm in diameter, firmly embedded in shiny cream-coloured firm flesh which turns pinkish when exposed to air; testa dark brown; endosperm homogeneous, horseshoe-shaped in longitudinal section because of large chalazal cavity; seeds often fail to develop, resulting in fruits filled with the cream-coloured flesh only.



Metroxylon sagu Rottboell – 1, habit of flowering palm with tillers; 2, stem (upper part covered with leaf bases, lower part with leaf scars); 3, first-order inflorescence branch; 4, fruits.

Growth and development The seed is viable as soon as the fruit is shed but may quickly lose its viability through desiccation. In the field, germinating seeds are always fully ripe (brown testa and hard endosperm inside a straw-coloured husk), and are found on damp soil or even in a thin layer of water, under conditions of high relative humidity. Seeds usually germinate within 3 weeks. Vegetative growth is divided into a rosette stage of 3.5–6 years and a trunk stage of 4–14 years, depending on palm type and growing conditions. If these conditions are optimal, leaves form at a rate of 2 per month during the rosette stage, slowing down to 1 per month during the trunk stage; longevity of adult leaves is 18–24 months. Basal suckers are formed continuously, the first ones appearing already during the first year after germination. Starch is stored in the parenchyma (pith) of the trunk, which is gradually filled from the base upward. Maximum volumetric mass of the starch (kg per m^3 of pith) has been found to be about 190 in Sarawak, 330 in the Sepik area of Papua New Guinea, and 280 on Seram in Indonesia. During flowering and especially during fruit development, the starch is translocated towards the inflorescence. After fruits have been shed, most of the starch has disappeared from the trunk.

The generative stage is heralded by the 'shooting' of the main stem, forming the main flowering axis: new internodes become longer, stem diameter and leaf size decrease and rate of leaf formation increases. The development of the inflorescence is phased: first the main axis develops, then the first-order branches, subsequently the second-order branches, etc. Anthesis of a male flower lasts 1 day, of a hermaphrodite flower 1–2 days; the anthesis period for the entire inflorescence lasts 50–60 days. Within one inflorescence, most male flowers have opened (and aborted the next day) before most hermaphrodite flowers open: sago palm is largely, but not strictly protandrous. Stamens in the male and hermaphrodite flowers look the same, but the viability of pollen in the hermaphrodite flowers is uncertain.

As germinating seeds are often found where two palms close to each other have flowered simultaneously, it has been assumed that sago palm is mainly a cross-pollinator.

Recent research findings suggest that sago palm is most probably largely self-incompatible, i.e. only palms which are genetically sufficiently different are well able to fertilize each other. This, in combination with the natural vegetative propagation method of the palm, the small chance of overlap of the anthesis periods of palms, and the condition that these palms should be growing at a distance small enough to allow for the insect-assisted pollen transfer, would account for the very low percentage of seeded fruits often encountered.

A yield of 5000 (seeded or unseeded) fruits is common in Sarawak. A sample-based estimate of the number of fruit in a palm on Ternate was 28 800.

It takes about 3 years from the outwardly visible start of the generative stage to the shedding of the fruits, after which the trunk dies. So, the total life span of a sago palm ranges between 11–23 years.

In the meantime, suckers of various ages, some already with a trunk, may have developed under the parent palm. Some suckers may form trunks up to several metres away from the parent palm, after first forming a prostrate stem.

Other botanical information The distinction at species level of palms with and without spines (*M. rumphii* and *M. squarrosum* – spiny; *M. sagu* – spineless) cannot be upheld. The reduction of the number of taxa of lower order in true sago palm, however, from 21 to 4 in the latest revision of the genus, may be too drastic. For example, variation in life span, which appears to be mainly genetically determined, and which is one of the bases of the distinction of types by sago growers, is, unfortunately, not taken into account. Neither are other variations recognized, e.g. in leaf form, spine density, bark thickness, starch colour, and even starch taste.

The number of sago palm types distinguished by local sago growers increases eastwards: from 2 on Siberut island west of Sumatra and in Riau province, to 2–3 in Sarawak, to 4–5 on Ternate and Halmahera, to 5–8 in the Central Moluccas, to 10–13 on New Guinea island.

Ecology Sago palm is a tree of the per-humid tropical lowlands, occurring naturally up to 700 m above sea-level (up to 1200 m in Papua New Guinea). The best conditions for sago palm growth are an average temperature of at least 26°C, a relative humidity of 90% and an irradiance of about 9 MJ/m^2 per day.

Natural stands of sago palm occur on swampy coastal plains, river floodplains and higher up on flat valley floors. When growing downstream along rivers, tidal influences may be part of the habitat of sago palms, and may affect the level and salinity of flood water or groundwater. Daily flooding is harmful to seedling growth, as is salinity corresponding to electric conductivities (EC) of over 1 S/m. (EC of sea water is 4.4 S/m). Occasional flooding, even with very saline water is tolerated, however. Although found on mineral, peat and muck soils, sago palm grows best on mineral soils with a high organic matter content (up to 30%).

In New Guinea, sago palms occur mainly in 4 vegetation types. Ranging from land inundated most of the year to less flood-prone lands, one may successively encounter sago palm – *Phragmites* swamp (groves of trunkless sago palms in dense stands of the reed *Phragmites karka* (Retz.) Trin. ex Steud.), sago palm swamp (dense stands of sago palms, most of them trunkless), and sago palm forest (sago palms in various stages of development mixed with dicotyledonous trees in various proportions). On peat soils that are dry most of the year, *Campnosperma* – sago palm forest (sago palms forming an understorey under a closed canopy of *Campnosperma brevipetiolatum* Volkens) can be found. The most numerous and largest trunks are found in the sago palm forest.

As the water becomes more brackish, sago palm often borders on stands of the more salinity-tolerant nipa palm (*Nypa fruticans* Wurmb).

Propagation and planting Sago palm is mostly propagated from suckers. Rooted suckers about 1 year old with a basal diameter of 8–15 cm are severed from selected parent palms with a clean vertical cut through the runner (rhizomatous stem), leaving some 15 cm of the runner attached to the sucker to serve as food reserve. The cut wound is sometimes rubbed with wood ash to prevent rot. Treating the wound with a broad-spectrum fungicide has been shown to increase viability of the sucker. The runner with the roots should be kept from drying out. Usually, all the leaves are cut off; sometimes the spear and all or part of the youngest unfurled leaf are left on the sucker. Before planting in the field, suckers can first be kept in nurseries, either in polythene bags, or by simply putting them in shallow water, or if the water is deeper by tying them to a raft with only the runner and roots hanging in the water. Usually, only about half the propagated suckers are successful. The sucker survival rate may be increased by reducing the time between cutting the suckers and putting them in a nursery, by treating them with pesticide to prevent *Rhynchophorus* attack, and by shading them in the dry season. Propagation from seed has a considerably higher rate of success but viable seeds are difficult to obtain and the heterogeneity of the offspring, e.g. spininess, is a drawback.

Suckers are planted in the field at 6 m × 6 m to 7 m × 7 m. Planting depth is critical: the runner and especially the cut end should be buried to prevent *Rhynchophorus* attack and desiccation, but the shoot and especially the apical meristem inside it should be above water table (or above flood-water level), also in the wet season, to prevent rot. If necessary, the suckers are staked. Plenty of shade should be provided.

In vitro propagation of sago palms is still in the experimental stage. Plantlets have been derived from embryo culture, but micro-propagation through multiple shoot induction from sago explants has not yet been successful.

Husbandry The sucker is established as soon as the spear plus a new leaf have unfolded, normally within 3 months. Shade is then gradually removed.

Weeding is necessary until the leaf canopy has closed. Old leaves are pruned and used as mulch. One sucker is allowed to develop into a trunk every 2 years if clump spacing is 6 m × 6 m, or every one and a half years if the spacing is 7 m × 7 m. All other suckers are pruned. Thus, an annual yield of 136–139 trunks per hectare may be achieved. The water table should be no lower than 50 cm. Fertilizers are normally not used; in Peninsular Malaysia the palms grow on flood-prone river banks, the river water probably carries all the necessary nutrients. Deficiencies have been shown to reduce the rate of leaf formation and the leaf area of new leaves in seedlings.

Diseases and pests In extensive exploitation from semi-wild stands, none of the pests encountered are economically important. In intensive estate cultivation in Sarawak, however, many pests have become economically important, the most important being the larvae of the hispid beetle *Botryonopa grandis*, which attack the soft tissues of furled leaves, termites (*Coptotermes* sp.), which tunnel through the young trunk up to the growing point, and the larvae of the red-striped palm weevil *Rhynchophorus schach* (= *R. ferrugineus* var. *schach*), the so-called sago worms, which eat away at the trunk's pith. Other pests reported from elsewhere include *R. ferrugineus* from Siberut (Indonesia), rhinoceros beetle (*Oryctes centaurus*) from Papua New Guinea, and nettle caterpillars (*Darna* spp.) from Java.

Harvesting To get the most starch out of one palm, it should be harvested at the peak of its starch content, which is reached during the generative stage some time between the beginning of anthesis and the beginning of fruit development. To maximize starch production per unit time, however, trees should be felled before the inflorescence emerges, when starch accumulation rate has not yet slackened. After felling, the crown is severed from the trunk and the old leaf sheaths are removed. The leaf bearing part of the trunk contains little starch.

Yield Top annual yield of dry starch from a first crop of palms of short life cycle in Peninsular

Malaysia is about 25 t/ha, equivalent to 138 trunks of 180 kg each. Yields of the subsequent ratoon crops stabilize at about 15 t/ha (85 trunks of 180 kg each). Recorded production of dry starch from single 'mature' trunks in uncultivated stands range from 20–400(–800) kg. The production capacity of semi-wild stands is estimated at 50 trunks per ha per year, producing 10 t/ha, whereas good quality wild stands on the drier parts of swamps are estimated to produce 25 trunks per ha per year, yielding 5 t/ha.

Handling after harvest Processing consists of separation of bark and pith, pulverization of the pith and separation of the starch grains from the other pith constituents. Traditionally, most of the processing is done at the felling site. The trunk is split lengthwise with wedges or partly debarked (i.e. the bark proper plus the outer hard layer of fibre bundles is removed). The exposed pith is pounded loose and pulverized with a hoe-like or adze-like instrument or grated with a nail-studded plank. The starch grains are leached out of the pulverized pith with water over a sieve and the starch is recovered from the slurry passing through the sieve by letting it settle. Pith starts fermenting spontaneously soon after it is pulverized, giving off an acid smell and causing irreversible staining of the starch. So starch extraction should follow pith pulverization as soon as possible.

Traditionally, only the wet starch (starch content 60%) is removed from the field. In planted stands, the trunks are usually cut into lengths of about 1 m. These logs (starch content 20–25%), weighing 80–120 kg, are rolled and floated to a central mill for further processing, a network of waterways being indispensable.

Genetic resources In Sarawak (Department of Agriculture, and Land Custody and Development Authority) and in the Moluccas, Indonesia (Makariki Experiment Station of the Coconut Research Institute at Seram Island), a start has been made with the collection of sago palm types from Eastern Indonesia and Papua New Guinea.

Breeding For estate cultivation, palm types are needed which (1) have a short life cycle (brief rosette stage and quick 'maturation') to allow an early first harvest, (2) have a high starch accumulation rate (high yield per unit time), (3) can be planted densely (high yield per unit area), (4) are responsive to fertilizers, (5) have pest and disease resistance/tolerance, and (6), especially in Sarawak, are able to grow well on peat soil.

Prospects Sago palm is one of the underexploited trees in South-East Asia. Sago starch is mainly harvested from wild or semi-wild (i.e. planted but neglected) stands. Vast areas of natural sago palm stands, in New Guinea in particular, are left unused because of the inaccessible habitat and their remoteness. Until the mid 1980s, sago palm had been cultivated regularly only in Peninsular Malaysia, especially in the State of Johor. Since about 1970, international interest in sago palm as a plant resource in equatorial swamps has increased and desk studies have demonstrated its economic viability as a plantation crop. In 1987, the development of an 7700 ha sago plantation was started near Mukah, Sarawak, on deep peat. A new plantation has also been opened up in Indonesia in Riau province. New large-scale schemes exploiting natural stands have come into operation in Indonesia on Halmahera and in Irian Jaya.

At present research is intensifying. In Sarawak, an experiment station devoted to research on growing sago palm on deep peat has been operating since 1982. Indonesia is planning to establish a sago palm research station.

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D.L. Schuiling & F.S. Jong

Musa L. (plantain and cooking banana)

Sp. pl.: 1043 (1753), Gen. pl. ed. 5: 466 (1754).

MUSACEAE

$x = 11$ (all plantains are triploids, but diploid, triploid and tetrapoid cooking bananas occur)

Major taxa and synonyms

- *Musa* (AAB group & ABB group), synonyms: *Musa paradisiaca* L., *Musa ×paradisiaca* L.
- *Musa* (BB group & BBB group), synonym: *Musa balbisiana* Colla (1820).

Vernacular names Plantain, cooking banana (En). Bananier plantain (Fr). Platano (Sp). Indonesia: pisang (general). Malaysia: pisang. Papua New Guinea: banana. Philippines: saging. Burma (Myanmar): nget-pyaw. Cambodia: ché:k. Laos: kwàyz khauz. Thailand: kluai. Vietnam: chu[oos]i.

Origin and geographic distribution The greatest diversity in *Musa* germplasm is found in South-East Asia, the recognized centre of origin of bananas and plantains. Malesia is thought to be the primary centre for dessert bananas, whereas plantains and cooking bananas originated along the peripheral areas of the region, spreading eastward to the South Pacific and westward from India to Africa and hence to the warm regions of Latin America.

Plantains and cooking bananas are found wherever dessert bananas are grown. In western and central Africa and in some island countries in the Pacific, plantains are more common than dessert bananas. In certain areas in South-East Asia such as the Philippines, eastern Indonesia and Papua New Guinea, where the long dry season poses a problem for the production of dessert bananas, cooking banana cultivars predominate and serve as part of the staple diet, particularly among the poorer segments of society.

Uses Plantains and cooking bananas flower and fruit the whole year round; therefore, there is little need to preserve and process fruits. The fruits are cooked green or just after ripening, and are immediately consumed. Boiling, roasting and frying are the simplest and most popular ways of preparing the fruit. The ease and speed of preparation contributes to their popularity. Whole bananas are boiled, but the fruits are peeled and sliced before frying. To roast bananas, the peel may be removed if a grill is used, but whole fruits may also be placed directly into a low fire or hot ashes.

Not all banana recipes are simple; hundreds of delicacies in Thailand, Malaysia, Indonesia and the Philippines require sophisticated techniques. Dried bananas and banana chips (crackers) are two of the more popular snack products that have found a niche in the export market and contribute to the foreign exchange earnings of some countries like Thailand and the Philippines. The cultivar 'Saba' is used in the manufacture of banana chips in the Philippines, but plantain cultivars are preferred in Indonesia for the same purpose. Another very popular manufactured product using the cooking cultivar 'Saba' is banana ketchup, which has replaced tomato ketchup in the Philippines because of its superior flavour and much lower cost. Products of minor importance made from cooking bananas include flour, jam and jelly, dried banana fritters and vinegar.

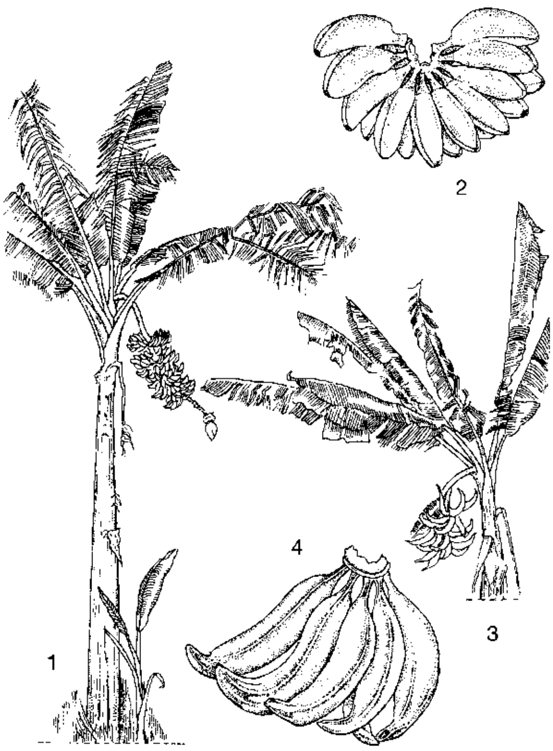
Although fruits are the primary product of bananas and plantains in human consumption, the male bud and the heart of the growing pseudostem are also eaten in many parts of South-East Asia. An interesting observation is the preference of consumers for the male bud of wild *Musa balbisiana* and of the cooking cultivar 'Saba' (Philippines) or its equivalents (Indonesia, Malaysia, Thailand and Vietnam).

Bananas also play popular roles in cultural traditions of many South-East Asian countries. Whole plants, leaves, fruits and bracts are used as decorations during religious ceremonies, weddings and parties. The leaves of bananas, especially the thick leaves of triploid cultivars, are used as wrappers in cooking native delicacies. The cooked food is also served on banana leaves. The split pseudostems and leaves are used as a mulch in banana gardens and other orchards, or as temporary shade for transplanted seedlings. Leaf sheaths are used locally to make baskets and handbags.

Production and international trade Bananas and plantains constitute the fourth most important global food commodity (after rice, wheat and milk) in terms of gross value of production. The high ranking is not due to the revenue generated by the international banana export trade (which is recognized as the most important fresh fruit export), but the real value is in the huge volume of fruit produced and consumed locally throughout the tropics. Only about 10% of the estimated 70 million t produced annually is exported. The export trade is almost exclusively made up of dessert bananas belonging to the Cavendish clones, whereas plantains and cooking bananas compete with dessert bananas in domestic markets. Unfortunately, production statistics on bananas do not differentiate dessert from cooking bananas (including plantains), but INIBAP (International Network for the Improvement of Banana and Plantain) estimates that plantains and cooking bananas comprise 40% of total world production and dessert bananas 42%. Highland bananas in East Africa, consumed either fresh or cooked, with significant volumes used in beer manufacture, make up the remaining 18%. Plantain, *Musa* (AAB group), predominates as the most important cooking type in Africa and Latin America, but not in South-East Asia. The great susceptibility of plantain cultivars to diseases and pests and to the occasional droughts in some areas of South-East Asia has caused farmers to shift to the culture of the hardy cooking banana cultivars belonging to *Musa* (ABB group) 'Matavia' or 'Bluggoe' and *Musa* (BBB group) 'Saba'. Only in Java (Indonesia) can one find plantain cultivars still rivalling the importance and popularity of cooking bananas.

Properties Plantains and cooking bananas contain per 100 g edible portion: water 55–58 g, protein 1.2–1.6 g, fat 0.25–0.30 g, carbohydrates 34–35 g, fibre 6–7 g, ash 0.8 g. They are good sources of K, Mg, Ca, P and Fe as well as vitamins A and C. Their energy value is 540 kJ/100 g.
Compared to the fruits, the edible male buds contain more water (about 92%), less carbohydrates (7%) but similar protein and fat contents of 1.2% and 0.3%, respectively. Per 100 g edible portion, male buds contain: Ca 30 mg, P 50 mg and Fe 0.1 g. Their energy value is about 150 kJ/100 g.

Description Tree-like perennial herb, 2–9 m tall, with a short underground stem (corm) with buds, from which short rhizomes grow to produce



Musa L. (plantain and cooking banana) – 1, habit Musa (BBB group) 'Saba'; 2, cluster of fruits Musa (BBB group) 'Saba'; 3, habit Musa (AAB group) 'Tindok'; 4, cluster of fruits Musa (AAB group) 'Tindok'.

a clump of aerial shoots (suckers) close to the parent plant. Roots adventitious, spreading 4–5 m laterally, descending to 75 cm, but mainly in the top 15 cm, forming a dense mat. Shoots cylindrical pseudostems of overlapping leaf sheaths, tightly rolled round each other, forming a rigid bundle of 20–50 cm diameter. New leaves originating from the corm growing up continuously through the centre of the pseudostem with their laminas tightly rolled; emerging leaf unfolding a large oblong blade, 150–400 cm × 70–100 cm, with a pronounced supporting midrib and well-marked, pinnately arranged, parallel veins. One terminal inflorescence arising from each corm with axis (peduncle) extending through the centre of the pseudostem and bending down when exserted, being a compound spike with flowers arranged in several groups, compact and conical when young; each group consisting of two closely appressed rows of flowers, enclosed in a large ovate, pointed reddish bract; bract becoming reflexed when flowers develop and being shed when fruits start to develop; female flowers proximally, male flowers at distal end of inflorescence, sometimes neuter flowers in the middle; commonly 12–20 flowers per node, and usually 5–15 nodes with female flowers; bracts open in sequence (about 1 per day) from base to top while the peduncle elongates; mature infructescence about 50–150 cm long, bearing hands of fruits, followed by a long bare axis formed if – as in most cultivars – male flowers and subtending bracts abscise, terminating in a growing point ('male bud') which continues to produce bracts and male flowers; female flower (about 10 cm long) with inferior ovary of 3 united carpels, roughly triangular in section, surmounted by a short perianth of 5 fused segments and 1 free segment, together forming a tube around style and sterile androecium; stigma 3-lobed; staminodes 5; male flower about 6 cm long, stamens 5, rarely bearing pollen, pistillode small. Fruit berry-like, seedless, 6–35 cm × 2.5–5 cm, green, yellow or reddish, curved in plantains but straight in cooking bananas; each cluster of fruits at a node is a 'hand' (2–15 per bunch) and each individual fruit is a 'finger' (12–20 per 'hand').

Growth and development The underground rhizome is sympodial, producing lateral shoots called suckers. Suckers originate from buds on the upper portion of the corm. The rate of suckering differs among cultivars and determines the period between successive harvests. A characteristic of plantains is the strong dominance of the apical meristem of the mother plant. Sucker production is held back until flowers have initiated in the parent corm, but then many suckers sprout at the same time. Sucker production in cooking banana cultivars is regular and harvesting of ratoon crops is well-spaced.

A mature and healthy plant has a whorl of 8–12 leaves, with the outer and older leaves dying as new ones are produced. The plants produce a definite number of leaves, i.e. 30 in many cultivars. The successive leaves increase in size until shortly before flower emergence. The appearance of a flag leaf signals the end of vegetative growth and the start of flowering and fruiting in which the apical meristem expends itself. At fruit maturity, the whole bunch is harvested and the mother plant cut down. If left alone, it will slowly die and suckers will take over.

Other botanical information The French plantain, *Musa paradisiaca*, was first described by Linnaeus in 1753 and served as the type species of the genus *Musa*. But recent studies have shown that plantains are triploid hybrids of two wild and seedy species, *Musa acuminata* Colla and *M. balbisiana* Colla. For a brief period, the scientific name of plantains was modified to *Musa ×paradisiaca* L., but the original description was rather restrictive and could not adequately accommodate the great diversity of hybrid groups that occur in South-East Asia. This observation led to the wide acceptance of a classification scheme whereby *Musa* (AAB group) 'French' plantain and *Musa* (ABB group) 'Bluggoe' are widely accepted technical terms for the common cultivars of plantains and cooking bananas in Africa and Latin America. Cultivars belonging to *Musa* (AAB group) have two genomes from the *M. acuminata* parent and one genome from *M. balbisiana*, whereas *Musa* (ABB group) indicates that the cultivars have inherited two genomes from the *M. balbisiana* parent and only one genome from *M. acuminata*. A tetraploid (ABBB group) is common in Thailand. In South-East Asia, where the greatest diversity of bananas occurs (particularly cooking bananas), parthenocarpic diploid and triploid forms of pure *M. balbisiana* derivatives exist. Being seedless forms of the wild parent, these groups of hardy cultivars are classified by some banana taxonomists simply as *M. balbisiana*. Here, however, *Musa* (BBB group) 'Saba' is applied to the subgroup of cooking bananas. The curators of banana germplasm collections in South-East Asia believe that a parallel evolutionary pattern occurred in the development of seedless and parthenocarpic forms: the diploid *Musa* (BB group) 'Abuhon' and triploid *Musa* (BBB group) 'Saba' among the *M. balbisiana* cultivars, are the evolutionary equivalents of the edible diploid and triploid forms of dessert bananas, typified as *Musa* (AA group) 'Pisang Mas' and *Musa* (AAA group) 'Pisang Ambon'. The *M. balbisiana* genome is believed responsible for the vigour and hardiness of the hybrids.

The problem in the application of the technical terms for plantains and cooking bananas also exists in the vernacular names. In western and central Africa where the common starchy bananas belong to the plantain subgroup, *Musa* (AAB group), the use of the term plantain is clear and straightforward. In eastern Africa where the great majority of starchy bananas belong to *Musa* (ABB group), the popular term cooking banana includes the few plantain cultivars present in the region. In Latin America, the Spanish term 'plátano' is confusing; it may refer to plantains, to dessert bananas only, or both, depending on the country.

In South-East Asia, the vernaculars 'pisang', 'saging', 'kluai' and 'chuoi' cover dessert bananas, cooking bananas and plantains. The term plantain is of foreign introduction; there is no equivalent in the local languages of the region. At first, the term was applied to all cooking bananas, including true plantains (the reverse of the situation in eastern Africa). Since the gross morphology of the two subgroups of bananas is quite distinct, this was found confusing and unacceptable. The application of the term is changing and the word plantain is presently restricted to a special group of bananas with long and slender fruits that remain starchy upon ripening and require some form of cooking for the fruits to become palatable. Included in the term is the classical 'Horn' plantain with extra large fruits but with few hands and no male bud. The term is also used for the 'False Horn' plantain which has more hands in a fruit bunch and a small male bud. The third subgroup, which is called 'French' plantain, is the most common in Africa. It has large fruit bunches with medium-sized fingers, many hands and a well-developed male bud. In South-East Asia, two additional subgroups exist, the Asian plantains and the Pacific plantains. The Asian plantain typified by *Musa* (AAB group) 'Laknao' is distinct from the 'False Horn' and the 'Bungaoisan' of the Philippines in having cream-coloured compound tepals, cream fruit pulp and dehiscent bracts. This is different from the common plantains in Africa and Latin America, which have orange-yellow tepals, orange-yellow pulp and persistent bracts. All other gross morphological characters are very similar. In fact, some roadside fruit vendors try to pass off the lower quality 'Laknao' for the higher priced 'Bungaoisan'. The Pacific plantains actually originated in Papua New Guinea but spread to the Pacific islands following the path of Polynesian migrations. Three types are recognized: Maia Maole, Popoulo and Iholena. So, in South-East Asia, all plantains are bananas but not all bananas are plantains!

Ecology Plantains and cooking bananas originated in the humid tropics and perform best under warm (27–30°C) and very wet (200–220 mm per month) conditions. The cooking banana cultivars can stand warmer and drier climates. The best soils are deep, friable loams with good drainage and aeration. High soil fertility and organic matter content are desirable. The crop tolerates pH values of 4.5–7.5. It is sensitive to typhoons which cause blow-downs.

Propagation and planting The fruits are seedless and propagation is asexual; suckers are the primary propagation material used. Tissue culture is becoming popular as a means of disseminating disease-free materials.

Three production systems are common in South-East Asia: home gardens, mixed intercropping and commercial smallholder plantations. There are few large corporate plantations as those in Latin America specializing in the production and export of dessert bananas. Bananas are grown in the home gardens of virtually every farm in the region. A wide range of dessert and cooking banana cultivars are planted for home consumption, the choice depending on the family's quality preferences rather than on productivity. But in mixed intercropping systems and commercial plantations, selection of cultivars is dictated by market demands and productivity. Commercial plantations that specialize in plantains and cooking bananas grow them as sole crops. In mixed intercropping systems, they are grown as a nurse crop for shade-loving plants such as coffee and cacao, or grown under coconut trees. In Papua New Guinea, a traditional AA diploid banana is commonly used as temporary shade for cocoa, while a tough AAB triploid may be found planted under coconut in a permanent stand.

Husbandry The crop receives minimal inputs in home gardens. The mats of banana are generally used as compost and the crop benefits from the decaying organic matter. In commercial plantations, weeding, fertilizing and crop protection practices are applied.

Diseases and pests Plantains are very susceptible to black Sigatoka (*Mycosphaerella fijiensis* var. *difformis*) and require regular fungicidal sprays to prevent premature death of the foliage. Therefore, Asian farmers have shown strong preference for the hardy cooking bananas for staple food. But even these are not immune to diseases, as they succumb to Cordana leaf spot (*Cordana musae*), bugtok in the Philippines and blood disease in Indonesia caused by *Pseudomonas solanacearum* and *P. celebense*. The recent discovery of banana bract mosaic virus (BBMV) attacking 'Saba' and 'Cardaba' in the Philippines is causing concern. It is believed the virus is widespread but undetected in the region.

Plantain cultivars are also the favourite host of weevil borer (*Cosmopolites sordidus*). Cultivars 'Saba' and 'Cardaba' are also affected by root-knot nematode (*Meloidogyne incognita*) but are resistant to the burrowing nematode (*Radopholus similis*).

Harvesting Some plantain cultivars mature and fruit within a year under favourable conditions but most cooking bananas, especially the pure *M. balbisiana* derivatives, take 18 months to harvest.

Yield Yields can be very high, sometimes reaching 50 t/ha per year. However, average yields in home garden production are only from 8–30 t/ha per year.

Genetic resources South-East Asia is host to major banana and plantain germplasm collections. The Regional Banana Germplasm Resource Centre in Davao, Philippines, is the most complete, with 80 distinct cultivars from the Philippines, 35 accessions from Thailand, 29 from Malaysia and 16 from Indonesia. It also has 148 clones from Papua New Guinea. The national collections in Malaysia (MARDI) and Thailand (Kasetsart University) have been classified, and whereas each varietal garden has more than 100 accessions, Malaysia lists 54 and Thailand 39 distinct cultivars. Indonesia has recently launched a nationwide banana and plantain collection and conservation programme and will rehabilitate its germplasm collection garden. Vietnam is building up its germplasm collection in Phu Ho Fruit Research Centre. The wealth of *Musa* germplasm found in Laloki Agricultural Research Station in Papua New Guinea deserves global support, as the materials found there include not only *M. balbisiana*, *M. acuminata* and their hybrids, but also *M. schizocarpa* Simmonds and their putative hybrids with *M. acuminata* which opens a new evolutionary pathway in the domestication of edible *Musa*.

Breeding An unusual situation exists in banana and plantain breeding. Although the wealth of germplasm resources needed in breeding programmes is found in the centre of diversity in South-East Asia, all the major banana and plantain improvement programmes are located outside the region. The International Institute of Tropical Agriculture (IITA), which specializes in plantain breeding, is located in Nigeria. The Fundacion Hondureña de Investigacion Agricola (FHIA), which specializes in dessert banana breeding, is based in Honduras. Since all major diseases and pests such as Sigatoka, Fusarium and banana weevil borer co-evolved with the crop, the progenies of the breeding programmes are not subjected to the extreme disease pressures prevailing in South-East Asia. If it proves impossible to relocate the breeding centres, priority must be given to providing an early screening research facility in the region, for the benefit not only of South-East Asia, but for the entire international banana community. The Maroochy Horticultural Research Station, Nambour, Queensland, Australia, maintains 260 lines of *Musa* from Papua New Guinea in tissue culture. Nine lines have been selected for their resistance to black Sigatoka, fusarium wilt and nematodes. One highly resistant cultivar to black Sigatoka is currently used for breeding plantains in Belgium and Nigeria (IITA).

Prospects The role of plantains and cooking bananas will remain important in South-East Asia. With increasing research facilities and germplasm collections, higher yielding and more disease-resistant cultivars will be developed.

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R.V. Valmayor & M.E. Wagih

Nelumbo nucifera Gaertner

Fruct. sem. pl. 1: 73 (1788).
NYMPHAEACEAE
$2n = 16$

Synonyms *Nymphaea nelumbo* L. (1753), *Nelumbium speciosum* Willd. (1799), *N. nelumbo* (L.) Druce (1913).

Vernacular names Lotus, sacred lotus, Indian lotus (En). Lotus sacré (Fr). Indonesia: terate, seroja, padma. Malaysia: seroja, padema, teratai. Philippines: baino (Tagalog), sukan (Bikol), sukaw (Ilokano). Cambodia: chhu:k. Laos: bwà. Thailand: bua-luang (general), ubon (central), sattabut (central). Vietnam: sen, hoa sen.

Origin and geographic distribution *N. nucifera* originates from continental Asia (possibly India), but is now widely distributed (wild or cultivated) from north-eastern Africa to north-eastern Australia, including South-East Asia, China and Japan. For at least 6000 years it has been associated with Indian culture and religion as a sacred flower. It is also occasionally cultivated as an ornamental in Europe, Africa and America.

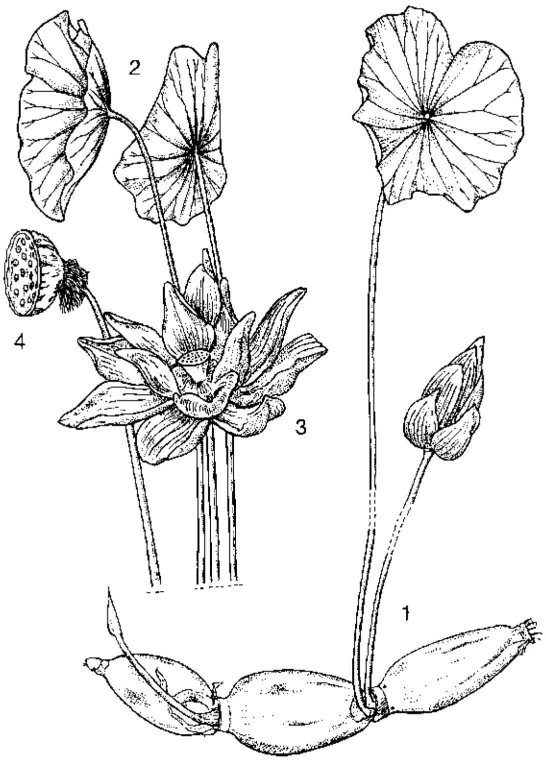
Uses The starchy rhizomes are eaten raw or cooked and are marketed fresh, dried, canned, as flour, pickled or preserved as sweetmeats. They are in demand by Chinese the world over. Unripe seeds are eaten fresh as nuts. Ripe seeds are eaten raw, boiled or roasted, usually with the bitter embryo removed. Before being sold in dried form, the seed coat and embryo are removed. The young rhizome shoots and unexpanded leaves are eaten boiled as a vegetable, and the very young leaves can be eaten raw.

In traditional medicine, lotus has many applications. The Chinese use the rhizomes to treat diarrhoea and dysentery, while the Cambodians use them to make a tea for menorrhagia. Embryos are used in China for reducing fever, for treating cholera, haemoptysis, spermatorrhoea and as a tonic; in Malaysia they are used as an application against fever and are taken as tea. In Indonesia, the petals are given against diarrhoea and vomiting; in Malaysia they are pounded and administered to treat syphilis; the Chinese use them in cosmetic applications; in India they are used against fevers and dysentery, in Cambodia and the Philippines against dysentery. The Chinese apply the stamens as astringent, diuretic and in cosmetics; in India they are applied as astringent and for cooling, and in Indo-China for flavouring tea. In Indonesia and India, the slimy juice from the petioles and peduncles is used to treat diarrhoea. The leaves are convenient wrappers, especially for food to be cooked. In India, the fibres in the petioles are made into wicks for religious lamps and a perfume is extracted from the flowers. Besides its many uses, *N. nucifera* is perhaps most important as an ornamental for the beauty of its flowers and fruits, the latter also in dried form. In India, lotus is the 'national flower'. It is the symbol of divineness, purity, beauty, kindheartedness, fragrance, coolness, fertility, prosperity and is given due prominence by poets, artists, sculptors, architects, and craftsmen.

Production and international trade No statistics are available but lotus is most important in India, China and Japan. In South-East Asia, lotus is grown only for the local market, and seeds and rhizomes are on sale throughout the year. Dried lotus seeds are produced in southern China and exported to many parts of the world where Chinese communities have settled. The seeds are easily available at Chinese sundry shops and medicinal halls in South-East Asia. The fresh, dried or processed rhizomes are also exported by China. Some produce is obtained from natural stands, but most is from cultivation.

Properties Per 100 g edible portion, fresh rhizomes contain approximately: water 80–85 g, protein 2–3 g, fat 0.1–0.2 g, carbohydrates 10–12 g (starch 9–10 g, sugar 1–2 g), fibre 0.5–1 g, ash 1–2 g, Ca 60 mg, thiamine 0.2 mg, riboflavin 0.06 mg, niacin 2 mg, ascorbic acid 15 mg. The starch grains are large, elongated, 65–100 μm long. Dried seeds contain per 100 g edible portion: water 12 g, protein 18 g, fat 2 g, carbohydrates (starch and sugar) 62 g. The embryos contain an alkaloid called nelumbine, which is also found in young leaves and petioles. Other alkaloids isolated are nuciferine, roemerine and nornuciferine.

Description A large, perennial, glaucous, glabrous, aquatic herb, 1.2–2.5 m tall, containing milky latex, rooting in the substrate (usually mud). Rhizomes creeping, jointed, up to 10 m long, 6–9 cm in diameter, interjoints ellipsoidal, 10–30 cm long, white to light brown, fleshy, mucilaginous and slightly fibrous. Leaves peltate, arising from the joints, one per joint; petiole terete, up to 2.5 m long, covered with short fleshy prickles, inside with numerous air canals; blade depressed



Nelumbo nucifera Gaertner – 1, habit with rhizome, mature leaf and flowerbud, and young developing leaf; 2, mature leaves; 3, flower; 4, receptacle with fruits in the cavities.

orbicular or shallowly cup-shaped, up to 90 cm or more in diameter, entire, glaucous above, purplish beneath, raised above the water. Flowers solitary, axillary, projecting above the water higher or as high as the leaves, erect or nodding, 15–25 cm in diameter, fragrant, pink with a white base, rarely entirely white; pedicel erect, terete, up to 2 m long or longer, prickly like the petiole; sepals 2–5, up to 2.5 cm × 2 cm, falling off before anthesis; petals about 20, unequal, obovate, up to 7–15 cm × 3–7 cm, inserted at the base of the receptacle, the outer ones smallest, the intermediate ones largest, the innermost ones medium-sized; stamens numerous, inserted immediately above the corolla, filaments linear, up to 2.5 cm long, anthers yellow; receptacle obconical with a flat apex, 2–4 cm × 3–4 cm, spongy, yellow at anthesis, turning green to finally black-brown and 6–11 cm in diameter; ovaries 10–30, wide apart, sunken in apex of receptacle, free, uniovulate; style short, stigma thickened. Fruit an aggregate of indehiscent nutlets; nutlets 10–30 per aggregate fruit, ovoid-oblongoid, 1–2.5 cm × 1–1.5 cm, black-brown. Seed with one bifid cotyledon and endosperm enveloping the embryo as a thin membrane.

Growth and development Plants raised from seed take longer to flower than those grown from rhizome parts. Under ideal conditions, rhizomes can grow 6–9 m in a season. The plant requires 5–6 years to establish well and to reach the stage of full bloom.

Other botanical information Lotus is often miscalled and confused with the Egyptian sacred lotus, *Nymphaea lotus* L. *Nelumbo nucifera* can easily be distinguished from *Nymphaea* L. by its round peltate leaves mostly reaching high above the water and by its distinct uniovulate carpels embedded in the receptacle. The genus *Nelumbo* Adans. comprises only 2 species and is sometimes separated from the *Nymphaeaceae* as a distinct plant family *Nelumbonaceae*.

The second species is the American lotus, *N. lutea* (Willd.) Pers., occurring in eastern North America, and having smaller leaves and yellow flowers.

Based on flower colour (pink, red or white), flower size (single or double flowers), fragrance, and leaf colour (green or variegated), many cultivars of *N. nucifera* are distinguished. Well-known cultivars include:

- 'Alba': flowers white, large and fragrant.
- 'Alba Plena' or 'Shiroman': a Japanese cultivar with double large flowers, cream with a green centre, turning pure white on the third day, very fragrant.
- 'Chawan Basu': a semi-dwarf cultivar with pink flowers that are white-edged.
- 'Pekinensis Rubra': flowers carmine-pink.
- 'Red Lotus': flowers deep red and large.

Ecology The natural habitat for lotus is freshwater bodies in tropical and subtropical Asia. Lotus grows in old mining pools, natural or man-made lakes, canals and ponds. Because the rhizomes lie deep in the mud under water, they are beyond the reach of frost that would kill them. Therefore, lotus is widely distributed in Asia even in regions not free from frost. It occurs from sea-level up to 1800 m altitude.

Propagation and planting Pieces of rhizomes are usually used as planting material and planted with the buds just above the mud under about 1 m of water. Lotus seed will also easily produce plants, but it takes more time to produce rhizomes of marketable size. From seed, seedlings are raised in nursery beds and planted out after about 2 months. Lotus fruits (seeds) are said to remain viable for more than a century. The fruit wall forms a hard cover protecting the seed. Fruits which have been kept for a long time need to be scarified to stimulate germination of the seed. About 45 kg of rhizome pieces or 10 kg of seed are required to plant one ha.

Husbandry Water weeds like *Eichhornia crassipes* (Mart.) Solms and *Typha* spp. compete with lotus plants and must be removed. Application of organic fertilizer stimulates growth.

Diseases and pests Under natural conditions, lotus is a hardy plant with few serious diseases and pests. Under cultivation, however, two common diseases are leaf spot (caused by *Cercospora* sp. and *Ovularia* sp.) and rhizome rot (caused by *Bacillus nelumbii* and *Fusarium* sp.). Considerable leaf damage can be caused by aphids and beetles. In some areas, the rice root worm (*Donacia provostii*) causes damage. Application of fungicides and insecticides is often not possible because of the danger of killing fish as well.

Harvesting In non-seasonal climates, the flowers, fruits and rhizomes are harvested throughout the year. In seasonal climates, harvesting follows the rainy season. When cultivated in ponds, the rhizomes are dug up by hand after the ponds are drained. Flower buds, picked 2–3 days before opening, withstand long-distance transportation quite well, and are popular among Buddhist and Hindu communities. Lotus fruits are collected when ripe.

Yield In a survey of 12 plots of lotus in the Kinta Valley in the state of Perak, Malaysia, the yield of rhizomes varied from 3.1–8.2 t/ha per season. In Punjab, India, about 62 ha of lotus were reported to produce 3.8–4.7 t of rhizomes per ha.

Handling after harvest Rhizomes are sold fresh in the market or made into preserved sweetmeats. Fresh rhizomes have a shelf life of about 2 weeks. Rhizomes are also dried and made into flour. The wall and embryo of ripe fruits (seeds) are removed before sun-drying. Seed is packed and sold dried or made into flour.

Genetic resources There are no known germplasm collections of *N. nucifera*. The species does not seem to be in danger of genetic erosion.

Breeding Lotus plants for the production of rhizomes are mainly of the pink-flowered type, and rarely of the white-flowered type. Systematic plant breeding concentrating on rhizome number and size may improve production.

Prospects Lotus is one of the few crops that can be cultivated in water bodies of 2 m or more deep, producing food rich in carbohydrates. Others such as rice, Chinese water chestnut (*Eleocharis dulcis* (Burm.f.) Trinius ex Henschel), water chestnut (*Trapa natans* L.) and arrowroot (*Maranta arundinacea* L.), all need shallower water. Lotus can be grown in old mining pools and natural water bodies which would otherwise have no use.

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H.C. Ong

Nypa fruticans Wurmb

Verh. Batav. Genootsch. Kunsten 1: 350 (1781).

PALMAE

$2n = 34$, (?16)

Synonyms *Nipa fruticans* Thunb. (1782), *Cocos nypa* Lour. (1790), *Nipa litoralis* Blanco (1837).

Vernacular names Nipa palm, mangrove palm (En). Palmier d'eau, palmier nipa (Fr). Indonesia: nipah (Indonesian), buyuk (Javanese), bobo (Moluccas). Malaysia: nipah. Papua New Guinea: biri-biri (Koriki). Philippines: nipa (Filipino), lasa (Tagalog), sasa (Bisaya, Ilokano, Bikol). Burma (Myanmar): dane. Cambodia: cha:k. Thailand: chak (general). Vietnam: d[uwf]a n[uw][ows]c, d[uwf]a l[as].

Origin and geographic distribution Nipa palm is one of the oldest angiosperm plants and probably the oldest palm species. Eocene and miocene fossil findings in Europe, North America and the Middle East and the Paleocene strata in Brazil suggest that nipa palm had a pantropical distribution 13–63 million years ago. Today it is mainly found in the equatorial zone, 10°N–10°S, stretching from Sri Lanka through South-East Asia to North Australia. It was introduced to West Africa in the beginning of the 20th Century. The largest natural nipa stands are found in Indonesia (700 000 ha), Papua New Guinea (500 000 ha) and the Philippines (8000 ha). The northernmost natural occurrence is on the Ryukyu Islands of Japan and the southernmost in North Australia. In South-East Asia, nipa palm is also cultivated.

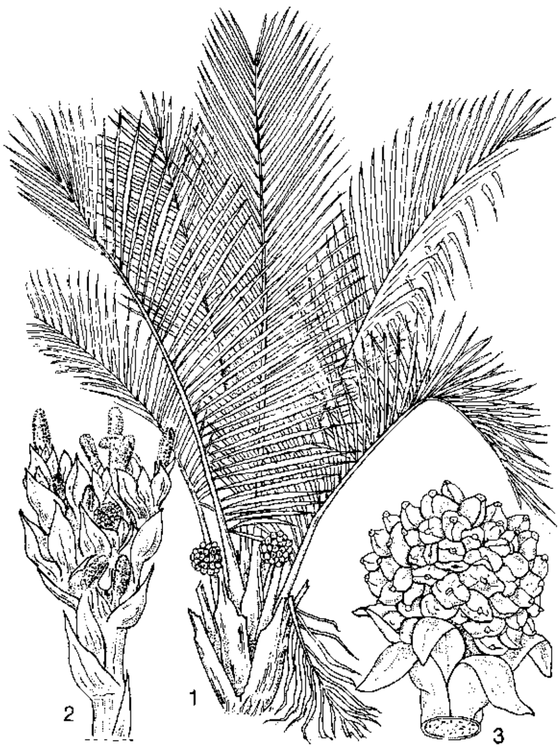
Uses In South-East Asia, there is a long tradition (hundreds of years) of using palm sap obtained by tapping the inflorescence stalks (peduncle) as a source of treacle (molasses), amorphous sugar ('gula malacca'), alcohol or vinegar. The slightly fermented sap called 'toddy' ('nera' in Indonesia and Malaysia, 'tuba' in the Philippines) is sold and consumed as local beer. In Papua New Guinea, there is no tradition of using the sap. The long, pinnate leaves (fronds) provide material for thatching houses. In the Philippines, Malaysia, Indonesia and Thailand the fabrication of thatching panels, called locally 'shingles', 'pawid' or 'atap', is a significant local source of income. Leaflets and midribs are used for manufacturing of brooms, baskets, mats and sunhats. The white endosperm of immature seeds is sweet and jelly-like, and is consumed as a snack. The cuticle of young, unfurled leaves, has locally been used as cigarette wrapping. Various parts of nipa palm are a source of traditional medicines (e.g. juice from young shoots is used against herpes, ash of burned nipa material against toothache and headache) and material for salt extraction. Some early trials to use the endocarp of mature fruits, called 'plant ivory', for the manufacture of buttons failed because they were vulnerable to attack by fungi, and have largely been replaced by plastic materials.

Production and international trade There are no internationally traded products of nipa palm. The production of thatching material, sugar, vinegar, mats and baskets has only local significance. The sugar, produced in family enterprises in Malaysia and Thailand, is used for confectionery and for small-scale production of distilled spirits. Recently, a pilot scheme was established in West Kalimantan (Indonesia) to produce sugar from nipa palm on a larger scale. It is planned to exploit some 10 000 ha. The production of fuel alcohol from nipa palm was seriously studied in the 1920s in the Philippines and Malaysia, and in the early 1980s in Papua New Guinea. Because of the high input of manual labour required to produce fuel alcohol, the process was not economically feasible in Papua New Guinea, whereas vinegar and treacle showed good potential for cottage-industry development. The quality and price of vinegar produced with the method developed, compared favourably with commercially produced vinegars elsewhere.

Properties Fresh nipa palm sap has an average density of 1.076 g per litre in the Philippines and 1.062 g in Papua New Guinea. The dry matter content is 17.0% and 18.3% respectively. The sucrose content of the sap is 15% in the Philippines and 16.4% in Papua New Guinea, and the corresponding nitrogen contents are respectively 0.049 g and 0.030 g per litre. In Papua New Guinea, the fresh sap has a pH of about 7.5 as it drips from the peduncle.

The leaves of nipa palm are rich in fibres, which make them particularly lasting for weaving and thatching material. The average life-time of 'shingles' is a few years. Leaves may also contain up to 10% tannin.

Description A large, creeping, unarmed, pleonanthic, monoecious palm. Stem prostrate or subterranean (rhizome), up to 45 cm in diameter, branching dichotomously at regular intervals, with curved leaf scars above, and roots along the underside. Leaves in tufts of 3–5 per plant, erect, 4.5–14.2 m long, simply pinnate; petiole very stout, up to 1.5 m long, channeled adaxially, terete distally, dilated towards the base into a short sheath; leaflets up to 163 per leaf, linear, single-fold, 1.2–1.5 m × 6.5–8.6 cm, coriaceous, midrib bearing appressed brown scales on lower surface. Inflorescence solitary, interfoliar, erect, branched, multibracteate, protogynous, up to 2.1 m long with a stout, terete, up to 2.4 m long peduncle; rachis usually shorter than the peduncle,



Nypa fruticans Wurmb – 1, habit; 2, inflorescence; 3, infructescence.

terete, terminating in a globose head of female flowers surrounded by numerous, short, catkin-like rachillas (spikes) terminating the lateral branches and bearing densely crowded, spirally arranged, solitary male flowers; most branches subtended by large, tubular, rubbery bracts protecting flowers and fruits; male spikes usually in pairs, cylindrical, often slightly curved, up to about 5 cm long; flowers extremely dimorphic but 6 perianth parts similar for both sexes; male flowers with 3 stamens, filaments united into a column, without pistillodes; female flowers without staminodes; carpels (pistils) 3, distinct, much longer than perianth, irregularly polyhedric, curved and angled, with a funnel-shaped stylar opening. Fruiting head subglobose, up to 40 cm in diameter, fertile and partially developed fruits intermixed; fruit a drupe, developing from 1 carpel, compressed and irregularly angled, pyramidal, 10–15 cm × 6–8 cm, brown to blackish, exocarp smooth, mesocarp fibrous, endocarp thick and composed of interwoven fibrous strands. Seed broadly ovoid, grooved adaxially, hilum basal, endosperm homogeneous. Germination is on the infructescence (viviparous), with the plumule exserted and pushing the fruit away; eophyll bifid or with several leaflets.

Growth and development After maturing, the fruits are usually pushed off from the infructescence by the developing plumule. They float on tidal water and start growing on suitable substrate. The radicle is probably aborted and the first root that appears is likely to be the first adventitious root. The seedling is prostrate first, but after being attached to the substrate, the plumule becomes erect and additional adventitious roots arise from the lower part of the stem. In very young seedlings the leaves are arranged distichously but later they become arranged spirally. At first, up to 8 bladeless sheaths develop per plant, followed by the first juvenile foliage leaves 3–6 months after germination. During early growth the stem grows obliquely downwards until it is about 1 m deep in the ground (rhizome). About 1 year after germination the rhizome starts branching dichotomously and a new plant develops vegetatively on each branch. This branching pattern gives rise to the nipa palm 'colony' structure of a mature stand, in which older rhizome parts decay simultaneously and dichotomous divisions produce new plants. There is also a constant decay of old leaves and formation of new ones throughout the life of a nipa palm, which is estimated to be about 50 years. First flowering occurs 3–4 years after germination. Pollination is effected by flies. In a mature nipa palm stand, normally about one quarter to one half of the palms flowers or fruits randomly. The fruits mature in 5–9 months. In young fruits the endosperm is liquid, becoming solid in older ones. Frequently, more than one infructescence develops simultaneously per plant. In Papua New Guinea, the weight of one infructescence is 6–30 kg and its circumference 1.1–1.4 m, bearing 88–133 individual fruits.

Other botanical information In South-East Asia, the size of the nipa palm varies: in the Philippines plants are smaller than in Papua New Guinea and Malaysia. In Malaysia, 2 forms of nipa palms are distinguished, 'nipah gala' and 'nipah padi', differing in the tilt of the leaflets. No cultivars have been developed.

With its prostrate, dichotomously branched stem and its erect inflorescence bearing a terminal head of female flowers and lateral spikes of male flowers, nipa palm occupies a unique position in the *Palmae*. It is considered an advanced palm species, with a very long history; possible relations with the genera *Pandanus* L.f. and *Sararanga* Hemsley (both from the *Pandanaceae*) have been suggested.

Ecology Nipa palm is a tropical plant. The average minimum temperature in its growing areas is 20°C and the maximum 32–35°C. Its optimum climate is subhumid to humid with more than 100 mm rainfall per month throughout the year.

Nipa palm thrives only in a brackish water environment. It is rarely seen directly on the seashore. Optimum conditions are when the base and the rhizome of the palm are regularly inundated by brackish water. For this reason, nipa palm occupies estuarine tidal floodplains of rivers. The optimum salt concentration is 1–9 per mil. Nipa palm swamp soils are muddy and rich in alluvial silt, clay and humus; they have a high content of various inorganic salts, calcium, and sulphides of iron and manganese, contributing to the typical odour and dark colour. The pH is around 5; oxygen content is low with the exception of the topmost layers.

Typically, nipa palm forms pure stands, but in some areas it grows mixed with other mangrove trees. In the understorey some *Acanthus*, *Acrostichum* and *Crinum* species are found.

Propagation and planting Generative propagation is by seed (fruit) and vegetative propagation is through dichotomous branching of the rhizome. In Papua New Guinea, the 'pocket and channel' method has been used successfully to propagate nipa palm. It involves placing fruits directly into 10–20 cm deep pockets along the edge of irrigation channels. In the Philippines, seedlings are first grown in a seed-bed and then transplanted into pockets. Spacing is 1.5–2 m, eventually thinned to about 400 plants per ha. Natural stands of nipa palm are usually dense; in Papua New Guinea 2000–5000, in the Philippines up to 10 000 plants per ha occur.

Husbandry When utilized for sap production, very dense natural nipa palm stands should be thinned and cleared of old leaf debris. These operations increase the amount of light, improve the flowering frequency, and extend the flowering period as well. Wider spacings apparently improve production.

In palms tapped for sap, the cutting of leaves for thatch will reduce yield. Preferably, old leaves should be cut out before they fall off, because they might injure the peduncles of other palms in their fall.

Diseases and pests Nipa palm suffers from few diseases and pests. Rats in Papua New Guinea and pigs and monkeys in northern Borneo may damage the peduncles. In Malaysia, damage of young peduncles by weevils was avoided by removing the rubbery bracts at an early stage of fruit development when preparing the stalks for pretreatment and tapping. Grapsid crab is the main pest of young seedlings.

Harvesting Tapping of nipa palm can start from the development of the second inflorescence onwards, when plants are about 5 years old. Before sap can be obtained, peduncles must be pretreated or 'gongchanged'. The modality, frequency and duration of this treatment varies. The most detailed and recent account is from Papua New Guinea, where the optimum frequency was 4 times a week during 10 weeks. The treatment consists of bending the peduncle of the infructescence 12 times, patting along the length of it with hands 64 times and kicking its base 4 times. The treatment can be performed at various stages of development, starting 2–6 months after flowering. The infructescence is then chopped off. To ensure sap flow the cut surface of the peduncle should be renewed, 'shaved', by slicing 1–2 mm off, twice a day. An internode of bamboo or another container is hung or tied to the peduncle to collect the sap. The duration of sap tapping depends on the length of the peduncle. In Papua New Guinea, the individual peduncle can be tapped for 100 days, in Malaysia for 340 days, in Indonesia for 300 days and in the Philippines for 60 days. Contradictory information exists on the number of peduncles per plant that can be tapped simultaneously. Early studies showed that 2–4 peduncles per plant can be used, but later experience in Papua New Guinea indicates that it is preferable to tap only one per plant.

When palms are harvested for thatching material, mature leaves may be cut off near the ground, on condition that 2–3 leaves are left on the plant.

Yield In Papua New Guinea, sap yield per plant in 24 hours is 1.3 l, in Malaysia 0.47 l, in Indonesia 2.5 l and in the Philippines 1 l. In Indonesia annual sap yield per ha can be 168 500 l, in Papua New Guinea 169 000 l, in Malaysia 140 000 l and in the Philippines 126 000 l. Cloudy weather decreases transpiration and increases sap yield but high soil salinity has a decreasing effect. Yield also decreases near the nodes of the peduncle; genetic factors may also be involved. Young stands of nipa palm may be higher yielding than old ones, albeit there is no reliable method for estimating the exact age of a nipa palm.

It has been calculated that 15–20 t of sugar per ha per year can be obtained from nipa palm as compared with 8–9 t from sugar cane.

Handling after harvest When sap is collected in a bamboo container, fermentation starts quickly. The alcoholic fermentation is completed within 30 hours, resulting in an alcohol content of 6.2–9.5%. Thereafter, the spontaneous acetic acid fermentation proceeds. This process is utilized in the Philippines, where vinegar is produced by natural acid fermentation. The acid content, however, remains low (2–3%) as compared with the simple surface film method, using pure *Acetobacter* species, developed in Papua New Guinea. There, the final acetic acid content was 6.2–7.2% and the product could be diluted to a 4% commercial product.

The ease with which sap sugar inverts from sucrose into glucose and fructose, and the beginning of fermentation of the sap are disadvantages in sugar making. Various methods of inhibiting the inversion have been tested, including sterilizing the bamboo containers by heat and alcohol. The latter was successfully used in Papua New Guinea, where after 17 hours, the alcohol content of the sap was less than 0.5%, meaning a loss of less than 1% of sucrose. Earlier, the addition of lime, potassium or sodium bisulphite or sulphite, copper sulphate or acetate or formaldehyde had been tested.

Genetic resources and breeding No germplasm collections are available and there seems to be no actual need to start breeding in nipa palm.

Prospects Nipa palm has a good potential for sugar, vinegar and alcohol production. The sugar is already available in the form of sucrose. Sap is in liquid form, so there is no residual bagasse problem as with sugar cane. Nipa palm also occupies lands that are unsuitable for other food crops. Tapping can be carried out all the year round, thus minimizing seasonal labour movement and associated social problems. The disadvantages of exploiting nipa palm include the high demand for manual labour (5 per ha) as compared with sugar cane, and the difficulty of getting machinery into wild stands because of the soft soils and fluctuating water levels. For a nipa palm sugar industry to be developed successfully, non-toxic methods must be developed to inhibit rapid inversion of sucrose and fermentation of the sap. Further research is needed to clarify the physiological mechanisms that regulate sap flow and the effect of pretreating the peduncle. These might prove to be the keys in the effort to decrease the high demand for manual labour in utilizing nipa palm.

Potentially, nipa palm might become an energy crop, since it can produce annually about 11 000 l of alcohol per ha. This is substantially more than the production obtained from sugar cane (5 500 l) and cassava (1350 l). But, while prices on the world market for fossil energy remain low, it will not be a serious alternative.

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A.E.A. Päivöke

Pachyrhizus erosus (L.) Urban

Symb. Antill. 4: 311 (1905).

LEGUMINOSAE

$2n = 22$

Synonyms *Dolichos erosus* L. (1753), *Pachyrhizus angulatus* Rich. ex DC. (1825), *P. bulbosus* (L.) Kurz (1876). Sometimes erroneously spelled '*Pachyrrhizus*'.

Vernacular names Yam bean (En). Chop suey bean, jicama (Am). Dolique bulbeux, pois batate (Fr). Indonesia: bengkuang (general), besusu (Javanese), bangkowang (Sundanese). Malaysia: sengkuwang, bengkuwang, mengkuwang. Philippines: sinkamas (Tagalog), kamias (Ilokano). Cambodia: pe' kuëk. Laos: man ph'au. Thailand: man-kaeo (general), huapaekua (peninsular), man-lao (northern). Vietnam: c[ur] d[aaj]u (northern), s[aws]n (southern).

Origin and geographic distribution Yam bean originated in Mexico and Central America as far south as Costa Rica. The crop has been known in cultivation in this region from approximately 1000 BC. The yam bean was originally introduced to the Far East by the Spanish via the Acapulco–Manila route, reaching Amboina prior to the end of the 17th Century. *P. erosus* is presently found in cultivation (or escaped and naturalized) pantropically.

Uses The tubers are mostly consumed fresh in salads or lightly fried. In Indonesia, the young tubers are sliced and eaten raw in a mixture of immature fruits with a sweet and pungent sauce ('rujak'), or cut into small cubes as an ingredient of fruit cocktails. In Mexico, they are commonly consumed fresh, sliced and sprinkled with chili and lime juice, or cooked in vegetable soups. As the speciality vegetable on the United States market with the most rapidly increasing demand, *P. erosus* is sold in supermarkets and salad bars, used in vegetable salads and chop suey. Older tubers from plants grown for seed production or rejects are used as fodder for cattle and pigs. A highly digestible starch may be obtained from old tubers. The immature pods are used locally in South-East Asia as a vegetable. The oil from the seed can be used just like cottonseed oil.

The insecticidal compounds rotenon and rotenoids may be extracted from mature seeds. The seeds may also be ground and used as an insecticide or to poison fish with no residual effects. The vegetative parts of the plant may be used as a high protein fodder after the tubers have been harvested, or serve as a green manure.

Production and international trade The only reliable statistics concerning production area and trade are from Mexico where about 10 000 ha are cultivated annually for export to the United States at prices reaching US$ 2.50 per kg. As the crop is usually either marketed locally or grown directly by consumers (this applies to Mexico as well as South-East Asia and China), few statistics are available. Judging from the readily available tubers in most South-East Asian countries, however, the production area must be considerable.

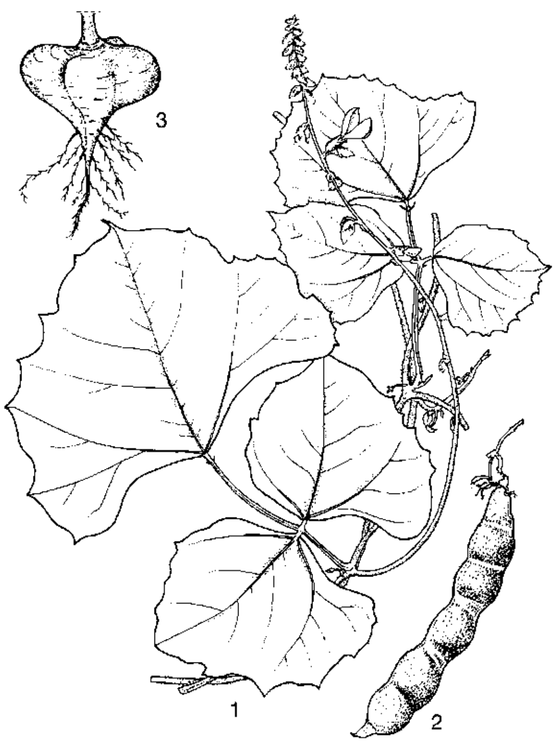
Properties Depending on cultivar, 100 g edible portion of 5–8-months-old tubers contains approximately: water 80–90 g, protein 1.0–2.5 g, fat 0.2 g, carbohydrates 10–17 g, fibre 0.5–1.0 g, ash 0.5–1.0 g, vitamin C 18 mg. The energy value averages 197 kJ/100 g. The high quality starch contained in older tubers has a grain diameter of 8–35 μm.

Per 100 g edible portion, immature pods contain: water 86 g, protein 2.6 g, fat 0.3 g, carbohydrates 10 g, fibre 2.9 g, ash 0.7 g, vitamin C 27 mg.

Mature seeds contain about 30% fatty oils, 0.5–1.0% rotenon and 0.5–1.0% rotenoids. The fatty oils have a quality comparable to cottonseed oil. The foliage contains less than 0.01% rotenon and rotenoids; the tubers are free of these toxic substances.

The weight of 1000 seeds ranges from 150–250 g, depending on the cultivar.

Description Perennial, herbaceous, strigose to hirsute, climbing or trailing vine, 2–6 m long. Roots tuberous, in cultivation one turnip-shaped tuber per plant, in wild types numerous elongated tubers per plant; tubers of cultivars up to 30 cm × 25 cm, skin cream or light to dark brown, flesh white to whitish-yellow. Leaves trifoliolate, strigose, with dentate, palmatilobed or entire leaflets; lateral leaflets obliquely rhomboidal to ovate, 2.5–10.5 cm × 2.5–18 cm, 3-veined from the deltoid base; terminal leaflet ovate to reniform, 3.5–17.5 cm × 4–21 cm, 3–5-veined from the cuneate base. Inflorescence a many-flowered pseudoraceme, up to 55 cm long; pedicel hirsute, up to 1(–2) cm long with caducous and sericeous prophylls; flowers 1–2.5 cm long; calyx brown, hirsute both internally and externally, about 1 cm long, upper lobe formed by 2 adaxial sepals fused almost to the tip, 2.5–7.5 mm long, tube 2.5–6.5 mm long, the 3 lobes acute and shorter than the tube; corolla violet-blue or white; standard, auriculate wings and keel glabrous; stamens about 1–2 cm long, anthers elliptical and dorsifixed; ovary subsessile, multiovulate, with a crenulate disk



Pachyrhizus erosus (L.) Urban – 1, habit of flowering plant; 2, mature fruit; 3, tuber.

round its base, style recurved and ventrally ciliated, stigma with subglobose vertical surface. Fruit a legume, linear-oblong, 6–13 cm × 8–17 mm, septate between seeds internally, slightly to deeply contracted between seeds externally, strigose to hirsute when young, often glabrous at maturity. Seed flat, square to rounded, 3–9 mm × 4–9 mm, olive green to brown or dark reddish brown. Seedling with hypogeal germination; first pair of leaves simple and usually entire.

Growth and development Germination occurs 5–12 days after sowing, depending on cultivar. Flowering is initiated 2–3 months following germination, depending on cultivar and climate; however, since yam bean is short-day sensitive, time of flowering varies with daylength. The flowering period usually lasts 1–2 months. *P. erosus* is self-pollinated, although 2–4% cross-pollination does occur.

The yam bean is inoculated mainly by *Bradyrhizobium* strains, but inoculation by *Rhizobium* strains also occurs. The irregular nodules form clusters (sometimes large) on the lateral roots and occasionally directly on the surface of the tuber; the latter is not desirable.

Tuber growth is initiated about 7 weeks after germination; rapid growth occurs from week 10–15 and coincides with the flowering period. The peak tuber growth is reached after 20 weeks. Marketable tuber size is reached after 4.5–7 months, depending on cultivar and climate. The growing period needed for seed production is 8–10 months, the tubers from these plants are usually of inferior quality.

Other botanical information In West Java, two different yam bean cultivars are distinguished: 'Huwi hiris', with small, sweet tubers and 'Bangkowang' with larger tubers; the latter is also cultivated for green manure. In Thailand, both early and late cultivars are grown. Cultivars used in the main production areas in Mexico differ in sap quality: the Nayarit-type tubers have a milky sap, whereas the Guanajuato-type tubers have a watery sap. The latter are preferred by consumers in the United States.

Ecology Yam bean is quite tolerant of differences in climatic and edaphic conditions, but is generally associated with regions having moderate precipitation (often seasonal) or high precipitation with well-drained soils. In Mexico, it grows up to 1400 m altitude. Optimum daytime temperature level is (21–)24(–28)°C with daylength approaching 12 hours. However, field trials indicate that the nocturnal temperature may be as important in obtaining optimal yields. Both tuber growth and flowering are initiated by decreasing daylength (and night temperature). A well-drained soil, alluvial or volcanic, is preferable, as the crop does not tolerate waterlogging. In areas with high precipitation, cultivation on ridges is recommended.

Propagation and planting Yam bean is mainly grown from seed. In northern Thailand, yam beans are planted at the beginning of the early monsoon rains in June–July, while in the north-east, the planting is delayed until July–August (if an early cultivar is used) or August–September (when using a late cultivar); in the eastern-central area, planting takes place in November–December in order to obtain the highest economic returns. In central Thailand, the plant densities used are high: 50–120 cm between ridges (or seedbeds), 7–12 cm between rows and 4–12 cm between plants. The seeding rate in Thailand ranges from 60–180 kg/ha. When introducing the crop to a new field, it is recommended to inoculate the seeds with a suitable *Bradyrhizobium* strain prior to planting.

In the two main areas of cultivation in Mexico, the states Guanajuato and Nayarit situated at the same latitude, the cultivation periods are virtually opposite: in Guanajuato at 1700 m above sea-level, planting takes place in January–March with harvesting in September–November, whereas in Nayarit at 0–100 m altitude, planting takes place in October–November with harvesting following in February–March.

The recommended spacing in Guanajuanto is 80 cm between ridges and 2 rows per ridge with 20 cm between rows and 20 cm between plants; this gives a plant population of 103 000 plants/ha (about 35 kg seed/ha). In Mexico the same plant density is used when growing yam beans either for seed or for commercial tuber production.

Most yam bean in Thailand is cultivated as a sole crop. However, some farmers in the central area intercrop it with coriander (*Coriandrum sativum* L.). The coriander, used as a culinary herb, is gradually harvested during the first 45 days when the yam bean crop is producing a good ground cover. In West Java, yam bean is often intercropped with staked yard-long bean (*Vigna unguiculata* (L.) Walp. cv. group Sesquipedalis). Intercropping with maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) is the traditional cultivation practice in Mexico and Central America. The 3 crops are planted simultaneously on ridges, with 2 rows of yam bean (like a commercial sole crop), the common bean (20 cm between plants) between the 2 rows of yam bean on every ridge and the maize (1 m between plants) also between the 2 rows of yam bean, but on every second ridge. The common beans are harvested after about 90 days, yielding about 0.5 t/ha and the maize is harvested after 110–120 days, yielding 1–2 t/ha.

Husbandry Usually weeding by hand is practised once or twice during the first 1–2 months, until good ground cover has been achieved. When grown on a large scale as a sole crop, weeding is mechanized. Although various reports mention the beneficial effect of trellised cultivation of yam bean on yields, this has not been confirmed in field trials carried out in Tonga (South Pacific) or in Costa Rica. However, when grown for seed production, trellising yam bean facilitates harvesting and may lead to increased seed yield. Reproductive pruning (the removal of fertile shoots) is commonly practised 1–3 times during the flowering period in order to increase tuber size. Thinning is not practised.

The crop is irrigated in some areas. In Thailand overhead irrigation is usually used, while surface irrigation is the common practice in Guanajuanto, Mexico.

Fertilizing is practised in Thailand, usually 180–300 kg/ha, in 1–2 applications during the first 20–30 days after sowing (or just after the first weeding) and the same amount in a later application at the time of the first reproductive pruning. In Mexico, the crop is never fertilized. In some areas in Thailand, a green manure crop is grown prior to yam bean. Both in Thailand and Mexico the crop is usually grown in rotation with maize.

Diseases and pests A mosaic virus, probably a strain of bean mosaic virus, transmitted by aphids (*Aphis* spp.) or mealy bugs (*Ferrisia virgata*) and possibly by seed, results in smaller-sized tubers (yield reductions of 20–30%), discoloured leaves and brittle stems. Occasionally, plants suffering from witches' broom disease have been observed in Tonga, apparently from contamination originating in the indigenous flora.

Several pests have been reported damaging the leaves, the most serious being the rose beetle (*Adoretus versutus*) in Tonga; *Diabrotica* spp. have caused extensive damage in some cultivars.

In some parts of Central and South America, various bruchids (*Bruchus* spp.) cause severe damage to seed while attacking the young and immature pods. Seed yield may be reduced by as much as 70%.

Harvesting In both Thailand and Mexico, the tubers are lifted manually, usually after using a chisel plough along the ridges (in Thailand) or a 'subsoiler' equipped with a crossbar (in Mexico) in order to loosen up the soil.

The marketable size varies according to consumer preferences. In Thailand as in most of South-East Asia, preference is for smaller-sized tubers weighing 0.2–0.4 kg, whereas Mexican and American consumers prefer large-sized tubers of 0.5–2 kg. Old, oversized tubers and rejects are used for livestock feed.

In areas with a seasonal climate, or in irrigated fields where irrigation can be withheld, tubers may be left in the field for up to 3 months after maturity before being lifted. Lifting after heavy rainfall or irrigation is not recommended, especially when temperature is high, as this may cause the tubers to crack or to split.

In Mexico, dried yam bean hay is mixed with maize and lucerne hay (*Medicago sativa* L.), passed through a roughage mill and fed to livestock.

Crops grown for seed production are generally harvested after 8–10 months, depending on the cultivar. The pods are left to dry in the open when possible until they split open. The use of mechanical shellers is not widespread because, as the seed tends to be somewhat fragile, the percentage of damaged seed is too high.

Yield Under irrigated conditions, tuber yields range from 40–90 t/ha in Thailand and from 70–100 t/ha in Mexico. Under rainfed conditions yields in Thailand range from 20–40 t/ha and from 40–60 t/ha in Mexico. Maximum yields in experimental fields amount to 80 t/ha (rainfed, Benin), 105 t/ha (rainfed, Tonga), 148 t/ha (rainfed, Costa Rica) and 160 t/ha (surface-irrigated, Mexico). In Tonga, a field trial yielded 72 t/ha (rainfed), giving a dry matter yield of 7.2 t/ha. At 7.4% crude protein this yields 540 kg of crude protein per ha.

Seed production in Thailand ranges from 480–600 kg/ha, in Mexico from 500–1000 kg/ha.

Handling after harvest After the tubers have been washed and sorted according to size, they can be stored for 1–2 months at a recommended temperature ranging from 12.5–17.5°C at 65–75% relative humidity. The starch content declines to about 2/3 of the value at harvest when stored at 12.5°C for 2 months and to 1/3 after 3 months storage. The level of total soluble sugars rises correspondingly during storage. The rate of water loss is 0.12% of the initial weight per day at 12.5°C and 0.21% per day at 22°C.

Genetic resources The neotropical genus *Pachyrhizus* Rich. ex DC. comprises 5 species, of which *P. erosus*, *P. tuberosus* (Lamk) Sprengel and *P. ahipa* (Wedd.) Parodi are cultivated. The germplasm collection at the Department of Botany, Dendrology and Forest Genetics at the Royal Veterinary and Agricultural University, Copenhagen, Denmark, includes some 200 accessions representing all species and more than 400 interspecific hybrids.

Breeding When selecting new lines, Mexican breeders grow the breeding materials as a commercial crop, i.e. with reproductive pruning at commercial planting density. The best tubers are then selected at harvest and replanted at a much lower planting density in order to produce seed the following season.

Breeding for photothermal-neutral cultivars is currently in progress. This is accomplished by combining the best *P. erosus* cultivars identified in field trials with the best photothermal-neutral genotypes belonging to either *P. tuberosus* or *P. ahipa*. In addition to photothermal neutrality, the resulting interspecific hybrids exhibit a combination of the yield capacity of *P. erosus*, with either the earliness and bushy erect habit of *P. ahipa* or the vigour and tolerance to excess precipitation of *P. tuberosus*. Amazonian *P. tuberosus* materials in particular possess several attractive agronomic traits for the breeding of new cultivars for the humid tropics. Some of these rare landraces have a higher dry matter content and are used as an attractive and more nutritious alternative to cassava (*Manihot esculenta* Crantz) by several Amazonian tribes.

Prospects Yam bean is a promising leguminous tuber crop for the humid tropics. Although already established in many areas of South-East Asia, yam bean might successfully be introduced to many humid zones at present regarded as unsuitable, through breeding efforts involving *P. tuberosus*.

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M. Sørensen & W.C.H. van Hoof

Plectranthus rotundifolius (Poiret) Sprengel

Syst. veg. 2: 690 (1825).

LABIATAE

$2n = 64, 84$

Synonyms *Coleus tuberosus* (Blume) Bentham (1832), *C. parviflorus* Bentham (1848), *Solenostemon rotundifolius* (Poiret) J.K. Morton (1962).

Vernacular names Madagascar potato, Hausa potato, country potato (En). Pomme de terre de Madagascar (Fr). Indonesia: kentang Jawa (Indonesian), kentang ireng (Javanese), huwi kentang (Sundanese). Malaysia: ubi kembili, ubi keling. Thailand: man-khinu (southern), man-nu (southern).

Origin and geographic distribution The origin of *P. rotundifolius* is thought to lie in Madagascar or tropical Africa, but at present it is only known from cultivation. It is frequently cultivated in Madagascar, tropical and southern Africa, Sri Lanka, India, throughout continental Asia to Peninsular Malaysia, Sumatra, Java, the Moluccas and possibly in the Philippines.

Uses The aromatic tubers are eaten as a delicacy, cooked or steamed, often with rice, but sometimes raw. Young tubers (white) are often used in soups or in vegetable dishes. A meal made from adult tubers is used in Indonesia as a substitute for Irish potatoes in the preparation of mincedmeat balls, or cooked with palm sugar and coconut milk. Cooked leaves are eaten as a vegetable.

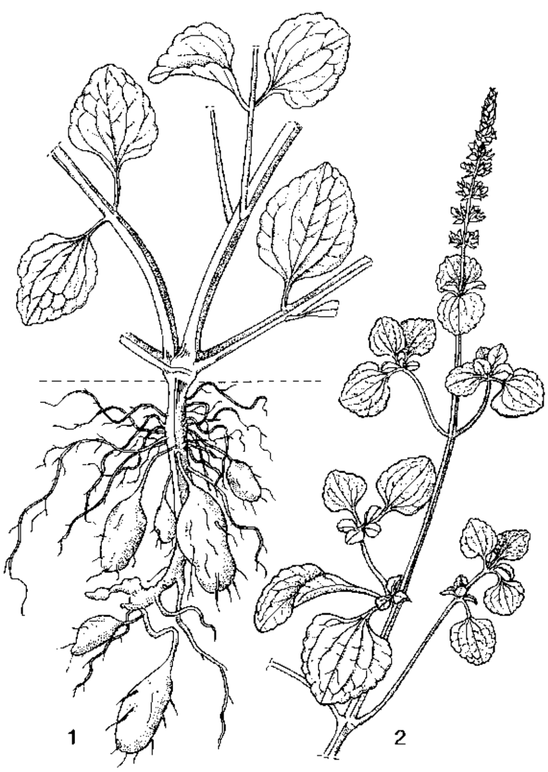
In Africa, the tubers are regarded as a most suitable substitute for Irish potatoes. There they are also used against dysentery and certain eye diseases.

Production and international trade *P. rotundifolius* is primarily a home garden crop which is only traded locally if at all. No production or trade statistics are available.

Properties The approximate composition of 100 g fresh tubers is: water 73–78 g, protein 1.3–1.5 g, fat 0.3–0.6 g, carbohydrates 20–23 g, fibre 0.4–0.9 g, ash 1 g, Ca 17 mg, Fe 6 mg, thiamine 0.05 mg, riboflavin 0.02 mg, niacin 1 mg, ascorbic acid 1 mg.

The starch has potential as a binding or disintegration agent in tablet formulations (medicines).

Botany Perennial, aromatic, semi-succulent herb, up to 1 m tall, cultivated as an annual. Roots producing ovoid to oblongoid sessile potato-like tubers, up to 4.5 cm × 1.5 cm, blackish, brownish, reddish-grey or whitish, with rough skin. Stem decumbent or ascending, quadrangular, densely pubescent on the angles, rooting at the nodes. Leaves rather thick, juicy, faintly aromatic when bruised, opposite; petiole 1–3(–5) cm long, puberulous; blade ovate to suborbicular, 2–6 cm × 1.5–4 cm, cuneate at base, margin coarsely crenate, apex puberulous, dotted with glands below. Inflorescence a terminal false spike, 5–15 cm long, with verticillasters of 4–6 flowers; pedicel 1–2 mm long; bracts small; calyx campanulate, 1.5–3 mm



Plectranthus rotundifolius (Poiret) Sprengel – 1, habit; 2, flowering and fruiting shoot.

long, glandular-hispid, 5-toothed, upper tooth oblong, acute, median teeth very short with rounded apex, lower teeth highly connate forming an almost truncate apex but ending abruptly in 2 widely apart acute tips; corolla tubular and 2-lipped, 7–12 mm long, light to dark violet, pubescent and dotted with glands, tube strongly curved, upper lip very short and 4-lobed, lower lip boat-shaped; stamens 4, curved within the lower lip, up to 2.5 mm long, shortly united at base and enveloping the style; style 2-fid, slightly exceeding the stamens. Fruit unknown.

Flowering occurs between February and August. Normally the crop reaches maturity in 5–8 months.

P. rotundifolius is a variable species and several varieties have been distinguished, based mainly on tuber colour (e.g. var. *javanicaminum* A. Chev. with blackish tubers). However, as a cultivated species, subclassification into cultivar groups and cultivars seems more appropriate. In the literature some confusion exists about the identity of species belonging to the so-called *Coleus-Plectranthus* complex. Here the view of Flora Malesiana is followed, in which only one large genus *Plectranthus* L'Hérit. is recognized. Synonymous genera involved are: *Germanea* Lamk, *Coleus* Lour., *Solenostemon* Schumacher, *Rabdosia* Hassk., *Majana* Kuntze, *Isodon* (Bentham) Kudo. Distinguishing characteristics are mainly based on the stamens and the calyx, but some intermediate species exist, making distinction doubtful.

Other tuber-bearing species that are sometimes confused with *P. rotundifolius* are:

- *Plectranthus esculentus* N.E. Brown (synonyms: *Plectranthus floribundus* N.E. Brown, *Coleus dazo* A. Chev., *C. esculentus* (N.E. Brown) G. Taylor): the kafir potato, occurring wild and cultivated in tropical and southern Africa, with yellow flowers and corolla 14–16 mm long.
- *Plectranthus edulis* (Vatke) Agnew (synonyms: *Coleus tuberosus* A. Rich., *C. edulis* Vatke): the Galla potato, occurring wild and cultivated in East and Central Africa.
- *Plectranthus barbatus* Andr. (synonyms: *Coleus barbatus* (Andr.) Benth., *Plectranthus comosus* Sims): occurring wild and cultivated in East and Central Africa and India, occasionally also cultivated elsewhere.

Ecology *P. rotundifolius* is preferably grown in tropical high rainfall lowlands, rarely up to 1000 m altitude. Evenly distributed rainfall and low night temperature favour tuber development. The crop cannot stand waterlogging. Well-drained sandy loams are preferred, but heavy clays are unsuitable. In South-East Asia it is often planted on dry rice fields after rice.

Agronomy *P. rotundifolius* is propagated by stem cuttings. The cuttings are usually raised by planting selected tubers in well watered nursery beds. The tubers start sprouting in 10–15 days and the cuttings can be taken after about 3 months. Cuttings 15–30 cm long are usually planted out on ridges. Coiling the lower part of the cuttings before planting stimulates rooting. Planting distance is about 20 cm between cuttings and 90 cm between ridges. Weed control is done about 3 weeks and 7 weeks after planting. NPK fertilizer (125 kg/ha) and cattle manure (25 t/ha) are recommended. To promote tuber production the rooted cuttings are earthed up about 2 months after planting if not planted on ridges.

P. rotundifolius has no serious diseases and pests. Caterpillars occasionally attack the leaves.

Tubers can be harvested when the leaves begin to wither. Harvesting should not be delayed long because mature tubers deteriorate rapidly if left in the soil. They can be stored for some time in dry sand in a cool well-ventilated room. Yield of tubers normally ranges from 7.5–15 t/ha, but may attain 18–20 t/ha.

Genetic resources and breeding No comprehensive *P. rotundifolius* germplasm collections and breeding programmes are known.

Prospects *P. rotundifolius* deserves more scientific attention. It is now subordinate to other starchy food crops such as cassava and sweet potato, but its easy propagation and its disease resistance make it an interesting tuber crop for the lowland tropics. The properties of the starch make its possible use in pharmacy worth investigating. Germplasm collection is urgently needed to start breeding for high-yielding cultivars.

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P.C.M. Jansen

Saccharum officinarum L.

Sp. pl.: 54 (1753).
GRAMINEAE
$2n = 80$

Vernacular names Sugar cane (En). Canne à sucre (Fr). Indonesia: tebu (general), tiwu (Sundanese), tep (Halmahera). Malaysia: tebu. Papua New Guinea: ale, kowu, tuma. Philippines: tubo (Tagalog, Bikol), tubuh (Tausug). Cambodia: 'âmpëu. Laos: 'o:yz. Thailand: oi (general), oi-daeng (central), ka-thi (Karen, Mae Hong Son). Vietnam: m[is]a.

Origin and geographic distribution Sugar cane originated in New Guinea where it has been known since about 6000 BC. From about 1000 BC it spread gradually through the Malay archipelago. It is assumed that it then hybridized with the wild canes of India and China. It reached Hawaii between 500–1000 AD and the Mediterranean between 600–1400 AD. From there it was brought to the Caribbean and the Americas in the 16th and 17th Centuries. Currently, cane is being produced in almost 70 countries, mainly in the tropical zone but to some extent also in subtropical areas. In South-East Asia, the main cane sugar producing countries are Thailand, the Philippines, Indonesia, Malaysia and Papua New Guinea.

Uses Sugar cane is cultivated for its stem (cane). The main product of sugar cane is sucrose, constituting about 10% of the crop. Sucrose is a highly valued food and sweetener but also serves as a preservative for other foods. Moreover, it provides the basis for various food products and beverages.

The fibrous residue of cane, bagasse, is mostly used as fuel for the generation of energy needed for sugar manufacture. However, it can also serve as raw material for fibre and particle board, plastics, paper and furfural. For these purposes, the fibre is separated from the pith which can, in turn, be used as a feed. Filter cake, consisting of juice impurities and lime (CaO), is mainly used as a soil amendment; sometimes waxes are extracted from the cake.

Molasses, left over after centrifuging the sugar crystals, is used as a feed; converted into a proteinic substance, it is used as a fertilizer or for the production of yeast, CO_2 and various acids such as essential amino acids for animal feeds, e.g. L(-)lysine. However, it is mostly processed into potable and industrial alcohols.

A more recent development is the direct production of industrial ethylene, not requiring refining and crystallization, in response to the energy crisis of the 1970s and the subsequent steep rise in oil prices. Brazil was particularly active in this development, but since the decline in oil prices no new investment has been deemed necessary.

Production and international trade From 1986–1993, the annual world cane sugar production gradually increased from 62.8 million t to 79.2 million t raw value. In 1992, Indonesia produced 2.35 million t from 418 000 ha, Malaysia 105 000 t from 200 00 ha, the Philippines 1.92 million t from 350 000 ha, Thailand 5.08 million t from 915 000 ha and Papua New Guinea 30 000 t from 6000 ha. In 1992, consumption of cane sugar in Indonesia was 2.7 million t, in Malaysia 715 000 t, in the Philippines 1.6 million t, in Thailand 1.3 million t and in Papua New Guinea 27 000 t.

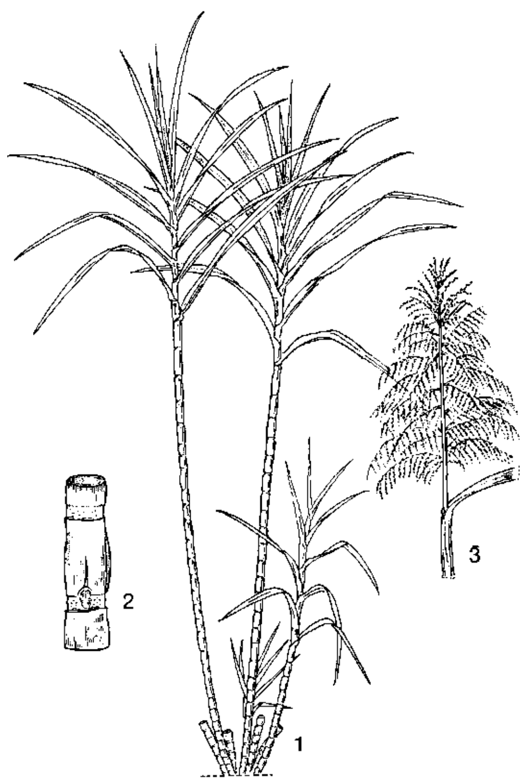
Exports in 1992 were 212 500 t from the Philippines, 3.7 million t from Thailand, and 7000 t from Papua New Guinea, whereas Indonesia imported 41 000 t and Malaysia 900 000 t. Sugar cane by-products provide a significant additional income, especially important in periods of low sugar prices on the world market.

Properties The sugar sold on the world markets is valued according to colour, size of granules, polarization, and ash and moisture content. Most sugar is sold as coarse or fine granulated raw sugar with a purity of 97–99%. 'Plantation white' sugar for direct consumption has a purity of 99–99.5%, while refined sugar's purity is virtually 100%.

Besides centrifugal sugar, various products obtained by traditional processing methods can be found in almost all cane-growing countries. The traditional cane sugar known as 'gula jawa' and 'gula mangkok' in Indonesia, 'panocha' in the Philippines, and 'jaggery' or 'gur' in the Indian subcontinent, has an average composition of 3.5–9.5% water, 50–85% sucrose, 2.3–15.6% glucose and other sugars, 2.0–3.5% ash and some proteins and aromatic substances.

Description A large, perennial grass up to 6 m tall. Root system large, but concentrated in the upper 60 cm of the soil, adventitious. Stem robust, profusely tillering at base, 2–5 cm in diameter, and divided into 10–40 internodes; internodes long or short, swollen, spindle-shaped, conoidal, obconoidal, or cylindrical. Leaves borne at nodes, alternate in two rows on either side of the stem; sheath tubular, encircling the stem; ligule varying in cultivars, linear, deltoid, crescent-shaped or arcuate; blade linear, 70–200 cm × 3–7 cm, tapering, thick at the centre and paper-thin at the margins, rolling up under moisture stress conditions. Inflorescence a terminal panicle, 25–50 cm long; two spikelets borne at each node of ultimate branches, one sessile and one pediceled; spikelet consisting of two boat-shaped glumes, surrounded by long, silky hairs, and two flowers; lower flower sterile with a single glume, upper one bisexual with a small, thin palea, enfolded by the glume of the sterile flower, 2 lodicules, 3 long stamens and a pistil with 2 feathery, usually purplish stigmas. Fruit a small caryopsis, about 1 mm long.

Growth and development Within 1–3 weeks the buds of planted cuttings start to germinate while set roots (primordial roots) start to grow from the cutting's root band. These set roots gradually die and are replaced by shoot roots growing from the basal part of the shoot. After germination, secondary and subsequently tertiary shoots develop. Each cane stool can consist of 1 primary, 3 secondary and 3 tertiary stalks, depending on the growing conditions. The tillering period starts at about 1.5 months after planting and continues for 1.5–3 months, depending on the cane cultivar. Late tillers (suckers) may develop before harvest (at 8–10 months). They are thick and succulent. They grow especially where light can freely enter, e.g. at field edges and in lodged cane. After the cane canopy has closed, fewer tillers will develop and most existing cane stalks elongate further. Their growth is influenced by the production of leaves and consequently of internodes. The time lapse between the formation of subsequent leaves is known as the 'plastochrone'. Under favourable growing conditions, the plastochrone is 5–7.2 days long and under unfavourable conditions it is 2 or more weeks. The growth period of cane in South-East Asia is 6–8 months and is related to water availability.



Saccharum officinarum L. – 1, habit of plant; 2, part of stem; 3, inflorescence.

The final stage of sugar cane development is the ripening stage, and 11–14 months after planting, maximum sucrose content of the fully grown stalk will be reached. This stage can be recognized by reduced growth of the stalks and by yellowing of the leaves. With increasing maturity, the sucrose content rises, especially in the top part of the stalk. Whereas in earlier stages, sugar is accumulated mainly in the bottom part, there is hardly any difference in sucrose content between the top and bottom parts at full maturity.

Other botanical information Besides *S. officinarum*, four other *Saccharum* species have been used for sugar production or as hybridization material for commercial cane breeding. *S. officinarum* is known as 'noble cane' and has a high sucrose content, low fibre content, long and thick stems, and long and broad leaves.

- *S. barberi* Jeswiet ($2n$ = 82, 90, 124), known as 'Indian cane'. The sucrose content is medium, the fibre content high. The plant is semi-early maturing, has slender and medium long stems, with short and narrow leaves. It originated in India but was distributed early and was the major cultivated species in America until the 19th Century.
- *S. robustum* Brandes & Jeswiet ex Grassl ($2n$ = 70, 80, 84). The sucrose content is low, the fibre content very high. The plant matures early or late, and has very long and thick stems, with broad leaves of medium length. It is indigenous in New Guinea and adjacent islands in Melanesia. It probably gave rise to *S. officinarum*.
- *S. sinense* Roxb. ($2n$ = 116, 118), known as 'Chinese cane'. The sucrose content is medium, the fibre content high. The plant is semi-early maturing, has long and slender stems, with long and narrow leaves. It is thought to be a hybrid between *S. officinarum* and *S. spontaneum* and is found in India, Indo-China, southern China and Taiwan.
- *S. spontaneum* L. ($2n$ = 54, 112, 118), known as 'wild cane', is used for hybridization purposes. The sucrose content is very low, the fibre content very high. The plant is early maturing, has slender but short and hard stems, narrow leaves, and is resistant to most cane diseases. It occurs wild from eastern and northern Africa through the Middle East to India, China, Taiwan and throughout South-East Asia.

Cane breeding for commercial cane is carried out in Indonesia, the Philippines and to some extent in Papua New Guinea. Commercial cane cultivars produced are POJ and PS (Pasuruan, Indonesia), CAC and Phil (Philippines) and NG (Papua New Guinea). At present the major cultivars in Indonesia are PS 56 and PS 58, and two imported ones, i.e. M (Mauritius) 442-51 and F (Formosa) 154. The major cultivars in the Philippines are Phil 56-226 and Phil 66-07, and in Thailand Q 83 (Australia), F 140 and local cane cultivars Chainant 1 and Uthong 1.

Ecology Sugar cane, being one of the most efficient natural converters of solar energy and carbon dioxide (C4-cycle photosynthetic pathway), makes optimum use of arable land. Its photosynthetic efficiency is 20 times higher than the average world's biomass production. However, it needs high temperatures. The optimum temperatures are 26–33°C for germination and 30–33°C for vegetative growth. During maturation, a period with relatively low night temperatures (below 18°C) is conducive to the formation of a high sucrose content.

Sugar cane thrives under full sunlight where its leaves saturate at about 10 750 lux and the compensation point is approximately at 430 lux. It is a quantitative short-day plant; a daytime period of 12–14 hours is optimum for growth and flowering. An average rainfall of 1800–2500 mm/year is desirable. If rainfall is insufficient, water should be supplemented by irrigation. Vegetative growth is promoted by a uniform and high precipitation; during maturation the cane requires a marked dry spell in order to reduce growth and induce sugar accumulation. Air humidity is of little importance for cane development.

At high altitudes, the potential to grow cane is limited because lower temperatures, particularly during the night, retard growth and development, although they increase the sugar content. Within the South-East Asian region, the maximum altitudinal limit for normal cane growth is 600–700 m above sea-level. At higher altitudes longer growth cycles of 14–18 months must be adopted.

Sugar cane thrives on a wide variety of soil types, but deep, friable and well-drained soils with a pH of 5–8, ample nutrient and organic matter contents and a good water-holding capacity are most suitable. Some cane cultivars can stand relatively high soil salinity and an extended period of deep inundation, especially in flowing water. Being a vegetative crop, sugar cane requires large quantities of nitrogen, although potassium, phosphorus, calcium and silica are also in relatively large amounts. Trace elements play an important role in the development of cane. Insufficient availability of each of these elements may cause growth disorders. The related symptoms, however, may be mistaken for those of diseases and mechanical damage.

Propagation and planting Generally sugar cane is vegetatively propagated by cuttings of mature stalks. Each cutting or 'seed set' usually has 2–3 buds. The cuttings are put down horizontally and covered with a thin layer of soil. There are three kinds of plant materials, i.e. top cuttings, stem cuttings and 'rayungans'. Top cuttings are 'seed sets' taken from plants in the upper part of the stalks of recently harvested cane. Stem cuttings are 'seed sets' taken from plants in special nurseries at about 6–8 months of age. Whole cane stalks can also be planted; because of top dominance these are cut up into 'sets' in situ, using an ordinary cane knife. 'Rayungans' are obtained by removing leaves and top ends of seed cane in the field, the buds of which are then allowed to germinate on the standing cane stalk. When the new shoots have attained a certain length, the cane is cut into sets and planted. These pregerminated sets are excellent planting material but vulnerable during handling and transport and very labour-intensive to produce.

True seed of sugar cane is only used for the purpose of breeding new cultivars.

'Seed sets' are planted in a narrow planting furrow which should have good tillage. They are covered with a thin layer of soil from the interrow. These planting furrows can be made on flat land or on the bottom of an irrigation/drainage furrow. In wet sites, planting may be on the top of the ridge between the furrows. Alternatively, planting is mechanical: the stalks are cut into pieces, disinfected, fertilized, planted and covered with soil in one go. Irrigation water is usually applied before or immediately after planting. The multiplication rate of cane is about 8–10, i.e. a nursery of 1 ha is needed to plant 8–10 ha of cane.

Cane is usually planted as sole crop. However, in areas with light soils and sufficient irrigation water, cane is intercropped, e.g. with maize, groundnut or soya bean. In such cases the intercrops are planted on the ridges and the cane is planted 3–4 weeks later in the furrows.

After levelling the land and determining the direction of the cane rows, the land is disk-ploughed to a depth of 30–40 cm and harrowed into a fine tilth. If required, irrigation furrows with a depth of 25–30 cm and a spacing of 1.10–1.30 m are made for hand-cultivated cane. For mechanical cultivations, a minimum furrow distance of 145 cm is required (minimum wheel base of tractors).

In irrigated rice fields in Java, the 'Reynoso' method is followed for preparing the land for sugar cane. This highly labour-intensive method, necessary for a good aeration of the heavy soil, consists of digging 30–45 cm deep and 35–45 cm wide trenches. In between these trenches high ridges of dug-up soil are created.

The planting time is early in the dry season for irrigated fields; unirrigated fields are planted at the onset of the rainy season.

Husbandry Weed control is carried out manually, chemically and mechanically. Where sufficient labour is available, weeding is carried out at 3–4 week intervals with 3–4 weedings per season. In areas with less labour, herbicides are applied, sprayed twice, at 1–2 weeks after planting and 4–6 weeks later. The chemicals commonly used are one or two of the following: diuron, ametryne, atrazine, paraquat + diuron, or asulam + atrazine, mixed with 2,4-D amine salt. Other herbicides, e.g. pre-emergence ones, may also be used. Mechanical weed control, if economically more justified, is done with tractor- or bullock-drawn cultivators.

Irrigation water, if necessary, is supplied every 2–4 weeks to the cane rows in the case of furrow irrigation, and to the cane on flat land or in small furrows in the case of sprinkler irrigation. When the cane grows taller, more water has to be applied, but intervals between the applications need not always be shortened.

Fertilizers are given twice, the first application during planting or one week later, the second application 4–6 weeks later. The fertilizers commonly used are urea or ammonium sulphate as N source at rates of 120–180 kg/ha, triple superphosphate as P source at 45–180 kg/ha and muriate of potash as K source at up to 180 kg/ha. In newly established sugar cane fields, additional applications of dolomite at 1 t/ha and limestone at 1–4 t/ha are given every three years. Actual application rates for each fertilizer depend on physical soil conditions and fertility.

In most cane fields the cane rows are earthed up 1–2 times by hand or mechanically. On the heavy clay soils of Java this is even done several times. Eventually the cane stands on ridges separated by furrows. This practice stimulates root growth, consolidates the cane stools and improves drainage on the heavy clay soils. On the lighter textured soils it helps against early lodging of cane and can prevent erosion (if the direction of the furrows is chosen well).

The official rotation of crops, particularly in farmers' cane on irrigated fields in Java, is conducted in such a way that 2 consecutive cane crops (planted cane and first ratoon) are followed by maize, soya bean or groundnut, and later by rice. In other areas 4–6 ratoons are maintained, after which the old stubble is ploughed-up and the field replanted to cane again. Ratoon management after harvesting the previous crop consists of stubble shaving, burning the cane residues and trash, trash raking, filling the gaps with top cuttings, fertilizer application at 0.5–1.5 month after stubble shaving, and, if necessary, subsoiling the interrows. Weed control usually follows immediately after fertilizer application.

Diseases and pests Four major sugar cane diseases are encountered in the South-East Asian region: mosaic virus disease, ratoon stunting disease (caused by the bacterium *Clavibacter xyli* var. *xyli*), yellow spot (*Cercospora koepkei*) and rust (*Puccinia melanocephala*). Growing cane cultivars resistant or tolerant to these diseases is considered an economic and effective control measure. Hot water treatment (at 50°C for two hours or at 52°C for 20 minutes) of seed canes is a satisfactory control measure for ratoon stunting disease. If not controlled properly, both mosaic virus and ratoon stunting disease may depress sugar yield by 10%, especially in ratoons. In Papua New Guinea, a previously unknown etiology disease ('Ramu stunt disease') was first recorded in 1985; it severely reduced growth and yield.

Major pests attacking sugar cane are the stem borer *Chilo sacchariphagus*, the top borer *Scirpophaga nivella* var. *intacta*, the woolly aphid *Ceratovacuna lanigera*, and the rat *Ratus-ratus argentiventer*. Satisfactory control of the stem borer can be achieved by releasing the larvae parasite *Diatraeophaga striatalis* and the egg parasites *Trichogramma* spp. Partial control of the top borer is achieved by treating the soil and injecting the cane plant whorl with carbufuran granules. The woolly aphid is controlled with insecticide (dimethoate and monocrotophos) fogging, or at the initial infestation by releasing *Encarsia flavoscutellum* parasites. Every 5–6 years rat explosions occur, mainly attacking food crops and sugar cane. Distribution of anti-coagulant poisoned baits can control the plague in sugar cane crops.

Harvesting The harvest time of sugar cane for most Indonesian sugar factories is between May and October. In the Philippines and Thailand, the harvesting season is from November to March/April. The cane is cut and loaded manually, hand-cut and grab-loaded or loaded in bundles by chains pulled by a tractor. Mechanical harvesting by chopper harvesters or whole-stalk harvesters has not yet been adopted on a large scale. Burning before cutting is not practised, except in several areas in the Philippines.

Yield Average sugar yields in 1992 were 7.86 t/ha in Indonesia, 5.62 t/ha in Malaysia, 6.62 t/ha in Papua New Guinea, 8.27 t/ha in the Philippines, 6.11 t/ha in Thailand, 4.13 t/ha in Vietnam, and 4.53 t/ha in Burma (Myanmar). The average world sugar yield is 5.16 t/ha.

Handling after harvest Production processes in sugar mills are as follows:
- Extraction of juice from the cane by passing the cane through crushers or shredders and subsequently through a 3–5 roller tandem. At each roller unit the crushed cane is subjected to an imbibition process by addition of water or cane juice. Alternatively, shredded cane is passed through a diffuser in which sugar is extracted from the cane by osmosis and lixiviation at increased temperatures. The juice eventually obtained, which is turbid and slimy, is then sieved through fine-mesh copper or stainless steel gauze in order to remove mechanical impurities.
- Purification of juice by precipitating non-sugar constituents by treatment with sulphurous acids and phosphoric acids or surface active substances such as silicious earth (sulphitation process). Another method is treatment with a large excess of lime followed by heating (carbonation process). The flocculated impurities are then separated from the juice during the filter process.
- Crystallization of thickening juice is carried out under vacuum in the evaporation and boiling station. With a vacuum of 710 mm Hg and a temperature of 60°C, the extraction of water proceeds rapidly and sugar crystals soon begin to form.
- Centrifuging is conducted in cylindrical or conical drums whose walls are lined with perforated copper or stainless steel gauze. The sugar crystals are separated from the mother liquid at rapid rotation (800–1400 rpm).
- The sugar is packed by bagging either directly from the grasshopper conveyors or after passing rotating driers and cooling towers.

Genetic resources Global germplasm collections exist in Cannanore (Coimbatore, India) and in Canal Point (Florida, United States). A minor collection from the Indonesian archipelago is present in Pasuruan (Java, Indonesia); it consists of wild canes, such as *Erianthus* spp., *Miscanthus* spp., *Saccharum barberi*, *S. robustum*, *S. sinense*, *S. spontaneum*, and cultivated cane *S. officinarum* and their hybrids; the collection has been used worldwide by sugar research institutes for breeding purposes.

Breeding The main breeding objectives are to develop cane cultivars with the following characteristics: high and stable cane yield, high sucrose content, good ratooning ability, resistance to major diseases and pests, and tolerance of adverse environmental conditions, especially water stress. Furthermore, cultivars should not require exact harvest scheduling and should have desirable characteristics for local farmers, e.g. self-trashing and erect stalks.

Prospects Cane sugar underwent severe competition from other sweeteners in the early 1980s. Recently, however, the demand for sugar as compared with high fructose syrup sources is expanding. It seems to be regaining its former public acceptance as a natural sweetener with a stable form and chemical composition and without health hazards. Consumption may rise with higher incomes, especially in developing countries with relatively high population increases and low sugar consumption levels.

The development of sugar cane by-products offers new and very promising prospects. Recently, demand for animal feeds originating from cane and sugar by-products has increased. Japan is interested in silage from dry cane leaf tops while the EU countries have a significant demand for fodder yeast. Sugar as a primary chemical raw material can be used for the production of a wide range of derivatives such as esters, ethers and urethanes. These again can be used as components of synthetic resins and for the production of solvents, various acids, polysaccharides, amino acids, antibiotics and gases. One of the most promising developments is ethanol production, a renewable energy fuel as a substitute for dwindling fossil fuel. A recent development is the use of by-products of monosodium glutamate, itself a by-product of sugar cane processing, as liquid organic N fertilizer.

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Solanum tuberosum L.

Sp. pl.: 185 (1753).

SOLANACEAE

$2n = 4x = 48$

Synonyms *Solanum esculentum* Neck. (1768), *S. cultum* (A. DC.) Berth. (1911), *S. tuberosum* L. subsp. *tuberosum* [(L.) Hawkes] (1956).

Vernacular names Irish potato, English potato, white potato (En). Pomme de terre (Fr). Indonesia: kentang. Malaysia: ubi kentang. Papua New Guinea: poteto (Pidgin). Philippines: patatas (Filipino), papas (Tagalog). Cambodia: dâmlô:ng barang. Laos: man fàlangx. Thailand: man-farang (central), man-alu (northern). Vietnam: khoai t[aa]y.

Origin and geographic distribution The species of *Solanum* are considered native to Central and South America, mainly to the highland plains ('puna') and Andes mountains between 40°N to 45°S. The cultivated potato probably originated in the Peru-Bolivia region at least 8000 years ago, and spread rapidly through the Andean highlands during ancient civilization. The potato was introduced into Europe during the latter half of the 16th Century. It was then spread throughout the world, more particularly in the temperate regions of the northern hemisphere, especially continental Europe and the former Soviet Union.

During the 18th and 19th Centuries the potato was introduced into several tropical and subtropical countries, including the South-East Asian region, mainly by colonists from Europe. Most recently, it was introduced into Papua New Guinea in the early 1930s, where it is now a popular cash crop in the highlands at altitudes above 1500 m.

Uses Worldwide, tubers of the potato crop are used for direct human consumption (48%), processing (11% of which 2% is for the production of starch), vegetative propagation (13%), stock feed (20%), and the remaining 8% is waste. Worldwide the use of potatoes for alcohol production is negligible, but can be important in some locations. Consumption per capita in the developing countries of Asia and Oceania is low but rising.

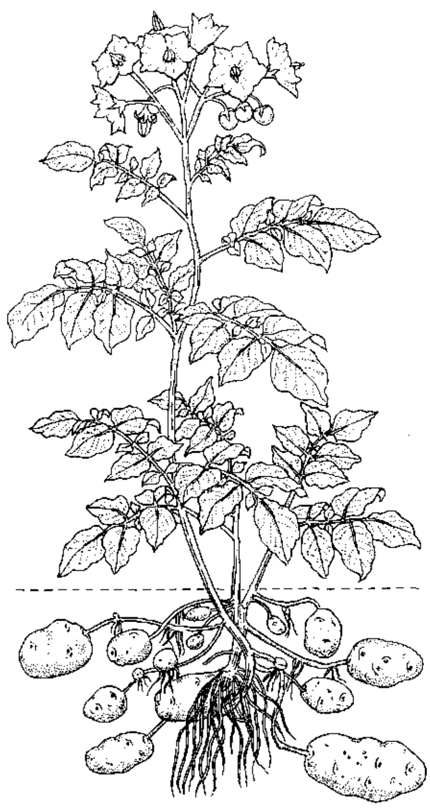
Potato tubers are consumed in many forms. Whole, they may be boiled, roasted or steamed in their skins; they may be peeled and then boiled or steamed and mashed with margarine, butter, or dripping, with or without milk, or they may be baked or roasted. Large quantities are consumed fried as chips (French fries, pommes frites), or as thinly sliced crisps. In many Asian countries, potatoes are part of various curry dishes. The fairly good storing ability of the raw tuber, in addition to processing into many forms of dehydrated, frozen and canned tubers, results in a supply reasonably independent of season. This and the simple cooking methods contribute to potato's importance as a major world crop.

Production and international trade Total world potato production is nearly 270 million t (1990). Production in Asia is nearly 65 million t, including China with over 33 million t. By contrast, production in Oceania is only 1.4 million t, of which Australia and New Zealand produce over 1.3 million t. Production in South-East Asia is 1.0 million t. Potato production in Papua New Guinea remains negligible. The world total potato export is estimated at nearly 8 million t. Asian exports are nearly 1 million t. Oceania potato exports amount to nearly 33 000 t, virtually all by Australia and New Zealand.

Properties The published analyses of potato's chemical composition and nutritive value are not strictly comparable. Considerable losses of constituents also occur during different preparation and cooking methods. In general, potato is competitive with other foodstuffs as a rich source of energy, high quality proteins and substantial amounts of vitamins, minerals and trace elements.

The freshly harvested, raw tuber consists of 20–25% dry matter, of which 65–80% is starch. Per 100 g the raw, edible portion of the tuber contains: water 77 g, protein 2.1 g, carbohydrates 18.5 g, fibre 2.1 g. It also contains niacin 1.5 mg, thiamine 0.1 mg, riboflavin 0.04 mg, ascorbic acid 20 mg, Ca 9 mg, P 50 mg, K 410 mg, and Fe 0.8 mg. Its energy value averages 335 kJ per 100 g. The tubers also contain a number of phenolic compounds, which are partly responsible for certain types of discolouration in raw or processed products, especially after bruising. In addition, potato contains about 0.01–0.1% (on a dry matter basis) of a steroid alkaloid, solanine, which is toxic. Solanine is mainly concentrated in the skin and exposure to light increases the amount present.

Description Erect, juicy herb with numerous fleshy, robust, angular, branched stems up to 1.2 m tall and subterranean tubiform stolons. Root system usually 40–50 cm deep, without obstructions up to 1 m. Tubers developing at the tip of the stolons, globose to ellipsoid, very variable in size, weight and colour; tuber skin with scars of scale leaves ('eyebrows'), axillary buds ('eyes', usually several eyebuds per eyebrow), numerous lenticels, almost impermeable to chemicals, gases and liquids, providing good protection against micro-organisms and water loss; number of eyes very variable, normally about 10–15 on a tuber of 50 g.



Solanum tuberosum L. – habit.

Stem up to 1.5 cm in diameter, usually hollow, winged; wings sometimes decurrent and undulate-crenulate. Leaves alternate, petiolate, odd-pinnately compound, with or without numerous interstitial leaflets, in outline 10–30 cm × 5–15 cm; lateral leaflets opposite or alternate, usually 3–4 pairs, very unequal in size, largest ones stalked, ovate to ovate-elliptical, 2–10 cm × 1–6 cm, smallest ones subsessile, ovate to suborbicular, 1–15 mm in diameter; terminal leaflet usually largest; all leaflets thinly to densely pubescent, dark green, pinnatinerved. Inflorescence a many-flowered cymose panicle, sometimes with small bracteoles; peduncle 5–15 cm long, branching above; pedicel up to 3.5 cm long, articulate at or above the middle; flowers white or white suffused with pink or violet, typically with a greenish-yellow central star; calyx campanulate, 1.5–2 cm in diameter, deeply 5-partite, pubescent outside; corolla subrotate to rotate-stellate, 2–4 cm in diameter, with 5 acuminate lobes, finely veined, pubescent outside; anthers 5, 5–7 mm long, free, erect but slightly curved around the style, yellow, opening by 2 apical pores, each on a short, thick filament; style up to 13 mm long, stigma clavellate to capitate. Fruit a subglobose berry, up to 2 cm in diameter, yellow-green, 2-carpellate, many-seeded, poisonous. Seed flat, subcircular to ovate, 1–3 mm in diameter, pale yellow-brownish.

Growth and development The general growth and development pattern of potato plants are characteristic within cultivars, but also vary with the environment and fertilizer treatments.

After harvest, tubers usually enter a period of dormancy, meaning that the buds do not start to grow when exposed to favourable conditions (e.g. darkness, 20°C and high humidity). The duration of dormancy depends on cultivar, maturity of the tuber, soil and climatic conditions during growth, and storage conditions. It often lasts for 2–4(–6) months, but in some cases bud growth has already started before harvest. High temperatures during growth and storage tend to shorten dormancy and low temperatures prolong the dormancy period.

Dormancy can be broken by treating tubers with chemicals such as chlorhydrin, thiourea, or gibberellic acid. However, naturally sprouted tubers without the use of chemicals are preferred, as they give a more uniform germination and better growth. Once the period of natural dormancy has ended, the seed tuber passes through various subsequent physiological stages: apical dominance of sprouts, multiple sprouting, and senility. An apical sprout is dominant over the other buds, so these remain dormant. Only when this apical or top sprout is removed (de-sprouting) will the other buds of the tuber develop sprouts during this phase. The degree of apical dominance depends on the cultivar. The optimum stage for planting is multiple sprouting, not only because of the number of sprouts, but also because of the vigour of individual sprouts. The number of eyes per tuber depends mainly on tuber size and cultivar, the number of sprouts (germinating eyes) per tuber strongly depends on environmental conditions. After prolonged storage seed tubers may reach the stage of senility and have then become unfit for planting.

After planting, sprouts develop into stems. A main stem grows directly from the seed tuber. The lower lateral branches from the main stem are called secondary stems. Apart from secondary stems, a stem may develop branches at higher nodes several times during its growth. Main and secondary stems grow and behave like independent plants, and develop roots, stolons and tubers. Plant population is, therefore, best expressed as number of stems, rather than number of plants.

In plants growing from tubers, adventitious roots arise from the nodes of the underground stems. Plants grown from true seed develop a slender taproot with lateral branches.

The tuber is a modified stem which develops by the swelling of the tip of an underground stem (stolon).

The length of the growing period mainly depends upon cultivar, amount of fertilizer (particularly N) and climatic conditions. In South-East Asia, cultivars generally mature in 3–5 months.

Other botanical information *S. tuberosum* is a complex species with diploid, triploid and tetraploid representatives. It is mainly known in cultivated state and it is quite questionable whether it has existed or still exists in the wild. The tetraploid plants are most important worldwide; they are classified into two cultivar groups:

- cv. group Andigena (synonym: subsp. *andigena* Hawkes), mainly occurring in South America from Venezuela to northern Argentina and is supposed to have originated from unknown wild diploid species from the Andean region between Bolivia and Venezuela, by doubling of the chromosome numbers. Its members are tall, often straggling; leaves intensively dissected with numerous leaflets; adapted to short days; they usually produce rather irregularly shaped, deep-eyed and often pigmented tubers that are usually not acceptable in the more sophisticated markets of Europe and North America. To a very small extent they are also grown in Mexico and Guatemala.

- cv. group Tuberosum (synonym: subsp. *tuberosum*), mainly occurring in Europe and North America, supposed to have originated from selections during the last 300 years from cv. group Andigena. Its members are smaller, less straggling, leaves less dissected; adapted to long days. This group has become a world crop and is now cosmopolitan in distribution. It was first introduced into Europe where selection began and from where cultivars spread to North America. With growing interest in the crop, supplementary introductions from South America were made to both these regions. Continuing selection has led to the establishment of numerous cultivars, a process still going on wherever the crop is grown. Cultivars vary in characteristics of their tubers, sprouts, foliage, flowers, growth cycle and disease resistance; much of the variability is also influenced by the environment. Propagation by true seed, however, produces variability due to genetic recombination.

Ecology Potato requires a well-distributed rainfall of 500–750 mm in a growing period of 3–4.5 months. Most commercial cultivars of potato tuberize best in cool climates with night temperatures below 20°C. Little or no tuberization occurs at night temperatures above 22°C. Optimum day temperatures for dry matter production are within the range of 20–25°C. High light intensities favour dry matter production through their effect on photosynthesis. Short daylengths (12–13 hours) lead to earlier maturity.

In the short daylength conditions of the tropics and subtropics, maximum yields can usually be obtained in cool highland areas and in cooler seasons. In Papua New Guinea, optimum growth of potato takes place at altitudes between 1500 and 2200 m above sea-level, where day temperatures are about 25°C and night temperatures about 20°C.

Potato is tolerant of a rather wide variety of soils, except heavy, waterlogged clays. Good drainage is of great importance. Impermeable layers in the soil limit rooting depth and the amount of available water, and so greatly reduce yields. Deep soils with good water retention and aeration give best growth and yields. The most suitable soil pH is between 4.8 and 7.0. At higher pH, tubers are liable to suffer from scab disease.

Propagation and planting Potato is normally propagated vegetatively by small (40–100 g) tubers, called 'seed tubers' or 'seed potatoes'. It can also be propagated by pieces of tuber ('seed pieces') or by true seed. The seed rate (tubers) ranges from 1.5–4.0 t/ha. The first problem facing growers in developing countries is that of obtaining supplies of healthy planting material of a suitable cultivar at an acceptable price. In many countries there are no provisions for local propagation of tubers and the import of seed potato is expensive and poorly organized. Some countries undertake traditional propagation of the seed tubers on sites in the highlands with suitable cool but frost-free climates and where the population of insect vectors of diseases can be kept at an adequately low level.

Another line of development is that of plant tissue culture. In recent years a variety of rapid multiplication techniques has been developed based on tissue culture. These techniques start with in-vitro multiplication of disease-free plantlets by nodal cuttings. Subsequently, pathogen-free plants are raised from in-vitro plantlets transplanted to insect-free greenhouses to produce high quality seed potatoes. Alternatively, mini-tubers are produced from in-vitro plants planted at high plant densities. These mini-tubers are then planted in isolated fields or otherwise protected from insects to produce normal size seed potatoes. The next phase is for seed potato farms and private seed growers to conventionally multiply these seed tubers. Optimal planting and crop management techniques ensure high multiplication rates and high health status. In various countries, including Vietnam and Papua New Guinea, this scheme has resulted in a gradual change from dependence on seed imports for field planting to self-sufficiency.

Other useful methods of propagation are the production of micro-tubers through in-vitro tuberization of plantlets, and rapid multiplication methods by means of sprout cuttings, single-node cuttings, stem cuttings and leaf bud cuttings. These rapid multiplication methods are used to multiply healthy plant material of a certain cultivar for which a limited amount of clean material is available.

Recently, the use of true potato seed for propagation has aroused great interest. True seed does not transmit most of the potato diseases, is very light and is easy to transport. Promising methods to grow potatoes from true seed include raising seedlings in a nursery and transplanting them to the field. An alternative method includes the production of small seed tubers from true seed under protected conditions in nurseries. Considerable progress has been made in research efforts to reduce the variability among plants and tubers derived from true seed.

No single planting time is considered optimum for all potato growing regions. In regions with no critical dry season, potato can be planted at any time, provided that temperatures are not too high. Under normal conditions the longer the growing season the larger will be the yield.

In regions with a critical dry season, planting early in the rainy season is best. If the rainy season is long and excessive, time of planting is usually towards the end of the rainy season. The optimum time for planting in some parts of the lowlands of Papua New Guinea is towards the end of April when the wet season is coming to an end. In these areas, potato can be planted successfully until early September. Any potato grown after this date is subjected to heavy rainfall during growth or harvest which favours the development of diseases and reduces the effectiveness of chemical applications.

Tubers planted to produce consumption potatoes should generally be planted in rows 75–100 cm apart with a spacing of 30–40 cm within the row (25 000–44 000 plants/ha). The closer spacing should be used in fertile soils and good rainfall areas to avoid the production of very large tubers. Seed potatoes are planted at a spacing of 15–20 cm within the row (about 80 000 plants/ha).

Potatoes are planted at a depth of 5–15 cm (measured from the top of the tuber). Planting depth is greater under warm, dry conditions than under cool, wet conditions. Shallow plantings should be avoided, because the lower nodes of the stem must remain covered to encourage tuberization and to avoid greening of tubers and tuber moth damage. Earthing up or hilling is carried out to control weeds and to avoid greening of the tubers. Potatoes are normally planted by hand in Papua New Guinea, but mechanical planters are available. Wide ridges or mounds are required for intercropping. Potatoes can be intercropped with a wide range of annual crops such as sweet potato, maize or even pyrethrum.

Husbandry Adequate control of weeds is required to ensure high yields. In the tropics, manual weeding is generally practised in small-scale production, but herbicides are sometimes used in large-scale production.

Potato responds well to high fertility. Fertilizers are needed if the land has been continuously cropped. Well-decomposed animal manure or compost should be applied at 20–40 t/ha. The South-East Asian Programme for Potato Research and Development (SAPPRAD) recommends the use of 750 kg/ha of 12:12:17 NPK and 250 kg/ha of triple superphosphate.

Rotation is a common practice to avoid a build-up of pathogens affecting potato, and to reduce the level of soil infestation once the soil has been contaminated. Rotations should not include crops that are common hosts for these diseases and pests. Rice, maize and legumes are recommended.

Diseases and pests Diseases of potatoes are many and common in Asia and Oceania, affecting yield and quality. The most prevalent diseases are:

- bacterial diseases, including bacterial wilt caused by *Pseudomonas solanacearum*, bacterial soft rot caused mainly by *Erwinia carotivora*, and common scab caused by *Streptomyces scabies*;
- fungal diseases including late blight caused by *Phytophthora infestans*, early blight or target spot caused by *Alternaria solani*, black scurf caused by *Rhizoctonia solani*, and pink rot caused by *Phytophthora erythroseptica*;
- several viral diseases including potato leaf roll virus (PLRV) and the mosaic viruses, i.e. potato virus X (PVX), and potato virus Y (PVY).

Physiological disorders and tuber defects cause additional problems for the production of potato in many regions. The commonest physiological disorders are hollow heart and internal brown spot. Common external tuber defects are greening, growth cracking and tuber deformation.

Insect pests of potato are particularly destructive in all regions. The most common pests are aphids, tuber moth, mites, ants and ladybirds. As aphids are the main vectors of potato viruses, their population should be controlled in potato planted for seed production. Cyst nematodes (*Globodera* spp.) are very prevalent in many traditional potato-growing areas (e.g. the highlands of the Philippines).

Insect attack is usually of primary importance in hot, dry climates, whereas in hot, wet climates, fungal and bacterial attacks are extra virulent. Viral diseases are common in all developing countries or where it is difficult to obtain virus-free seed tubers. In general the use of disease-free planting material and crop rotation are the most common control measures in various parts of the world.

The constraints in the control of potato diseases and pests are not that methods of control are unknown but that farmers have limited access to adequate information and materials. In order to protect his crop, the farmer needs a reliable service to identify pathogens and pests, advice on control methods and access to pesticides and disease-free planting material. Increasingly, modern cultivars have resistance to or tolerance of some of the major diseases and pests.

Harvesting Time of harvesting of potato varies with cultivar, cultural practices, climate and price. Tubers harvested while still immature tend to have a low dry matter content and to suffer more skin damage, resulting in easier infection by fungal and bacterial pathogens. However, seed potatoes are often harvested early, to avoid virus infection which may occur during the latter part of the growing season. Late blight attack may also be a reason for early harvesting.

The harvesting operation involves destroying the aboveground parts (haulm), lifting and collecting the tubers. The haulm is destroyed either by manual or mechanical pulling, cutting, chemicals, or chemicals combined with haulm beating. The merits and demerits of each of these methods make the choice a compromise.

In Papua New Guinea, the crop is mature when the haulm is completely dry. This happens in 100–120 days with the cultivar Sequoia (most common), depending on altitude. The haulm is removed by hand after it has been cut with a bush knife, or is killed chemically with gramoxone. The tubers are left in the ground to harden the skin for 5–7 days and then dug up by hand or machine and bagged in the field with minimum handling or grading.

In small-scale farming in the tropics, lifting is done manually using simple implements such as sticks and spades. Mechanical harvesting is carried out only in large-scale farming areas using various types of potato diggers, e.g. ploughs, spinners, or elevator diggers. Semi-automatic diggers lift the tubers from the soil for hand-picking or collection. Harvesting should not be done during or immediately after rain.

Yield In 1990, the average yield of storage potato tubers throughout the world was about 15 t/ha. The average yield in Asia was 13.3 t/ha: 29.6 t/ha in Japan, 15.8 t/ha in India, 12.3 t/ha in Indonesia, 8.9 t/ha in Vietnam, 12.2 t/ha in the Philippines, 9.2 t/ha in Thailand and 11.5 t/ha in China. In Oceania, the average yield was 28.7 t/ha: 30.9 t/ha in New Zealand, 29 t/ha in Australia, 4.5 t/ha in Papua New Guinea. In many tropical and subtropical regions potential yields are much higher than actual yields. However, various constraints (e.g. environmental/seasonal, propagation, crop protection, economic and social) prevent the full expression of this potential.

Handling after harvest Harvesting or any other handling to which potato tubers are subjected may cause damage ranging from external injury to internal bruising. After harvesting it is advantageous to allow the tubers to dry in heaps for about 1–2 weeks at 10–20°C under high humidity before further handling. During this time the skin hardens, wounds heal, adhering soil dries and disease symptoms become more visible, which facilitates the removal of the infected tubers. Grading should not be started before the curing and hardening have taken place, otherwise further damage occurs.

Before the tubers go into storage, rotten and infected tubers, which may become sources of infection, should be removed. Potato tubers are usually delivered into stores in bags, baskets or crates. To facilitate handling, containers should not be too large; if they are large they should not be filled completely.

Adequate storage methods for seed are essential to ensure that seed tubers of the correct physiological stage are available at the required planting time. After cold storage, seed potatoes should be pre-sprouted in diffuse light to ensure optimal development of sprouts prior to planting. Light is a good alternative to low temperature when storing seed potatoes. By storing seed tubers in diffused light at ambient temperatures, excessive sprouting is avoided and they can be kept in good physiological condition for a long period of time. In South-East Asia, diffused light storage of seed potatoes has been widely adopted by farmers.

Storage of ware potatoes for the market is associated with undesirable quality changes (mainly sprouting, high sugar content, and weight loss due to evaporation and respiration). For prolonged storage, ware potatoes are best stored at about 4°C. However, for processing purposes tubers are better stored at 7–10°C to avoid high sugar levels which cause the browning of fried products. For short-term storage (1–2 months) in the tropics, ware potatoes may be stored at ambient temperatures in the dark, in well-ventilated buildings. In South-East Asia, emphasis is placed upon on-farm storage using inexpensive, well-ventilated constructions.

Processed potato products are of increasing importance in South-East Asian countries, particularly in the Philippines and in Thailand.

Genetic resources According to the International Plant Genetic Resources Institute (IPGRI), there are about 60 000 accessions of germplasm maintained in 40 countries worldwide. However, many cultivars, wild species and hybrids are duplicated. The largest collections are in the former Soviet Union, United Kingdom, United States and Peru. The collections in India, Japan, and China are the largest in Asia. In Oceania, many accessions are also maintained by individual national programmes, though, often in the face of serious management problems. The International Potato Centre (CIP) in Peru has accepted responsibility for maintaining a global collection of potato germplasm for long-term conservation, as a base collection within the IPGRI network of designated genebanks. During the last decade, SAPPRAD has provided special and significant support to countries in the region to enhance, conserve and use global potato genetic resources in production and breeding.

Breeding Potato selection and improvement had in fact been conducted by farmers and a few interested scientists in the 19th Century. Since the 1930s it has been concentrated in public agencies as well as private companies. Despite prolonged efforts, progress has been limited. The cultivar 'Russett Burbank' was released in 1876 but still accounts for 32% of the potato area in the United States and Canada. The cultivar 'Bintje' was released in 1910 and still accounts for 20–30% of the potato area in Western Europe and 40% in the Netherlands, and the parents of 'Early Rose' are still a major crop in the former Soviet Union. These cultivars are, of course, high yielding and of good appearance, but they are far from ideal in their agronomic and disease and pest resistance qualities.

Varietal genetic improvement of potato in South-East Asia has received special support from CIP and SAPPRAD.

The Philippines is the leading country in the CIP regional research network for South-East Asia. The collaborative breeding programme in the Philippines has made progress in developing cultivars with resistance to bacterial wilt, heat tolerance for the lowlands and thrips resistance.

Thanks to the leading role of CIP, great progress has been made over the last 30 years in taxonomic and genetic studies of numerous tuber-yielding potato species in tropical and subtropical regions. In 1987 CIP reported that 70 potato programmes in developing countries had received germplasm for evaluation and that 36 superior clones had been multiplied by 22 national programmes and released to farmers. In addition, a large number of clones are in advanced selection and cultivar trials in developing countries, to test their resistance to or tolerance of frost, heat, nematodes, viruses, late blight, or bacterial wilt.

Prospects Certainly, potato alone will not solve the impending tropical and subtropical food crisis, but millions of the rice-loving people of South-East Asia eat potato. The quantities of potato marketed are at present relatively small, but there is widespread interest in the crop. Recent biotechnological developments may be useful for producing improved cultivars, including cultivars with improved resistance to the most damaging diseases and pests, and cultivars adapted to the South-East Asian environment.

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M.E. Wagih & S.G. Wiersema

Stachys sieboldii Miquel

Ann. mus. lugd. bat. 2: 112 (1865).

LABIATAE

$2n = 66–70$

Synonyms *S. affinis* Bunge (1883, nomen, non Fresenius), *S. tuberifera* Naudin (1887).

Vernacular names Chinese artichoke, Japanese artichoke, spirals (En). Crosne du Japon (Fr). Malaysia: cordyceps, tung-tung chow. Thailand: thua-duang (northern). China: gan-lu-zi. Japan: chorogi.

Origin and geographic distribution Chinese artichoke is indigenous to China; there and in Japan it has been cultivated since ancient times. At the end of the 19th Century some tubers were introduced into France and planted successfully near the village Crosne (hence the French name). Since then Chinese artichoke has been cultivated on a small scale in France, and due to the research attention it has received since 1977, cultivation is increasing. In the 1980s, the crop was introduced into Malaysia by Chinese farmers, especially in the Cameron Highlands where cultivation has been commercialized. Occasionally the crop is also cultivated in other countries in Asia and Europe.

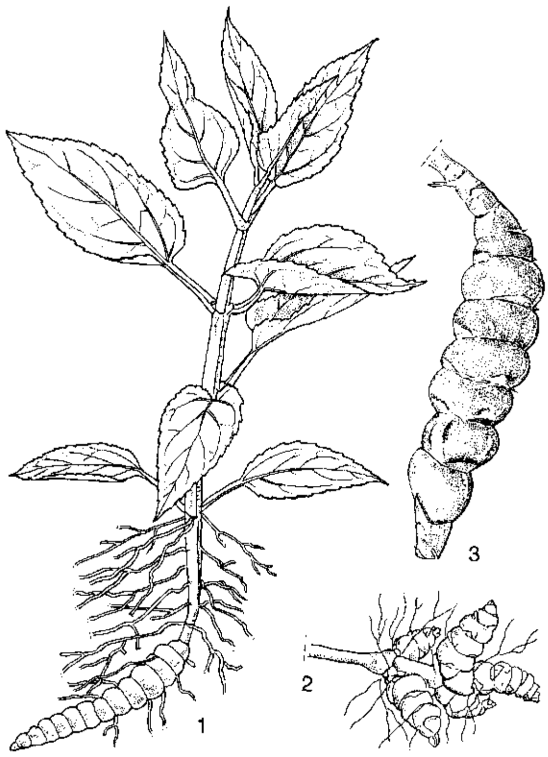
Uses The edible parts of Chinese artichoke are the tubers; they can be prepared variously and are eaten raw in salads, cooked or fried, and have a delicate taste. In Japan, they are appreciated for traditional dishes of New Year's Day. In China and Japan, the tubers are often pickled. Before preparing, the tubers have to be washed and, if necessary, carefully scrubbed to remove any adhering soil. They do not have to be peeled. The plant also has ornamental value. In China, extracts of the plant are used to cure lung diseases.

Production and international trade Chinese artichoke is cultivated on a small scale. In France cultivation is limited to a few hectares (about 150 ha in 1986), often to supply exclusive restaurants. In the Cameron Highlands of Malaysia, the tubers are a common product on the local markets. Production statistics are not available.

Properties Per 100 g edible portion tubers of Chinese artichoke contain: water 78.0 g, protein 4.3 g, fat 0.2 g, carbohydrates 14.6 g and ash 1.0 g. The energy value is 320 kJ/100 g. The main carbohydrate is the tetrasaccharide stachyose (gal-gal-sucrose), which is exclusively localized in the vacuoles. In dormant tubers 80% of the dry weight is stachyose (18% of the fresh weight). Other carbohydrates present are sucrose, raffinose and verbascose.

Botany Erect, hairy, perennial, stoloniferous herb, up to 120 cm tall. Tubers produced by thickening of the top part of the stolons, 5–8 cm × 1–2 cm, constricted at the internodes into rows of rounded segments, whitish, often in great numbers just below the soil surface. Stem quadrangular with opposite leaves; petiole 1–3 cm long; blade ovate to ovate-lanceolate, 3–12 cm long, cordate at base, margin obtusely dentate, roughly hairy at both sides. Inflorescence consisting of whorls of 6 flowers on upper 5–15 cm part of the stem and branches; bracts linear, pubescent; calyx with 5 triangular teeth, about 1 cm long, 10-veined; corolla bilabiate, 12 mm long, upper lip erect, lower lip 3-lobed, pinkish, purplish or whitish. Fruit composed of 4 nutlets, enclosed within the persistent calyx.

Stolons and tubers are formed 5–7 months after planting in the same way as in Irish potato (*Solanum tuberosum* L.). Tubers are formed at the end of the stolons when temperature drops. In temperate regions, tubers are dormant during winter time and start sprouting in spring. The plant rarely flowers, flowering and stolonization



Stachys sieboldii Miquel – 1, habit of young plant from seed tuber; 2, stolon with tubers; 3, tuber.

possibly being antagonistic processes.

Ecology Chinese artichoke is cultivated mainly in temperate climates but cultivation in tropical highlands is also possible. It is not sensitive to frost, in China it occurs up to 3200 m altitude. Long days are required for stolonization. A light, loose and sandy fertile soil is needed for good tuber formation and to facilitate harvesting. For vegetative growth a day temperature of 23°C is optimal, for tuberization 15°C. At higher temperatures, the tubers will become more elongated.

Agronomy Usually, propagation is by tubers and rarely by cuttings. Propagation by seed is also possible but seed is scarce. Large tubers of the last harvest are planted 2–3 together in upright position, 2–15 cm deep, directly in the field or first in pots. Planting distances vary from 15–40 cm in the row and from 30–80 cm between the rows. Wide spacing gives more tubers per plant. In Malaysia, Chinese artichoke is planted on beds after cabbage or in rotation with other tuber crops such as potato and yam. Until the canopy covers the soil it should be kept weed-free or covered by mulch or black poly-ethylene. The crop responds well to fertilizer. When the plants are 30–60 cm tall they are earthed up around the base of the stem. In Europe, Chinese artichoke can be infected by several viruses known from other crops. Aphids and caterpillars can also cause problems. The crop is very sensitive to *Rhizoctonia solani*. No information is available on diseases and pests on the crop in Asia. Harvesting is done manually 6–8 months after planting. Tubers are small and grow dispersed in the soil making harvesting rather time-consuming. All tubers must be removed, otherwise the plant can become a weed. Under optimal conditions a plant may form 40–220 tubers depending on the planting material. The yield is 8–20 t/ha. Cultivation trials in Switzerland gave maximum yields of 43 t/ha. Tubers dry and discolour in the open air and should therefore be marketed soon after harvesting. They can be stored in moist sand at 0–2°C or frozen at –18°C. For a short period they can be stored in a refrigerator, wrapped in paper.

Genetic resources and breeding There are no germplasm collections. Selection work on Chinese artichoke is carried out mainly in France and Japan. Tissue culture techniques are applied successfully to ensure fast propagation and virus-free plant material. Breeding objectives are focused on the improvement of quality and productivity.

Prospects Chinese artichoke is a minor crop, not suitable for large-scale cultivation because of the laborious harvest and relatively low return. However, it has potential to broaden the vegetable assortment. In France, the demand seems to exceed the supply. Little is known about its cultivation in China, Japan and the tropics. Its cultivation in the Cameron Highlands shows that the crop has potential in the tropics. More research and dissemination of knowledge is needed.

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M.H. van den Bergh

Tacca leontopetaloides (L.) O. Kuntze

Rev. gen. pl. 2: 704 (1891).

TACCACEAE

$2n = 30$

Synonyms *Tacca pinnatifida* J.R. & G. Forster (1775), *T. involucrata* (Limpr.) Schum. & Thonn. (1827), *T. viridis* Hemsley (1899).

Vernacular names East Indian arrowroot, Polynesian arrowroot, Tahiti arrowroot (En). Indonesia: gadung tikus (Indonesian), kecondang

(Javanese), taka laut (Sumatra). Malaysia: lukeh, poko lukeh. Papua New Guinea: masoa, pia. Philippines: gaw-gaw (Tagalog), tayobong (Bisaya), panarien (Ilokano). Thailand: thaoyaimom (central), buk-ro (eastern). Vietnam: b[aj]ch tinh, c[ur] n[uw]a.

Origin and geographic distribution The exact origin of *T. leontopetaloides* is not known but is thought to be in Malesia where the other species of the genus have their greatest variability. It is widely distributed wild and sometimes cultivated throughout the tropics of Africa, Asia, Australia and Oceania, from West Africa to India, throughout South-East Asia and in the Pacific as far as Easter Island.

Uses Although fresh tubers are inedible because of the presence of bitter toxic substances, they can be eaten after thorough preparation or, more important, an edible starch can be extracted from them. The starch can be used for baking bread, making pastes and puddings, often mixed with other ingredients like, for example, sugar, coconut juice, fruit pulp, wheat flour and flavourings. The cooked starch is easily digestible and is suitable for patients with digestive problems. In Fiji, undried starch is wrapped in leaves and buried into the ground to ferment before being eaten. In Samoa, fresh starch is used as a kind of glue between thin layers of beaten bark of the paper mulberry (*Broussonetia papyrifera* (L.) Ventenat) to make bark cloth ('tapa' or 'siapo'). The starch is also used for starching clothes and to make sweetmeats. In Gabon, the fruit pulp is eaten by children. Sometimes the leaves are used as a vegetable. The petioles and peduncles yield fibres that are used for making hats and fishing utensils. In traditional medicine the tubers and their starch are used against dysentery, diarrhoea and oedemas.

Production and international trade At present East Indian arrowroot is widely but only locally produced or collected and traded, and no statistics are available. In the past its role as a staple food was more important, especially in the Pacific Islands, where, for example, Hawaii, Tahiti and Fiji, exported about 5 t rough East Indian arrowroot material per year. Once it was also important in Thailand. Its role as staple food has largely been taken over by cassava. In many places, East Indian arrowroot is now considered as an emergency food.

Properties The composition of fresh tubers per 100 g is approximately: skin 2–3 g, fibre 6–7 g, starch 20–30 g and waste material 60–70 g. The starch extracted from the tubers is very white, much resembling cassava starch; the grains are simple polyhedrons or hemispheres, (8–)20(–40) μm in diameter. The analysis on a dry weight basis, for a tuber originating from Ivory Coast was: protein 5.1%, fat 0.2%, carbohydrates 89.4%, cellulose 2.1%, ash 3.2%, Ca 0.27% and P 0.2%. A bitter extract (about 2.2%) was also isolated from the tuber, containing β-sitosterol, cerylic alcohol, taccalin (a rather unusual, bitter principle in plants), alkaloids and steroidal sapogenins. Small young tubers are said to be more bitter than large older ones. The sapogenins have shown a strong activity against snails (*Bulinus truncatus* and *Biomphalaria pfeifferi*).

Description A perennial, erect, stemless herb, up to 3 m tall, with tuberous rhizome. Tuber depressed globose or broadly ellipsoidal, up to 20 cm in diameter, weighing up to 0.9 kg, usually smaller and lighter, thin-skinned, smooth, white when

Tacca leontopetaloides (L.) O. Kuntze – 1, habit of flowering plant; 2, tuber and basal plant part; 3, part of leaf segment; 4, inflorescence; 5, inner side of perianth segment with top of stamen; 6, seed surrounded by aril; 7, seed.

young, turning dark grey to brown, white and somewhat juicy within, growing near the surface up to 50 cm deep, renewed annually, provided with an apical cavity from which the leaves and inflorescences emerge. In young plants the base of the leaves and the inflorescence is surrounded by a special, linear-lanceolate leaf (cataphyll), 8–21 cm × 1–3 cm. Leaves 1–3; sheath 2–25 cm × 3.5 cm; petiole hollow, cylindrical, 17–150 cm long, 0.3–2.5 cm in diameter, light green, with white-green to blackish-purple dots, ridged longitudinally; blade broadly obovate, ovate or oblong-ovate in outline, up to 70 cm × 120 cm, glabrous, palmately 3-sect, with the 3 segments lobed to dissected into orbicular to linear lobes. Inflorescence 1–2 per plant, umbel-like, 20–40-flowered; peduncle (scape) hollow, 20–170 cm long, 0.2–2.5 cm in diameter, green, ridged longitudinally; involucral bracts of different size, 4–12, in 2 whorls, ovate to ovate-lanceolate, up to 10 cm × 3.5 cm, green; floral bracts filiform, 20–40, up to 25 cm long, purple or dark black-brown; flowers bisexual, regular, campanulate, drooping, 6–17 mm × 6–13 mm, yellowish to black-purplish-green; pedicel up to 6 cm long, in fruit up to 8 cm long; perianth fleshy, persistent, tubular and ending in 3 outer and 3 inner lobes; stamens 6, white, yellow, brown or purple, adnate to perianth segments, with short and flattened filaments which at top are free and helmet-shaped and hood the anthers; pistil on annular, ribbed, glandular-hairy disk, ovary unilocular, style short, stigma 3-lobed and umbrella-shaped with stigmatic surface beneath. Fruit subglobose, ovoid or ellipsoid, berry-like, up to 3.5 cm × 1.5–2.5 cm, pendulous, pale orange, many-seeded. Seed flattened ovoid to ellipsoid, 5–8 mm × 3–5 mm × 1.5–3 mm, 15–19-ribbed, glabrous, yellow-brown, but surrounded by a spongy white aril.

Growth and development *T. leontopetaloides* exhibits a seasonal growth rhythm. During the growing season, the tuber is replaced by a new main tuber which arises from a downward-growing runner-like thick rhizome at a lower level, and remains dormant after the yearly death of the aerial parts of the original plant until the new growing season. Secondary smaller runners, also forming tubers, may emerge above the old tuber and spread downwards. This cycle takes about 8–10 months, with 2–4 months of dormancy. In Malesia, flowering and fruiting may occur in all months of the year, but the aerial parts usually die off between December and March. It is not known whether a plant flowers more than once on the same tuber, but relatively older plants have relatively larger vegetative and generative parts. Plants grown from seed first produce palmately incised young leaves, and the mature leaves are 3-lobed with each lobe pinnately lobed; such plants do not start flowering until 2–3 years old. Most probably, pollination is effected by insects.

Other botanical information Due to its wide geographic distribution, many local forms have been described as species, subspecies, varieties or formas. Those forms were largely based on leaf characteristics, which are very variable indeed, depending on the environment and the age of the plant, but none deserves separate taxonomic distinction. Sometimes *T. leontopetaloides* in the vegetative stage is confused with *Amorphophallus* species, but it can be distinguished immediately by its ribbed hollow petioles, which in *Amorphophallus* are solid, smooth and usually flecked. It is possible (but no records are available) that some other tuber or tuberous rhizome-producing *Tacca* species are occasionally used in South-East Asia as emergency food, e.g. *T. ebeltajae* Drenth (Papua New Guinea, Solomon Islands; tuber globose to subcylindrical, up to 6 cm long and 2 cm in diameter), *T. integrifolia* Ker-Gawler (Sumatra, West Java, Borneo and continental South-East Asia; rhizome cylindrical, up to 12 cm × 3 cm), and *T. palmata* Blume (throughout South-East Asia; tuber globose to ellipsoidal, up to 8 cm long and 3 cm in diameter).

Ecology The natural habitat of *T. leontopetaloides* is distinctly the beach. In its distribution area, however, it is very indifferent to climate, soil, and vegetation. It rarely occurs in heavy shade and in primary forest, frequently in coastal vegetation, usually below 200 m, occasionally up to 1100 m altitude. It often grows in small groups, on and behind the seashore, in grasslands, alang-alang fields, thickets, savannas, moist or dry primary or secondary forests, coconut plantations and is often associated with beach vegetation of e.g. *Casuarina*, *Pandanus*, *Scaevola*, *Barringtonia* and *Eucalyptus* species.

Seeds can be dispersed by sea water, the spongy testa enabling them to float for many months, but nothing is known about the influence of sea water on their viability. Its occurrence on many Pacific islands suggests the possibility of dispersal by sea. Fruits are eaten by a white-eyed bird (*Zosterops masii*), which might also disperse the seed. Without doubt, the most important distributor of East Indian arrowroot has been man, mainly by planting tubers.

Agronomy *T. leontopetaloides* can be propagated by seed and by tuber. Usually, small secondary tubers are planted 15 cm deep, in rows at a spacing of 60–90 cm × 45 cm, preferably at the beginning of the rainy season. It is reported that the crop benefits greatly from weeding and partial shade, and no serious diseases or pests are known. When the leaves begin to wither the tubers can be harvested by digging them up. Individual tubers normally weigh 70–340 g, but may reach 900 g. They may be stored in pits for later use but are liable to sprouting. Harvested tubers are peeled, grated, washed several times in hot or cold water, and after the starch has settled, the water is removed and the starch dried.

Genetic resources and breeding Neither germplasm collections nor breeding programmes are known to exist for *T. leontopetaloides*. Germplasm collection is urgently recommended, as in many places its natural habitat is being rapidly destroyed.

Prospects The economic importance of *T. leontopetaloides* will remain quite invisible in official statistics. It undoubtedly remains important at the local level as a reserve food. Its ability to produce edible starch on marginal soils is of interest. More research is needed to investigate the feasibility and economics of large-scale production.

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J. Jukema & Y. Paisooksantivatana

Xanthosoma Schott

Melet. bot.: 19 (1832).
ARACEAE
$x = 12, 13$; $2n = 26$ (*X. nigrum*, *X. sagittifolium*)

Major species and synonyms

- *Xanthosoma nigrum* (Vell.) Mansfeld, Verzeichnis: 549 (1959), synonyms: *Arum nigrum* Vell. (1827), *Xanthosoma violaceum* Schott (1853), *X. ianthinum* K. Koch (1854).
- *Xanthosoma sagittifolium* (L.) Schott, Melet. bot.: 19 (1832) (*sagittaefolium*), synonyms: *Arum sagittaefolium* L. (1753), *A. xanthorrhizon* Jacquin (1797), *Xanthosoma xanthorrhizon* (Jacquin) Koch (1856).

Vernacular names General: Xanthosoma, cocoyam, tannia, yautia (En). Yautia, tanier, chou caraibe (Fr). Thailand: kradat (central).

- *X. nigrum*: Indonesia: talas belitung (Indonesian), kimpul (Javanese, Sundanese), dilago gogomo (North Halmahera). Malaysia: keladi hitam, birah hitam, keladi kelamino. Papua New Guinea: kong kong taro. Philippines: cebu-yautia (Filipino), gabing-cebu (Tagalog), cebu-gabi (Bisaya). Laos: th'u:n. Thailand: kradat-dam (central). Vietnam: khoai s[as]p, ho[af]ng thu.
- *X. sagittifolium*: New cocoyam (En).

Origin and geographic distribution *Xanthosoma* originates from tropical America. Cultivars with edible tuberous rhizomes or leaves have been cultivated in the same area since ancient times and several cultivars later spread throughout the tropics. During the slave-trading era *Xanthosoma* was taken to Africa and in the 19th and early 20th Centuries it spread throughout Oceania and into Asia. Species often escape from cultivation and become naturalized. No reliable information on individual species is available because the genus lacks a thorough, critical taxonomic revision. *X. nigrum* is commonly cultivated in tropical America (e.g. Puerto Rico, Haiti, Dominican Republic, Cuba, Panama, Guatemala and Venezuela) and occasionally in the other tropics. In South-East Asia, *X. nigrum* is probably more commonly cultivated than *X. sagittifolium* (e.g. in Java and the Philippines). In Malaysia, *X. sagittifolium* seems to be more common.

Uses In general, *Xanthosoma* species produce edible tuberous rhizomes (corms and cormels) and/or edible young leaves, and most species also have ornamental value. The tubers are washed and peeled before being further prepared. Some tubers are so hard that they require cooking before peeling. After being peeled, tubers are prepared in various ways; they may be boiled, baked, steamed, creamed, mashed or fried and are used in soups, chowders, stews and salads. They are also made into flour or meal for pastry which is stuffed with meat or other fillings, or to prepare puddings. In some taxa the main tubers (corms) are used (e.g. *X. atrovirens* K. Koch & Bouché, *X. undipes* (K. Koch & Bouché) K. Koch), in others the lateral tubers (cormels) (e.g. *X. nigrum*, *X. sagittifolium*). In Indonesia, cormels of *X. nigrum* (which are rather slimy after being cooked) are not as popular as tubers of *Colocasia esculenta* (L.) Schott; in the Philippines, *X. nigrum* is preferred. Young leaves of most cultivars are used as a vegetable; the leaves are cooked after the largest veins have been removed. In Indonesia, *X. sagittifolium* is even primarily used as a leaf vegetable. In times of food scarcity, certainly tubers and leaves from wild or semi-wild (escaped) *Xanthosoma* species are also eaten. All parts (including debris) can also be used as animal feed. In traditional medicine in Malaysia, the large leaves of *X. nigrum* are also used as blankets for patients with fever, because they are pleasantly cool and give temporary ease. Patients also bathe in a decoction of the plant. In the Philippines (Palawan), sap of the inflorescence is used to heal wounds and as an antidote for insect bites and stings.

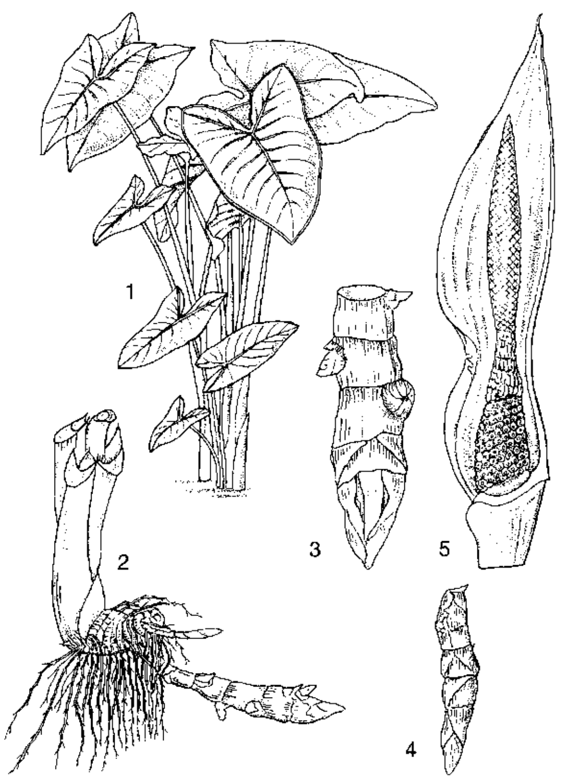
Production and international trade Statistics on world production are always combined for *Xanthosoma* and *Colocasia*; they amounted to 5.6 million t in 1993. More than half of this production should certainly be ascribed to *Colocasia*, but since the 1950s, *Xanthosoma* has been gaining importance, in South-East Asia for example in Papua New Guinea. National and international markets are growing in response to demand from people who have moved from the countryside to urban centres, and from tropical homelands to industrialized countries. In the Caribbean, *Xanthosoma* is shipped between islands and to the United States and Europe. In Africa, *Xanthosoma* ranks third behind cassava and yam, but in Asia and Oceania it has only achieved minor crop status. Because of its remarkable general resistance to diseases and pests it often replaces other root and tuber crops and is becoming more popular as a reliable reserve food crop. In South-East Asia it is mainly a home garden crop for which no statistics are available.

Properties In general, *Xanthosoma* (especially the yellow-fleshed types) is more nutritious than *Colocasia* and potato, but less nutritious than sweet potato, plantain and pumpkin.

Per 100 g edible portion, tubers of *X. nigrum* contain approximately: water 58–68 g, ether extract 0.2–0.4 g, nitrogen 0.2–0.4 g, fibre 0.5–1.7 g, ash 0.9–1.2 g, Ca 6.7–18.5 mg, P 48–83 mg, Fe 0.3–4.5 mg, carotene 0.002–0.012 mg, niacin 0.6–0.8 mg, vitamin C 7–14 mg. Per 100 g edible portion, tubers of *X. sagittifolium* contain approximately: water 70–77 g, protein 1.3–3.7 g, fat 0.2–0.4 g, carbohydrates 17–26 g, fibre 0.6–1.9 g, ash 0.6–1.3 g, carotene 2 mg, niacin 1 mg, vitamin C 96 mg and the energy value is about 560 kJ/100 g. The carbohydrates consist mainly of starch. The starch grains are relatively large, with an average diameter of 17–20 μm; the starch is less readily digested than *Colocasia* starch. Several cultivars may contain raphides (calcium oxalate crystals) in the leaves and the tubers, causing oral and intestinal irritation; the raphides can be made harmless by cooking. Coloured cultivars may contain saponins which can be released into the cooking water.
Per 100 g edible portion, leaves of *X. sagittifolium* contain approximately: water 87 g, protein 2.5 g, fat 1 g, carbohydrates 5 g, fibre 2 g, ash 1 g, Ca 95 mg, P 388 mg, Fe 2 mg, vitamin C 37 mg and the energy value is about 140 kJ/100 g.

Description Erect, unarmed, laticiferous, perennial herbs, often arising from a tuberous rhizome. Root system fibrous and superficial. Rhizome with main part (corm) short and stout, or thick globose to cylindrical, forming lateral tuberous outgrowths (tubers or cormels). Stem varying from only a short, thick, underground rhizome, to a stem with a tall and thick aboveground part. Leaves with long, thick, subterete petiole, sheathing below; blade sagittate or hastate, or trisect to pedatisect; venation reticulate with secondary veins forming a zig-zag collecting vein between primary lateral veins. Inflorescence a spadix; peduncle solitary or aggregate, short to stout; spathe in 2 parts, the lower part tubular and persistent, the upper part (limb) spreading and quickly withering; spadix cylindrical, shorter than the spathe, divided into 3 parts: female below, male above, with a constricted sterile area in between; flowers unisexual, naked; male flower consisting of 4–6 stamens completely united into a truncate synandrium with marginal thecas; female flower with a 2–4-locular, many-ovuled ovary, a thick annular style more or less connate to the ovary, and a half-globose to discoid, 3–4-lobed stigma. Fruit a berry, crowned by the impressed stigma, many-seeded. Seed ovoid, grooved longitudinally.

– *X. nigrum*. Vigorous plant, up to 2 m tall, lacking aboveground stem. Rhizome with a short,



Xanthosoma nigrum (Vell.) Mansfeld – 1, habit; 2, lower plant part with roots and tuberous rhizomes; 3, large tuber; 4, small tuber; 5, inflorescence with spatha partly removed.

stout main part with numerous tubers; tubers rather smooth, purplish-grey, with purplish-red buds (eyes), flesh violet, red, pink, yellow or white. Petiole 30–100 cm long, violet to brown-green; blade sagittate-ovate, 20–100 cm × 15–75 cm, dark green above with purple margin, pale green tinged with purple beneath, veins green to dark purple, 3 main ones prominent, central lobe 3–4 times longer than the 2 widely divergent, subtriangular basal lateral lobes. Inflorescence 30–60 cm long; peduncle 15–50 cm long; tube of spathe up to 10 cm × 4 cm, violet or pale green outside, creamy within; limb oblong-lanceolate, 15–25 cm × 6–7 cm, pale yellowish with longitudinal, purplish veins; spadix 15–25 cm long, female part 3–5 cm long, 1.5–2.5 cm in diameter, yellow-green, sterile part 3–5 cm long, pink-violet turning grey, male part 10–15 cm long, pale yellow, ending in a short obtuse tail. Fruit and seed unknown.

– *X. sagittifolium*. Robust plant, up to 2 m or more tall, with thick subarborescent stem up to about 1 m long on the apex of which the leaves are borne. Rhizome with a thick globose to cylindrical main part with up to 10 or more tubers; tubers flask-shaped, 10–25 cm long, 10–15 cm in diameter, broadening towards the apex, pale brown outside, flesh white, pink or yellow. Petiole up to 1 m long; blade sagittate-ovate, 40–90 cm × 40–60 cm, dark green above, glaucous below, central lobe acuminate and larger than the 2 subtriangular basal lobes, primary and secondary veins prominent. Inflorescence borne below the leaves, up to 4 at a node, but flowering is rare; peduncle up to 50 cm long; spathe up to 22 cm long, tubular part 8 cm, green, limb 14 cm, creamy; spadix up to 18 cm long, female part 2–3 cm, sterile part 3.5 cm, male part 11 cm, terminal appendage absent. Fruit and seed are rarely produced.

Growth and development *Xanthosoma* is a perennial herb with a continual turnover of leaves throughout its life, with the older ones dying as new ones appear. Often, however, it is grown as an annual, showing a growth cycle of 9–12 months. After a cormel is planted, shoot growth (mostly leaves) starts and increases rapidly, especially in the 5th and 6th months when the maximum leaf area index (LAI) of 4 and maximum dry matter weight of the leaves are reached; thereafter leaf number, leaf area and dry matter weight decrease until harvest. Dry matter accumulation in the corm starts 3 months after planting, increasing rapidly until the 7th month, after which it decreases slowly. Cormels start to develop 3 months after planting and increase in number until the 8th month. Dry matter accumulation in the cormels starts 4 months after planting, continuing until the 8th month, being greatest when shoot growth is decreasing. Flowering is relatively rare in most cultivars, but when it occurs it is usually early in the season. Flowers are protogynous and pollination is probably effected by flies. Fruits and seeds rarely develop in cultivars. At the end of the growing season the shoot may wither completely, leaving the corm and the cormels to perennate. In better climatological conditions the shoot may stay alive until the next growing season and if the cormels have not been harvested they start suckering.

Other botanical information The taxonomy of *Xanthosoma* is confusing and speciation in the genus is not yet well understood. The genus comprises 40–60 species, but many 'species' have been distinguished on the basis of vegetative characteristics of dubious value. A critical taxonomic revision is urgently needed. At present the situation for the cultivated *Xanthosoma* is as follows:

- *X. brasiliense* (Desf.) Engler. Indigenous in Central and South America, cultivated mainly in tropical America, but also in Tahiti, Hawaii and Micronesia. It is smaller than other *Xanthosoma* species, up to 40 cm tall, having characteristic hastate leaves with cuspidate apex and marked oblong basal lobes borne at right angles to the midrib. The tubers are small and although edible not usually eaten. It is only cultivated for its leaves which are eaten cooked as a vegetable.
- *X. nigrum* (Vell.) Mansfeld. In South-East Asia, the most important species; in the literature better known by its synonymous name *X. violaceum*. In Indonesia, 3 forms of *X. nigrum* are distinguished based on leaf colour: completely green leaves (tuber white-fleshy), leaves with blue-violet petiole and main veins (tuber white-fleshy), and a form with its petioles streaked with green or blue (tuber yellow-fleshed containing more milky juice). The latter form is not fit to eat; its rhizome causes a severe itching of the mouth.
  Well known cultivars are 'Kelly' and 'Dominicana'.
- *X. robustum* Schott. Occurring wild and cultivated in Central America. Although with edible tubers, it is more important as ornamental because of its large size (stem up to 1.75 m long and 35 cm in diameter; leaves almost 2 m long).
- *X. sagittifolium* (L.) Schott. Although originally described as a species from Central America, in practice it is now considered as a complex polymorphic species, cultivated pantropically for its edible tubers, comprising most or perhaps all cultivated forms of *Xanthosoma*, which is more a convenient agricultural unit than a taxonomic entity. It is an aggregate of the following difficult to distinguish species which are in effect mere cultivars and/or cultivar groups:
  - *X. atrovirens* K. Koch & Bouché. Originating from Venezuela, but cultivated in tropical America since pre-Columbian times and occasionally also elsewhere in the tropics. It is much favoured in Puerto Rico, Cuba and Jamaica. The plant is 1.5 m or more tall and has no aboveground stem. The corm is the major edible part because it is more tender than the tubers and its weight may attain 2.5 kg. The tubers are few, small and irregular and mainly used for planting. Corm and tubers are yellow-orange. Five botanical varieties have been distinguished based on differences in leaf form and colour. Well known cultivars are: 'Martinica Amarilla', 'Martinica' and 'Rascana'. In Puerto Rico, *X. atrovirens* is very popular and the supply is never sufficient to meet the demand.
  - *X. belophyllum* (Willd.) Kunth. Originating from Venezuela and Colombia where it is also cultivated for its edible leaves. Four botanical varieties have been distinguished, based on leaf form and colour.
  - *X. caracu* K. Koch & Bouché. Only known from cultivation in tropical America, from Mexico and the Caribbean to northern South America. It is thought that most of the Caribbean cultivars belong to this group. It is a vigorous plant, 1.5–1.8 m tall, lacking an aboveground stem. Its tubers are numerous and large, club-shaped, grey-brown with white flesh. It never flowers. Well known cultivars are: 'Rolliza', 'Blanca Del Pais', 'Rascana', 'Viequera' and 'Inglesa'.
  - *X. mafaffa* Schott. Originating from northern South America but perhaps most important in West Africa where most cultivars are thought to belong to this species (e.g. in Nigeria only cultivars of *X. mafaffa* occur). Three botanical varieties have been distinguished, based on differences in spathe and leaf form and colour. It is said to differ from *X. sagittifolium* because of its characteristic divergent (not overlapping) basal leaf lobes and its cylindrical spadix (not tapering at the top).
  - *X. undipes* (K. Koch & Bouché) K. Koch (synonym: *X. jacquinii* Schott). Originating from Mexico and much cultivated from Mexico and Florida to Venezuela and Ecuador. The plant has an aboveground stem, up to 2.5 m tall and 15 cm thick. The corm is the main edible part, with yellow-orange flesh that is acrid; it is made edible by slicing, drying and cooking. Tubers are rare and small. The plant has acrid milky sap and a foetid odour. In southern Colombia, an intoxicating drink called 'chicha' is prepared from ground, boiled and fermented tubers.

Xanthosoma and *Colocasia* are difficult to distinguish at first sight. Their main differences are: *Xanthosoma* has sagittate leaves, it cannot grow in flooded fields and its tubers store better; *Colocasia* has peltate leaves, can grow in flooded fields and its tubers do not store well.

Ecology *Xanthosoma* is a plant of tropical rainforest regions, requiring average daily temperatures above 21°C, preferably between 25–29°C, being not tolerant of frost. *Xanthosoma* is a lowland crop but it is occasionally grown, usually with progressively reduced yields, up to 2000 m altitude. Average annual rainfall should be at least 1400 mm, but preferably 2000 mm, well distributed over the year, and soil moisture should be adequate. Unlike *Colocasia*, it does not withstand waterlogging. Under heavy shade, plants often survive as tubers, starting to grow only when more light becomes available. It grows best on deep, well-drained, fertile soils, within a pH range of 5.5–6.5. It tolerates light shade and slightly saline soils.

Propagation and planting *Xanthosoma* is propagated vegetatively by planting the top of the corm (with petioles pruned to 15–30 cm length still attached), the whole corm, pieces of the corm (with at least 4 buds), tubers, suckers or by tissue culture. Top plantings give the highest yields and the larger the corm part the better the growth. Tissue culture is especially applied to obtain virus-free planting material; usually buds are excised from the primary corms or the tubers, disinfected, dried, treated with fungicides and planted in the nursery. After 2 months the young plants which have developed can be planted out in the field. Tissue culture starting from growing points is still experimental but is promising.

Land preparation varies from clearing in shifting cultivation to ploughing in permanent cropping systems. The best planting time is at the onset of the rainy season and planting on ridges makes harvesting easier. Planting distance varies from 0.6–1.8 m × 0.6–1.8 m, 0.9 m × 1.2 m being most common. Planting depth is about 5–7 cm and often 2–3 propagules are planted in the same hole. *Xanthosoma* is often planted as an intercrop in tree crops such as cacao, coffee, rubber, coconut, oil palm or banana because it yields better under 25–50% shade. Sometimes it serves as a shade crop for young plantings of cacao or coffee. In South-East Asia, *Xanthosoma* is primarily a home garden crop; in tropical America it is also cultivated on plantation scale.

Husbandry Weeding is essential in *Xanthosoma* as long as the crop does not shade the soil completely. Two weedings are usually sufficient, 1 and 2 months after planting respectively; weeding should be done carefully because the roots are easily damaged. In the Philippines, good results have been obtained with an integrated weeding system including ploughing between the rows 2 weeks after planting, weeding 3 weeks after planting and earthing up the plants after 5 weeks. Mulching, for example with coconut or banana leaves, also suppresses weeds and enhances yield. Chemical weed control is effective but is not recommended, being generally too expensive. Fertilizer is commonly applied and recommended quantities are 20–40 t organic manure per ha or NPK 110-45-110 kg/ha, divided over 2 gifts 2 and 6 months after planting. For good yields, water is essential and insufficient rainfall should preferably be complemented by irrigation. Inflorescences may appear 5–8 months after planting, depending on cultivar and growing conditions; they should be cut out.

Diseases and pests By comparison with *Colocasia* and many other root and tuber crops, *Xanthosoma* is remarkably resistant to diseases and pests. Bacterial blight caused by *Xanthomonas campestris* may attack the leaves; it can be controlled by burning attacked plant material and by spraying with a copper solution. Reported fungal diseases causing rot of the tubers are soft rot (caused by *Pythium* spp.), root rot (caused by *Corticium* spp.) and sclerotium rot (caused by *Sclerotium rolfsii*). Control is possible by starting with disease-free planting material and by spraying with fungicides. Dasheen mosaic virus (DMV) is almost always present and in practice can only be controlled by starting with virus-free planting material (tissue culture) and by burning diseased plants.

Reported insect pests are the beetles *Ligyrus ebenus* attacking tubers in the field and *Araecus fasciculatus* attacking stored tubers; cotton leaf worm (*Spodoptera litura*) attacks the leaves; only chemical control is effective but biological control methods are promising. Nematodes (*Meloidogyne* spp. and *Rotylenchus* spp.) are not usually problematic, but crop rotation is recommended. Nutrient deficiencies may cause disease-like symptoms on the plants, e.g. stunted growth (shortage of NPK or Ca), necrotic leaf parts (shortage of K or Ca), orange discolouration on the leaves (shortage of Mg). *X. atrovirens* is said to be less disease resistant than other species; *X. undipes* is highly resistant to *Pythium* rot.

Harvesting Partial harvesting of tubers may start about 6 months after planting; for about 1.5 years, the largest tubers can be harvested every 3 months. Continuous harvesting discourages foliage production and encourages tuber formation; when the plants become older than 2 years, it is recommended to renew the crop. Harvesting of all tubers at the same time is usually done after 9–12 months; in seasonal climates the best moment of harvesting is at the end of the growing season when the leaves start to wither. Mechanical harvesting is possible, but often tubers are damaged too much. Harvesting of leaves may start about 6 weeks after planting and can continue whenever needed as long as the leaves show no yellowing at the edges.

Yield Average annual yield of tubers varies with cultivar and growing conditions but for sole crops usually ranges between 12–20 t. In Papua New Guinea, yields of 15–25 t/ha per year have been reported. Best cultivars in Trinidad yielded up to 33 t/ha. As an intercrop between 6–8-year old coconut, tuber yield averaged 10 t/ha.

Handling after harvest Smallholders normally only harvest the amount of tubers needed for consumption, leaving the rest in the soil. Tubers can be stored well without losing eating quality for up to about 3 months under dry, cool, well-ventilated conditions. Harvested tubers are cleaned, peeled, cooked and prepared in various ways for direct consumption or, after grinding, prepared for commerce as deepfrozen pulp or as dried flour. At household level, flour is usually prepared from the tubers by peeling, slicing, drying in the sun and grinding.

Genetic resources Small germplasm collections of *Xanthosoma* are present in many countries where the crop is grown. Some major ones are: University of the West Indies, St. Augustine, Trinidad; Agricultural Experiment Station, Rio Piedras, Puerto Rico; Mayaguez Institute of Tropical Agriculture, Mayaguez, Puerto Rico; Agriculture Research and Education Center, University of Florida, Homestead, Florida, United States. In South-East Asia, some major collections are present in Malaysia (Malaysian Agricultural Research and Development Institute, Kuala Lumpur, and University Kebangsaan Malaysia, Bangi, Selangor), Philippines (Philippine Root Crop Research and Training Center, several locations), Papua New Guinea (Department of Agriculture, Papua New Guinea University of Technology, Lae), Thailand (Department of Agronomy, Kasetsart University, Bangkok) and Vietnam (Institute for Experimental Biology, Ho Chi Minh City).

Breeding *Xanthosoma* is a worthy target for improvement, e.g. to reduce acridity levels due to raphides, and to raise cultivars which are better adapted to adverse conditions of climate, soil and environment and better resistant to diseases and pests. Flowering can be induced by treating young plants with gibberellic acid.

Prospects Although aroids are often considered as static or declining crops, this is not true for *Xanthosoma*, which is increasing in some Pacific Islands, in West Africa and elsewhere. Its easy propagation, its remarkable resistance to diseases and pests and high yields under difficult conditions make it an excellent staple crop. More germplasm collection, taxonomic and agronomical research are badly needed. In South-East Asia too it deserves much more scientific attention.

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P.C.M. Jansen & V. Premchand

3 Minor species yielding non-seed carbohydrates

Abelmoschus crinitus Wallich

MALVACEAE

Synonyms *Hibiscus crinitus* (Wallich) G. Don, *H. cancellatus* Roxburgh, *Abelmoschus cancellatus* (Roxburgh) Voigt.

Distribution India, Pakistan, Burma (Myanmar), Indo-China, southern China, Indonesia (Java), and the Philippines (Mindoro).

Uses The tuberous roots are edible.

Observations Erect herb, up to 1.5 m tall with tuber-like taproot, aboveground parts often prickly pilose. Leaves orbicular or transversely elliptical in outline, 5–7-lobed, 10–15 cm × 7.5–12.5 cm, upper ones often smaller; petiole up to 18 cm long. Inflorescence consisting of solitary axillary flowers or partly racemose; epicalyx segments 10–16, linear, 2.5–5 cm long, persisting in fruit; flowers 10–12.5 cm in diameter, yellow with small purple centre. Fruit an ovoid, hispid capsule, 3.5–5 cm long, with numerous seeds. *A. crinitus* is found in lowland areas subject to a pronounced dry season, in grassy fields, waste places and in teak forests, up to 200 m altitude.

Selected sources 3, 37, 79, 87.

Alocasia (Schott) G. Don

ARACEAE

Major species and synonyms

- *Alocasia cucullata* (Loureiro) G. Don, synonyms: *Arum cucullatum* Loureiro, *Colocasia cucullata* (Loureiro) Schott.
- *Alocasia macrorrhizos* (L.) G. Don, synonyms: *Arum macrorrhizon* L., *Arum indicum* Loureiro, *Alocasia indica* (Loureiro) Spach. (often wrongly referred to as *Alocasia macrorrhiza* (L). Schott).
- *Alocasia portei* Schott, synonym: *Schizocasia portei* Schott ex Engler.

Vernacular names General: Elephant's-ear plant (En).

- *A. cucullata*: Chinese taro (En). Malaysia: bira. Thailand: wan-thorahot, wan-nokkhum, nangkwak. Vietnam: r[as]y.
- *A. macrorrhizos*: Giant taro, giant alocasia, elephant ear (En). Grande tayove (Fr). Indonesia: bira (general), sente (Javanese), mael (Timor). Malaysia: birah negeri, keladi sebaring. Papua New Guinea: abir, pia, via. Philippines: biga, bira, badiang. Burma (Myanmar):. pein-mohawaya. Cambodia: k'da:t haôra:. Laos: kaph'uk. Thailand: kradatdam, hora. Vietnam: khoai s[as]p, r[as]y, r[as]y [aw]n.
- *A. portei*: Philippines: badiang.

Distribution *Alocasia* contains about 60 species from tropical Asia, Australia and Oceania, often with subtropical extensions. Now cosmopolitan by introduction in ornamental horticulture, often naturalized in wet tropical areas. *A. cucullata* originates from China and possibly also from Indo-China. It is also cultivated (sometimes escaping) in India, Sri Lanka, Burma (Myanmar), Thailand and Peninsular Malaysia. *A. macrorrhizos* may have originated from Peninsular Malaysia, but has been introduced and often naturalized in the Malesian region and Oceania. *A. portei* is endemic to the Philippines (Luzon) and is occasionally cultivated elsewhere, e.g. in Peninsular Malaysia.

Uses The corms, cormels, stems and leaves are used as food, vegetable and forage, mainly in subsistence agriculture in South and South-East Asia and Oceania, but only *A. macrorrhizos* is really important and most widely used. It is a source of very white, easily digested starch or flour; boiled stems are used medicinally as a laxative; chopped-up roots and leaves act as a rubefacient; juice from the petiole is used against coughs. *A. portei* is only occasionally used for food in the Philippines. Most species are also important as ornamentals.

Observations Usually fleshy, large erect herbs, with thick starch-filled stems, with rhythmic or continuous growth and acrid, clear to milky sap; stems usually bearing short, slender, sometimes branched stolons or rhizomes terminating in small cormels. Leaves usually large with sheathing petiole and cordate-sagittate to hastate, sometimes peltate blades that are entire or deeply pinnatifid; venation usually conspicuous below. Inflorescence a spadix, usually paired; spathe tube-like at base with a lanceolate to oblong limb at the top; spadix monoecious, protogynous, finger-like, with female-flowered basal zone in the tube, sterile middle zone, male-flowered upper zone and ending with a conspicuous sterile appendix. Fruit a red to orange berry, several-seeded.

- *A. cucullata*: rhizome branched, tuberous; stem up to 50 cm long and 5 cm in diameter; leaves shortly peltate, shallowly cordate with very short basal lobes, up to 30 cm × 30 cm; petiole up to 75 cm long. Occurs in the lowlands, usually in open, wet locations.
- *A. macrorrhizos*: cormels rather large; stem 2–5 m tall, up to 30 cm in diameter; leaves sagittate, bluntly triangular in outline with strongly developed basal lobes, 25–75(–125) cm × 18–50(–75) cm; petiole up to 1.5 m long. Mainly known from cultivation, up to 1300 m altitude. Several forms and cultivars are known, varying mainly in leaf colour and size.
- *A. portei*: stem up to 60 cm tall and 12 cm in diameter; leaves ovate-sagittate, up to 2 m long, deeply pinnatifid with about 16 linear-lanceolate pinnae, dark metallic green; petiole up to 2 m long, marbled red-purple. Occurs in old clearings at medium altitude.

Propagation is possible by cormels or parts of cormels, and by seed if available. The crop usually needs 1–1.5 year. Long periods of drought or waterlogging are not tolerated. In many species all parts contain calcium oxalate crystals which can be removed by repeated cooking.

Selected sources 3, 5, 7, 9, 13, 14, 15, 19, 20, 25, 29, 32, 40, 43, 49, 51, 55, 58, 60, 69, 79, 81.

Aponogeton L.f.

APONOGETONACEAE

Major species and synonyms

- *Aponogeton lakhonensis* A. Camus, synonyms: *A. pygmaeus* Krause, *A. luteus* A. Camus, *A. monostachyon* A. Camus.
- *Aponogeton undulatus* Roxburgh, synonyms: *A. microphyllum* Roxburgh, *A. stachyosporus* de Wit.

Vernacular names

- *A. lakhonensis*: Cambodia: sbai mung. Thailand: phakkhuap. Vietnam: choi, rong, l[as] li[eex]u.

Distribution *Aponogeton* comprises about 40 species of aquatic plants, occurring in Africa (including Madagascar) and South and South-East Asia. *A. lakhonensis* occurs in India (Assam), Thailand, Cambodia, Vietnam, China (Canton) and Indonesia (Sulawesi); *A. undulatus* in India, Pakistan, Burma (Myanmar), Thailand and Peninsular Malaysia.

Uses The starchy tuberous rhizome of most species is edible and in times of famine can become an important food source. The leaves and inflorescences can be used as a vegetable. Most species are important worldwide as ornamentals for aquaria, e.g. *A. undulatus* is exported in large quantities from Thailand.

Observations Perennial aquatic plants with a tuberous, elongate or cylindrical, often branched, rhizome. Leaves submerged or floating, usually with conspicuous main and cross-veins. Inflorescence a long peduncled spadix, emerging above the water surface, composed of 1–11 spikes; flowers often bisexual, with 2 tepals, 6 stamens and 3(–5) ovaries.

- *A. lakhonensis*: rhizome elongated or obovoid, up to 2 cm in diameter; leaves very variable in shape and size, submerged ones up to 25 cm × 6 cm, floating ones smaller.
- *A. undulatus*: rhizome elongated, obovoid or globose, up to 2.5 cm in diameter; leaves with long petiole, up to 10–25 cm × 1–4 cm, alternately transparent or opaque in an irregular pattern, with undulating margins; the plant produces runners (resembling peduncles forming young plantlets at the top).

Aponogeton species occur in stagnant and running shallow water, mostly in the lowlands, but up to 1000 m altitude. *A. loriae* Martelli and *A. womersleyi* Bruggen occur in Papua New Guinea, *A. robinsonii* A. Camus (synonym: *A. eberhardtii* A. Camus) in Vietnam.

Selected sources 22, 24, 37, 49, 79, 81, 88, 89.

Arisaema Martius

ARACEAE

Major species and synonyms

- *Arisaema concinnum* Schott, synonym: *A. affine* Schott.
- *Arisaema speciosum* (Wallich) Martius ex Schott, synonym: *Arum speciosum* Wallich.

Vernacular names

- *A. speciosum*: Vietnam: thi[ee]n nam tinh.

Distribution *Arisaema* contains about 150 species, most in north-eastern Asia, a few on African mountains and in temperate North America. In tropical South-East Asia, only a few species occur at higher altitudes. *A. concinnum* occurs in the temperate Himalayas, from India (Assam) to Burma (Myanmar) and Tibet, whereas *A. speciosum* is found from India (Assam), Nepal to Bhutan and western China.

Uses The corms are rich in starch that only can be consumed after the numerous calcium oxalate crystals have been removed by boiling repeatedly. They are only consumed in times of scarcity. Sometimes corms are used as animal feed. No information is available on the edibility of South-East Asian species. Many species are important as ornamentals in the western world.

Observations Fleshy perennial herbs with subterranean subglobose to globose corms or thickened rhizomes. Leaves usually trifoliolate or pedately pinnatifid with 3–30 leaflets and long petiole. Inflorescence a solitary spadix, long-peduncled; spathe tube-like at base, with upper procurved blade; spadix unisexual or bisexual, usually with a naked appendix. Fruit a few-seeded ovoid berry.

- *A. concinnum*: up to 75 cm tall; corm globose; leaflets 7–11, oblong to lanceolate, 15–30 cm × 2–5 cm; petiole up to 60 cm long; spathe-blade ending in a very long decurved tail; spadix shorter than spathe, ending in slender appendix, usually unisexual; occurring at 1800–3000 m altitude.
- *A. speciosum*: up to 1 m tall; thickened rhizome horizontal, cylindrical, 7–9 cm × 2.5–6 cm; leaf only 1, trifoliolate; leaflets ovate to lanceolate, 20–45 cm × 8–12 cm; petiole up to 60 cm long; spathe-blade ending in a long decurved tail; spadix with appendix much longer than spathe, unisexual; occurring at 1900–3500 m altitude.

Arisaema species favour cool shady forest areas. Propagation is from corms or pieces of rhizome. In South-East Asia, the following species are possibly of interest because they have larger corms: *A. balansae* Engler (Thailand, Cambodia, Vietnam), *A. polyphyllum* (Blanco) Merrill (Indonesia-Sulawesi, Philippines) and *A. consanguineum* Schott (Himalaya, Burma (Myanmar), Thailand).

Selected sources 13, 20, 27, 37, 38, 40, 60, 79, 94.

Arracacia xanthorrhiza Bancroft

UMBELLIFERAE

Synonyms *Arracacia esculenta* DC.

Vernacular names Arracacha, white carrot, Peruvian parsnip (En). Arracacha, panème, pomme de terre céleri (Fr). Aracacha (Sp, South America).

Distribution Native to the South American Andean highlands from Venezuela to Bolivia. Introduced and cultivated also in the rest of South America, Jamaica, Puerto Rico, and Central America. Occasionally cultivated elsewhere, e.g. in India and Sri Lanka.

Uses Secondary tubers are starchy and eaten boiled or fried as a vegetable or as an ingredient in stews. Young stems are used in salads. Coarse main rhizomes and mature leaves are used as forage. In Brazil, arracacha is a popular vegetable. In Colombia it often replaces the potato.

Observations Perennial herb, about 1 m tall, glabrous, with hollow stem. Rhizome tuberous, subcylindrical, large; at maturity lateral roots emerge from its base which become tuberous; tubers smooth, resembling parsnips in texture, odour and colour; flesh white, creamy-yellow or purplish. Leaves alternate; petiole 15–30 cm long, sheathing at base; blade 15–23 cm long, ternately decompound, pinnae deeply and irregularly pinnatifid. Inflorescence a compound terminal umbel with small purple or yellow 5-merous flowers, central ones male, marginal ones bisexual. Fruit a schizocarp. It occurs in the Andes in valleys at 1800–2500 m altitude; in Brazil (Sao Paulo) successfully grown at 1000–1200 m. Propagation is from seed, but more often from lateral shoots produced on the crown of the tuberous rhizome (not from tubers). Optimum conditions are an average annual temperature of 15–20°C and an evenly distributed rainfall of 1000–1200 mm during the growing period of 8–12 months. Yield is up to 18 t/ha, or 6–10 tubers per plant together weighing 2–3 kg. Yellow-fleshed cultivars are preferred. Storage life of freshly harvested tubers is about 1 week at ambient temperatures; at low temperatures (e.g. 3°C) they can be stored longer. Arracacha is potentially an interesting crop for the tropical highlands in South-East Asia; the tubers contain 10–25% starch, which has a similar constitution to cassava starch.

Selected sources 11, 28, 31, 34, 36, 43, 54, 55, 61, 70.

Asparagus cochinchinensis (Loureiro) Merrill

LILIACEAE

Synonyms *Melanthium cochinchinense* Loureiro, *Asparagus lucidus* Lindley.

Vernacular names Cambodia: tumpèang. Vietnam: thi[ee]n m[oo]n d[oo]ng, t[us]t thi[ee]n nam, b[as]ch b[ooj].

Distribution The Philippines (northern Luzon), Taiwan, Japan, Korea, southern China, Indo-China.

Uses The tubers are eaten candied. They are also used medicinally against cough, sore throat and to allay thirst in wasting diseases.

Observations Dioecious herb with perennial rhizome and roots with distant, elongated fleshy tubers. Stem glabrous but with spines up to 0.5 cm long, erect, climbing or procumbent, with numerous spineless branches 10–30 cm long. True leaves reduced to small scales; in the axils of scale leaves on branches and stem tips 1–3 leaf-like branchlets (cladodes) are present, usually flat or less often 3-angled, linear-arcuate, 5–15(–40) mm × 0.5–1.5 mm. Flowers functionally unisexual, solitary or 2–3 together in the axil of scale leaves with cladodes; perianth segments 6, yellow-green to white, 2–3.5 mm long; pedicel articulated near or above the middle, 2–6 mm long; male flowers with 6 stamens, shorter than perianth, and rudimentary pistil; female flowers with obovoid ovary, 1–2 mm long, style with 3 stigmatic ridges and rudimentary stamens. Fruit a globose berry, 4–7 mm in diameter, green when ripe, with 1–4 seeds. *A. cochinchinensis* is usually found in arid areas, up to 1200 m altitude, on exposed slopes or in thickets, sometimes on coral or limestone substrates. It is closely related to and difficult to distinguish from *A. racemosus* Willdenow.

Selected sources 13, 22, 49, 51.

Asparagus racemosus Willdenow

LILIACEAE

Synonyms *Asparagus dubius* Decaisne, *Asparagopsis javanica* Kunth, *A. schoberioides* Kunth.

Vernacular names Indonesia: sangga langit (Java), niesie saub (Timor), skikirie (Tanimbar). Cambodia: më:m sa:m sö'b. Thailand: chuang-khrua (northern), samsip (central), phaknam (eastern).

Distribution Widespread in Africa and through southern Asia into China, Indo-China and Malesia to northern Australia. In Malesia, it occurs in Peninsular Malaysia and Indonesia (Java and from Lombok to Tanimbar).

Uses The tuberous roots are eaten candied in Indonesia ('manisan bek bun'). In India, a similar conserve is used medicinally against impotence and as a stimulant, restorative, demulcent, diuretic and anti-dysenteric. A lactogenic preparation is used to stimulate milk flow in cows. *A. racemosus* is sometimes planted as an ornamental.

Observations Herb with perennial rhizome and roots bearing distant, elongated fleshy tubers. Stem glabrous but with spines up to 1 cm long, usually climbing, 3–6 m long, with numerous solitary branches that branch again into final segments 5–10 cm long. True leaves reduced to small scales; the axil of scale leaves on branches and stem tips usually contain 2–3 leaf-like branchlets (cladodes) that are 3-angled, linear-crenate, 7–25(–40) mm × 0.5–1 mm. Flowers bisexual, fragrant, solitary or in pairs in the axil of scale leaves on branches usually lacking cladodes; perianth segments 6, white with a green band, 2–4 mm long; pedicel articulated near the middle, 3–5 mm long; stamens 6, up to as long as perianth; ovary obovoid, style 0.5 mm long with 3 stigmatic ridges or 3-lobed. Fruit a globose berry, 4–6 mm in diameter, red when ripe, with 1–3 seeds. *A. racemosus* is a distinctly drought-tolerant plant, bound to seasonal climates, from sea-level up to 1150 m altitude, often in coastal areas in sunny thickets and on dunes. It is closely related to and difficult to distinguish from *A. cochinchinensis* (Loureiro) Merrill.

Selected sources 3, 13, 22, 32, 49, 57, 79, 81, 95.

Calathea allouia (Aublet) Lindley

MARANTACEAE

Synonyms *Maranta allouia* Aublet, *Curcuma americana* Lamk.

Vernacular names Topee tambu, Guinea arrowroot, sweet corn tuber (En). Allélouia (Fr). Laren, leren, topitambou (Sp, Caribbean and South America). Vietnam: c[ur] l[uf]n, dong t[is]a.

Distribution Native to parts of the West Indies and the northern part of South America. Locally cultivated in its native area and occasionally elsewhere, also in South-East Asia.

Uses Tubers are eaten boiled like Irish potato. Although formerly locally used as a staple food, they are now eaten more as an occasional delicacy. Leaves are used in traditional medicine to treat cystitis and as a diuretic. Like most *Calathea* species, *C. allouia* is also grown as an ornamental.

Observations Perennial rhizomatous herb, 1–2 m tall, more or less pubescent, forming a clump of shoots; tubers developing at the end of fibrous roots, ovoid, 2–8 cm × 2–4 cm, orange-yellow to red, green or white. Leaves simple, papery; petiole long, sheathing; blade elliptical, 15–60 cm × 5–25 cm. Inflorescence terminal, spike-like, ellipsoid or ovoid, 6–10 cm long; peduncle 5–20 cm long; bracteoles 15–30, membranaceous, white; flowers in pairs, hermaphrodite, zygomorphic, 2.5–4 cm long, white; perianth segments differentiated into calyx with 3 free segments and tubular corolla with 3 lobes; androecium united to corolla with 1 petaloid fertile stamen and 3–4 petaloid staminodes; ovary trilocular. Propagation is from suckers or rhizome parts, as the tubers lack buds. About 9–14 months are required to produce a crop. Yields are up to 10 t/ha. *C. allouia* is a truly tropical lowland crop, requiring a high equable temperature (25–30°C) and a moderate rainfall (1500–2000 mm), similar to arrowroot (*Maranta arundinacea* L.). It is worth trying out in South-East Asia from sea-level up to 600 m altitude.

Selected sources 28, 31, 43, 50, 55, 56, 69.

Ceropegia cumingiana Decaisne

ASCLEPIADACEAE

Synonyms *Ceropegia horsfieldiana* Miquel, *C. curviflora* Hasskarl, *C. merrillii* Schlechter.

Vernacular names Australia: anareata.

Distribution Widespread in Malesia, from Indonesia (Java, Borneo) and the Philippines to Papua New Guinea and tropical Australia.

Uses The fleshy rhizome is edible; probably only used in times of food scarcity.

Observations Perennial, climbing, succulent, glabrous, deciduous herb, containing clear sap. Rhizome a cluster of white, fleshy, fusiform roots, each root up to 15 cm × 1–3 mm. Leaves opposite; petiole 2.5–4 cm long; blade ovate-elliptical, 2–13 cm × 1.5–7 cm. Inflorescence a cluster of 1–20 flowers at the nodes near the apex of the stem; peduncle up to 8 cm, pedicel to 2.5 cm long; sepals 5, linear-lanceolate; corolla tubular with 5 lobes, tube 12–20 mm × 3–6 mm, inflated at base, cream with purple blotches, the lobes connate near the tips. Fruit a pair of fusiform follicles, green-purple, up to 21 cm × 3–5 mm. Seed oblong, 14 mm × 2 mm, brown, with white coma up to 6 cm long. It occurs in mixed forest, forest borders, brushwood, up to 900 m altitude. In continental South-East Asia, several other tuberous *Ceropegia* species might be similarly used, e.g. *C. monticola* W.W. Smith (Burma (Myanmar), Thailand), *C. arnottiana* Wight (Burma (Myanmar), Thailand) and *C. lucida* Wallich (Burma (Myanmar), Thailand, Peninsular Malaysia).

Selected sources 3, 12, 39, 41, 60.

Codonopsis lancifolia (Roxburgh) Moeliono

CAMPANULACEAE

Synonyms *Campanula lancifolia* Roxburgh, *Campanumoea celebica* Blume, *C. lancifolia* (Roxburgh) Merrill, *Codonopsis celebica* (Blume) Thuan.

Vernacular names Indonesia: gordang-gordang (Sumatra), emlapagar (Sulawesi). Philippines: lakoronbolan (Bukidnon). Thailand: may-om-kaeo (northern). Vietnam: c[aa]y gai r[uwf]ng, d[awr]ng s[aa]m, ng[aa]n d[awf]ng.

Distribution From India throughout South-East Asia, southern China, Taiwan.

Uses The starchy rhizome, stems and leaves are used cooked as food and vegetable in times of scarcity.

Observations Sprawling or erect perennial herb, up to 3 m tall, glabrous to hairy, branched, with hollow stem and tuberous rhizome. Leaves opposite; petiole 3–15 mm long; blade ovate-elliptical, 3–14 cm × 1–4 cm, serrate. Flowers 7–15 mm in diameter, white to pale pink, axillary, solitary or in cymes of 3, through reduction of upper leaves resembling a terminal panicle; pedicel up to 6 cm long; calyx lobes 4–7, lanceolate; corolla tubular with 4–7 lobes; stamens 4–6; pistil with 4–6-celled ovary, style and 5–6 stigmas. Fruit a subglobular berry, up to 1 cm in diameter, whitish, with persistent calyx. Seeds numerous, with finely reticulated testa. It is often found in wet places in the open or along forest edges, streams, usually at altitudes of 300–1500 m. Other species in the region could have similar uses, e.g. *Codonopsis javanica* (Blume) Hook.f. (fruits also edible, rhizome used medicinally, all over South-East Asia).

Selected sources 3, 22, 24, 51, 57, 60, 96.

Corypha L.

PALMAE

Major species and synonyms

- *Corypha lecomtei* Beccari, synonym: *C. laevis* (Loureiro) A. Chev.
- *Corypha umbraculifera* L., synonym: *Bessia sanguinolenta* Raf.

- *Corypha utan* Lamk, synonyms: *C. elata* Roxburgh, *C. gembanga* (Blume) Blume.

Vernacular names

- *C. lecomtei*: Cambodia: trèang, sâmla:ng. Thailand: lan. Vietnam: l[as] bu[oo]n.
- *C. umbraculifera*: Talipot palm, great fan palm (En). Talipot, latanier (Fr). Burma (Myanmar): pe-pen. Laos: la:n. Thailand: lan (general), laang-mueng-thoeng (northern). Vietnam: khai, k[ef].
- *C. utan*: Gebang palm (En). Indonesia: gebang, gewang. Malaysia: ibus. Philippines: buri (Tagalog), ibus (Tagalog), silag (Ilokano). Thailand: lan, lan-phru (southern). Vietnam: l[as] bu[oo]n cao.

Distribution *Corypha* consists of about 8 species, mainly occurring in South-East Asia, extending to southern China, southern India and northern Australia. The distribution has probably been greatly influenced by humans through cultivation. *C. lecomtei* occurs in Indo-China and Thailand; *C. umbraculifera* is only known from cultivation, mostly from Sri Lanka, India, Burma (Myanmar), Thailand, and Indo-China; *C. utan* occurs throughout South-East Asia, Bangladesh, Assam (India), tropical Australia; in the Philippines, it ranks third in importance after coconut and nipa palm.

Uses Although most uses are reported for *C. utan*, it is assumed that the other species are or can be used similarly. When the palm approaches the flowering stage, sago can be obtained from the trunk. The starch is reddish, easily digestible, but only consumed by people in times of food scarcity. It is also used as pig food. Juice can be tapped from the palm tops (all leaves are removed; tree dies after tapping) or from the inflorescence (branches tied together, slices are cut off), from which palm wine, sugar, alcohol, or vinegar can be made. The wood of the stem is used to make drums or is split to serve as roof tiles. The young growing shoots are consumed cooked as a vegetable. Adult leaves are used for thatching, and to make umbrellas and coarse mats. The fibres of the petiole are used to make string and a famous type of hat (Philippine 'bangkok hats'). Young leaves are cut into strips and used to weave mats, bags, nets, and hats. A special kind of fibre is obtained by removing the epidermis of young leaves; the remaining part ('agel' or 'papas') is used to weave fine cloth, fishing nets, mats, etc. Formerly, leaves were also used as writing material. The young fruits are edible. Nearly-ripe fruits are toxic and are used as fish poison. Ripe seeds are as hard as ivory, and turn black; they are used to make buttons and rosary beads. In traditional medicine, juice of the roots is used against diarrhoea and coughs; the sago is applied for bowel complaints; the red-brown gum oozing from the apex of the palm is used against cough, dysentery, and is applied to wounds; a decoction of young plants is used against feverish colds. All *Corypha* palms are also occasionally planted as ornamentals.

Observations Massive, solitary, armed, hapaxanthic, hermaphroditic tree palms. Stem erect, closely ringed with leaf scars. Leaves induplicate, orbicular, costapalmate, withering early, tending to abscise under their own weight in trunked trees; petiole massive, long, deeply channeled, sharply-toothed margins; blade regularly divided to about half its radius into single-fold segments. Inflorescence a massive terminal much-branched structure, final branches ending as rachillae bearing spirally arranged adnate cincinni of up to 10 flowers, the whole inflorescence bearing up to 10 million flowers; calyx tubular, 3-lobed; petals 3, boat-shaped; stamens 6; ovary 3-grooved, globose. Fruit globose, single-seeded. Seed globose, germination remote-tubular.

- *C. lecomtei*: stem up to 10 m tall, 40–60 cm in diameter; petiole 8 m or longer; blade 4.5 m long with 50 segments; inflorescence about 2.5 m long; fruit 3–5 cm in diameter.
- *C. umbraculifera*: stem up to 25 m tall, up to 1 m in diameter; petiole 2–3 m long, blade 3–5 m long with 80–100 segments; inflorescence 3–8 m long; fruit 3–3.5 cm in diameter.
- *C. utan*: stem up to 30 m tall, 35–75 cm in diameter; petiole 2–5 m long, blade 1.5–3.5 m long with 80–100 segments; inflorescence 3–6 m long; fruit 2–2.5 cm in diameter.

The vegetative period lasts 30(–70) years, the flowering and fruiting period 1–2 years, after which the palm dies. The inflorescence is the largest among seed plants. Most *Corypha* palms are associated with human settlements. In the wild they are probably a feature of open seral communities such as alluvial plains or coastal forest. They do not occur in climax tropical rain forest. The group needs taxonomic clarification.

Selected sources 3, 9, 13, 17, 32, 40, 42, 48, 49, 57, 66, 69, 81, 85, 93, 94.

Costus speciosus (Koenig) J.E. Smith

ZINGIBERACEAE

Synonyms *Banksia speciosa* Koenig, *Costus sericeus* Blume, *C. nepalensis* Roscoe.

Vernacular names Crepe ginger, wild ginger, Malay ginger (En). Indonesia: tabar-tabar (Javanese), pacing (Sundanese), setawar (Sumatra). Malaysia: setawar, tawar, setengteng. Philippines: tubong-usa (Bikol), tiuasi (Subanum). Cambodia: trâthôk. Laos: 'üangz. Thailand: uang-maina (general), uang-yai (southern), uang-phetma (central). Vietnam: c[ur] ch[os]c, m[is]a d[of], d[os]t d[aws]ng.

Distribution Widespread from India throughout South-East Asia to Taiwan and Australia. Occasionally also cultivated and sometimes naturalized in other tropical areas, e.g. in southern America.

Uses The tuberous rhizome is eaten in times of food scarcity; on dry weight basis it contains about 66% carbohydrates, but is rather fibrous. Tender shoots are eaten as a vegetable. The rhizomes and seeds contain diosgenin (1.25-3% on dry weight basis) and β-sitosterol (sapogenins); the seeds also contain a sweet-smelling fatty oil. The juice from crushed leaves and young stems is used externally to treat eye and ear diseases, juice from fresh rhizomes is considered to be purgative. In Malaysia, *C. speciosus* is an important ceremonial plant, used as tonic, depurative and aphrodisiac. Rhizomes are eaten with betel against cough, and decoctions and bruised leaves are applied externally against skin diseases and fever. The saponins of the rhizome have significant anti-inflammatory and anti-arthritic activity.

Observations Perennial, much-branching herb, 2–3 m tall, glabrous to variously hairy, with rhizome that can become tuberous. Leaves spirally arranged; sheath 4 cm long, blade oblanceolate-acuminate, up to 23 cm × 6 cm. Inflorescence an ellipsoid cluster of cincinni, about 10 cm × 5 cm, terminal on a leafy shoot; corolla tubular, ending in lobes, 5–6 cm long, pinkish white; labellum curved, trumpet-shaped, 6–7 cm × 8–10 cm, white. Fruit bright red, dehiscing loculicidally. Seed black with fleshy white aril. *C. speciosus* occurs in forest edges and similar half open, rather wet locations, not in full forest shade, up to 1000 m altitude. Propagation is possible from seed, pieces of rhizome and by tissue culture.

Selected sources 3, 9, 13, 19, 20, 25, 32, 35, 49, 52, 53, 64, 81, 82, 84, 93, 94.

Dioscorea cumingii Prain & Burkill

DIOSCOREACEAE

Synonyms *Dioscorea echinata* R. Knuth, *D. inaequifolia* Elmer ex Prain & Burkill, *D. polyphylla* R. Knuth.

Vernacular names Philippines: lima-lima (Tagalog), kasi (Igorot), pari (Bagobo).

Distribution Throughout the Philippines.

Uses Tubers reportedly used as food in Luzon (Philippines).

Observations Perennial, dioecious herb with prickly stem twining to the left. Leaves palmately compound, 5–11-foliolate, herbaceous; petiole as long as middle leaflet; petiolule up to 1 cm long; leaflets lanceolate to elliptical, up to 18 cm long. Male flowering axes collected into large leafless branches up to 70 cm long, usually 2 axes together and unequal in length, up to 3 cm long; pedicel 0.5 mm long; 3 fertile stamens. Female flowering axes solitary or paired, angled, bearing more than 30 flowers. Capsule 2.5–4 cm long, wings up to 36 mm × 12 mm. Four botanical varieties have been distinguished based on number of leaflets, pubescence and length of capsule; the distinction is without much practical value. The usual habitat consists of areas with considerable rainfall close to mountains, up to 1400 m altitude.

Selected sources 22, 60.

Dioscorea divaricata Blanco

DIOSCOREACEAE

Synonyms *Dioscorea foxworthyi* Prain & Burkill, *D. oxyphylla* R. Knuth, *D. soror* Prain & Burkill.

Vernacular names Philippines: pakit, kiroi (Tagalog), dulian (Ilokano), bakliakang (Bisaya).

Distribution Philippines (Luzon, Panay, Cebu).

Uses Tubers used for food in the Philippines, baked, boiled or fried.

Observations Perennial, dioecious, glabrous herb with stem spiny at the base, twining to the right. Tubers slender, fleshy, spindle-shaped, up to 2 m long, 10 cm in diameter, borne solitary or several together on stalks up to 1 m long. Bulbils absent. Leaves simple, opposite, herbaceous; petiole up to 7 cm long; blade cordately sagittate to ovate-hastate, up to 16 cm × 8 cm, with divaricate, auriculate base. Male flowering axes 1–2 together on leafless branches up to 60 cm long, each bearing more than 30 sessile flowers. Female flowering axes solitary, up to 18 cm long. Capsule wings up to 21 mm × 22 mm. *D. divaricata* occurs in forests and thickets at low and medium altitudes; it is not cultivated because the tubers grow too deep in the soil. It is closely related to and much resembles *D. nummularia* Lamk which is common and widely distributed in eastern Malesia.

Selected sources 9, 22, 60.

Dioscorea filiformis Blume

DIOSCOREACEAE

Synonyms *Dioscorea gibbiflora* Hook.f., *D. myriantha* Kunth.

Vernacular names Indonesia: aroi huwi curuk (Sumatra), dudung (Java). Malaysia: wauh. Philippines: kiroi, kiru (Tagalog). Thailand: phakmaeo-daeng (southern), man-thian (central).

Distribution Thailand, Peninsular Malaysia, Philippines and Indonesia (but absent in the most equatorial parts).

Uses Tubers are used boiled as food in Peninsular Malaysia. Raw tubers burn the throat.

Observations Perennial, dioecious, glabrous herb with unarmed, cylindrical stem, twining to the right, often with bulbils. Tubers elongated, up to 50 cm long, 2 cm in diameter, with tender white flesh. Leaves simple, usually alternate but opposite on larger stems, herbaceous; petiole shorter than the blade; blade cordate to hastate, up to 10 cm × 7 cm, with auriculate base. Male flowering axes usually on leafless branches, sometimes in axillary fascicles, zigzagging, with a sessile flower on each angle. Female flowering axes solitary, up to 20 cm long, not zigzag. Capsule wings up to 24 mm × 22 mm, shiny when dry. It occurs in the lowlands, often on limestone cliffs or granite boulders.

Selected sources 13, 22, 60, 81.

Dioscorea glabra Roxburgh

DIOSCOREACEAE

Synonyms *Dioscorea siamensis* R. Knuth.

Vernacular names Thailand: man-dong (central), that, man-sai (southern).

Distribution From India, through Burma (Myanmar) and Thailand, to Peninsular Malaysia.

Uses Tubers are used for food in Peninsular Malaysia and in the Andaman Islands. They have a glutinous texture due to the characteristics of the starch.

Observations Perennial, dioecious, glabrous herb with stem armed at the base, twining to the right, up to 8 m long. Tubers usually single, deep in the soil on a long stalk, cylindrical, up to 50 cm long, 4 cm in diameter, with white flesh. Leaves simple, opposite or alternate, herbaceous; petiole usually 4–5 cm; blade long-cordate, up to 14 cm × 16 cm, with rounded, auriculate base. Male flowering axes 1–4 together, usually on leafless branches, up to 70 cm long, rarely in axillary fascicles, up to 4 cm long, with about 25 sessile flowers each. Female flowering axes solitary or in pairs, up to 40 cm long, with more than 50 flowers. Capsule wings 15–18 mm × 14–20 mm.
In general *D. glabra* is common. It is often difficult to distinguish from *D. nummularia* Lamk; its leaf blades are usually longer, and dry leaves and capsules are glaucous green (red-brown in *D. nummularia*).

Selected sources 11, 49, 81, 94.

Dioscorea laurifolia Wallich ex Hook.f.

DIOSCOREACEAE

Vernacular names Ghost's benzoin climber (En). Malaysia: akar kemenyan hantu, kemenyan batu, akar kemahang.

Distribution Peninsular Malaysia.

Uses In Peninsular Malaysia the tubers are used for food. In traditional medicine the raw tubers are used for poulticing sores, swellings and bites.

Observations Perennial, dioecious, slender herb, with unarmed stem, twining to the right. Tubers 1–2, not descending very deeply into the soil, with pink to red flesh. Leaves simple, alternate, coriaceous; petiole less than half of the length of the blade; blade lanceolate-ovate, but quite variable, sometimes auricled at the base, up to 16 cm × 5 cm. Male flowering spikes negatively geotropic, axes usually on leafless branches, up to 7 cm long, with 40–60 sessile flowers. Female flowering axes 1–2 together, up to 10 cm long. Capsule relatively large, 5 cm × 2.5 cm, wings up to 27 mm × 24 mm. It is common in the mountains of Peninsular Malaysia, up to 1200 m altitude. Flowers exhibit a strong scent of benzoin.

Selected sources 13, 22.

Dioscorea luzonensis Schauer

DIOSCOREACEAE

Vernacular names Philippines: pakit, mayatbang (Tagalog), kamengeg (Ilokano).

Distribution Philippines (Luzon, Palawan).

Uses Tubers are often used for food. Harvesting the tubers is laborious, but is rewarding because the plant is abundant in the wild. It is not cultivated.

Observations Perennial, dioecious herb with unarmed stem, twining to the right. Tuber 1 per year, subclavate, up to 5 cm in diameter, up to 1 m deep in the soil, with white to pinkish-white flesh. *Bulbils absent. Leaves simple, usually alternate*, opposite on thicker stems; petiole as long as the blade; blade cordate, up to 15 cm × 12 cm, herbaceous, auricles somewhat hastately extended. Male flowering spikes negatively geotropic; axes 2–4 together in fascicles in the axil of upper leaves, up to 7 cm long, with about 60 sessile, relatively large flowers. Female flowering axes solitary, up to 22 cm long, with up to 35 flowers. Capsule wings up to 22 mm × 15 mm, ashy-green when dry. The species is abundant at low elevations in areas with a drier period in the prevailing climate (e.g. around Manila). Starch grains of the tuber are round to oval, averaging 35 µm × 26 µm. *D. luzonensis* resembles *D. divaricata* Blanco, but the tubers do not reach as deep and the stems are not spiny.

Selected sources 9, 22, 60.

Dioscorea orbiculata Hook.f.

DIOSCOREACEAE

Vernacular names Indonesia: ubi garam. Malaysia: takob, ubi garam, janggut kelonak. Thailand: man-tayong (southern).

Distribution Southern Thailand, Peninsular Malaysia, Sumatra (Indonesia).

Uses Well-boiled tubers are used as food in Peninsular Malaysia; raw tubers burn the throat.

Observations Perennial, dioecious herb with stem sparingly armed at the base, twining to the right, up to 10 m long, pubescent. Several tubers produced each year, on stalks up to 2 m long, elongated, white fleshy. Bulbils absent. Leaves simple, usually opposite, rather firm; petiole up to 10 cm long, pubescent; blade orbicular-ovate-cordate, up to 18 cm × 14 cm, glabrescent, long acuminate. Male flowering axes 1–6 together, usually on leafless branches up to 70 cm long, rarely in axillary fascicles, up to 6 cm long and bearing more than 50 sessile flowers, covered with brown dendroid hairs. Female flowering axes solitary, up to 15 cm long, bearing more than 30 flowers, covered with brown hairs. Capsule wings up to 30 mm × 26 mm. *D. orbiculata* is rather common in Perak (Peninsular Malaysia).

Selected sources 13, 22, 81.

Dioscorea piscatorum Prain & Burkill

DIOSCOREACEAE

Synonyms *Dioscorea borneensis* R. Knuth.

Vernacular names Fish-poison yam (En). Indonesia: tuba gunjo (Batak). Malaysia: tuba ubi (Peninsular), tubah podeh gantung (Borneo).

Distribution Peninsular Malaysia, northern Sumatra, Borneo.

Uses Tubers are eaten roasted; if boiled or inadequately baked they remain bitter. The tubers contain a toxic saponin and are used as a substitute for *Derris elliptica* (Sweet) Bentham as fish poison in fishing and as insecticide to kill parasitic worms in rice. The poison is destroyed by heat and is less effective than that of *Derris*.

Observations Perennial, dioecious, glabrous herb with woody, prickly stem, twining to the left. Tubers arising in axils where the base of the stem touches the soil surface, numbering more than one, clavate, unarmed or with short roots becoming thorny, some coming aboveground; skin brown-red, flesh dark red. Leaves simple, chartaceous; petiole shorter than the blade, with scattered small prickles; blade ovate to cordate, up to 18 cm × 14 cm, prominently veined. Flowering and fruiting have rarely been observed, probably because flowering does not occur until the climber has topped the forest.

Selected sources 13, 22.

Dioscorea polyclades Hook.f.

DIOSCOREACEAE

Synonyms *Dioscorea polyclades* Hook.f. var. *oblongifolia* Uline ex Knuth and var. *velutina* (O. Kuntze) Burkill.

Vernacular names Indonesia: kedut (Sumatra). Malaysia: kedut (peninsular).

Distribution Peninsular Malaysia, Indonesia (Sumatra, Java).

Uses Tubers are used in Peninsular Malaysia for food after boiling several times or after baking.

Observations Perennial, dioecious, pubescent herb up to 30 m long, twining to the right. Tubers are produced more than one per year from a woody corm, up to 2.5 m deep in the soil, as elongated swollen ends of long stalks, with white flesh. Bulbils absent. Leaves simple, opposite, herbaceous; petiole up to 6 cm long, often prickly; blade elliptical-cordate, 12–25 cm × 12–22 cm. Male flowering axes 1–4 together on axillary leafless branches up to 30 cm long, up to 2.5 cm long, with 20 or more closely packed sessile flowers. Female flowering axes up to 20 cm long, bearing tawny hairs. Capsule wings up to 25 mm × 20 mm. *D. polyclades* occurs in lower hill forest, up to 700 m altitude. It much resembles *D. pyrifolia* Kunth which has less cordate leaves.

Selected sources 13, 22.

Dioscorea prainiana R. Knuth

DIOSCOREACEAE

Synonyms *Dioscorea deflexa* Hook.f., non Grisebach, *D. maliliensis* R. Knuth.

Vernacular names Malaysia: ubi kelonak, kelunoh, kelana.

Distribution Peninsular Malaysia, Singapore, north-eastern Sumatra, central Sulawesi.

Uses Tubers are used for food in Peninsular Malaysia, boiled or roasted. If not adequately cooked they taste bitter. In traditional ceremonial practices, tuber juice is dropped onto the mouth of new-borns to open the mouth.

Observations Perennial, dioecious herb with unarmed stem up to 16 m long, twining to the right. Tuber 1, subglobose, up to 30 cm long, 15 cm in diameter, at the end of a stalk in the soil up to 30 cm long, with yellow flesh, weighing up to 20 kg. Bulbils absent. Leaves simple, herbaceous, alternate on thin stems, opposite on thicker stems; petiole up to 6 cm long, less than half the length of the blade; blade ovate-elliptical, up to 15 cm × 7 cm. Male flowering axes together on decurved leafless branches up to 60 cm long, up to 8 cm long with more than 60 flowers each. Female flowering axes up to 50 cm long. Capsule relatively large, the wings up to 25 mm × 30 mm. It occurs up to about 500 m altitude.

Selected sources 13, 22.

Dioscorea puber Blume

DIOSCOREACEAE

Synonyms *Dioscorea anguina* Roxburgh, *D. cornifolia* Kunth.

Distribution Widely distributed in northern India, its natural home, with outposts in southern India and in Indonesia (Sumatra, Java).

Uses The tubers are used for food in India.

Observations Perennial, dioecious, pubescent herb with warted but unarmed stem, twining to the right. Tubers 1–2 each year, up to 2 m deep in the soil on long stalks, up to 8 cm in diameter, with tawny-orange skin and lemon-yellow, fibrous flesh. Bulbils large. Leaves usually alternate; petiole as long as the blade; blade ovate-cordate, 12–24 cm × 9–20 cm, lower surface always pubescent, upper side glabrescent, margin hyaline. Male flowering axes 1–2 together on leafless branches up to 18 cm long, up to 2 cm long with 30 or more sessile flowers each. Female flowering axes 1–3 together, up to 15 cm long with up to 40 flowers each. Capsule wings up to 15 mm × 18 mm. Sometimes remarkable large leaves are present. In Java, ripe fruits have never been observed.

Selected sources 22.

Dioscorea pyrifolia Kunth

DIOSCOREACEAE

Synonyms *Dioscorea diepenhorstii* Miquel, *D. oppositifolia* L. sensu auct. mult., *D. zollingeriana* Kunth.

Vernacular names Marsh benzoin climber (En). Indonesia: huwi upas (Sundanese), ilus (Javanese). Malaysia: akar kemenyan paya, ubi babi, badak.

Distribution Malaysia and Indonesia (Sumatra, West Java, Kalimantan).

Uses In Peninsular Malaysia the tubers are eaten after baking or 2–3 boilings. Raw tubers are used in Malaysian traditional medicine for poulticing sores, swellings and bites. In Indonesia, stems are used for cordage and wickerwork.

Observations Perennial, dioecious herb with stem usually abundantly armed at the base, twining to the right, up to 10 m long, glabrescent. Tubers are produced more than one per year from a woody corm, up to 2.5 m deep in the soil, as elongated swollen ends of long stalks, with white flesh. Bulbils absent. Leaves simple, usually opposite, herbaceous; petiole up to 4.5 cm long; blade ovate-elliptical with a cordiform base, up to 11 cm × 8 cm, pubescent, acuminate with large glands on acumen, hastate when young. Male flowering axes 1–4 together on leafless branches, up to 5 cm long, pubescent, bearing about 50 sessile flowers. Female flowering axes usually in pairs, up to 24 cm long, pubescent. Capsule wings 18–20 mm × 22 mm. *D. pyrifolia* is confined to per-humid climates, favouring wet, sunny locations (roadsides and river banks), up to 700 m altitude or higher. The flowers smell of benzoin. The tubers are considered as an emergency food, as they are difficult to dig up. Five botanical varieties of little practical value have been distinguished on the basis of prickliness of the stems and hairiness of the leaves. *D. pyrifolia* closely resembles *D. nummularia* Lamk which is, however, completely glabrous.

Selected sources 13, 22, 32, 94.

Eriosema chinense Vogel

LEGUMINOSAE

Vernacular names Indonesia: katil. Philippines: katil (Igorot), kitkitil (Bontok), kutil (Iloko). Cambodia: té:l (Mondulkiri), té:l tuëng' (Kampot). Laos: kh'o:nz ko:ng (general), daj kuab tang (Vientiane). Thailand: haeo-dam (northern), haeo-pradu (central), man-chang (southern). Vietnam: mao t[uwr] trung qu[oos]c.

Distribution From India, throughout South-East Asia to China and tropical Australia.

Uses Tubers are edible, containing about 30% starch on dry weight basis.

Observations Perennial, erect herb, up to 90 cm tall. Stem with few or no branches, covered with long red-brown hairs, the base thickened into a subterranean oblongoid tuber. Leaves unifoliolate, alternate, pubescent; stipules filiform, 4 mm long, persistent; petiole hirsute, 2 mm long; blade linear to oblong-elliptical, up to 8 cm × 2 cm. Flowers about 7 mm long, solitary or up to 3 together in a short axillary inflorescence up to 1.5 cm long; calyx campanulate, 5-lobed; corolla pale bright yellow, sometimes with some purple stripes. Fruit a broadly oblong-elliptical legume, 7 mm × 10 mm, dehiscent, blackish, covered with long red-brown hairs. Seeds 2, reniform, 2 mm × 1 mm, black. It occurs in grassland, savanna, open forest, roadsides, often in wet locations, sometimes as a weed, up to 2000 m altitude.

Selected sources 3, 24, 49, 60, 75, 79, 81, 91.

Eugeissona Griffith

PALMAE

Major species and synonyms

- *Eugeissona insignis* Beccari.
- *Eugeissona utilis* Beccari.

Vernacular names

- *E. insignis*: Indonesia: jato, kajatao (Kalimantan). Malaysia: pijatau (Sarawak).
- *E. utilis*: Wild Bornean sago palm (En). Indonesia, Malaysia: kajatao (Borneo).

Distribution *Eugeissona* is restricted to Peninsular Malaysia (2 species) and Borneo (4 species). *E. insignis* and *E. utilis* only occur on Borneo; *E. utilis* is also semi-cultivated.

Uses Sago from the stems forms the staple food of the nomadic Dayak Punan people of Borneo (especially from *E. utilis*) and emergency food for other people. Palm cabbage is used as a vegetable. Leaves provide thatch. Petioles are used in the manufacture of blinds, blowpipe darts and toys, and the pith of the petioles for the occlusions on blowpipe darts. The young endosperm of the seeds, and the pollen are edible. The stilt roots are useful for making walking sticks, umbrella handles and, after splitting, for wickerwork.

Observations Clustering, spiny, hapaxanthic, polygamous palms with stems often supported by stilt roots, and sympodially branching by basal suckers. Leaves pinnate, arranged spirally, with spiny sheath; petiole robust, deeply furrowed, usually densely spiny; leaflets single-fold, numerous, linear to lanceolate. Inflorescence terminal, richly branched, erect, with numerous rachillae each comprising a cupule of 7–11 imbricate, leathery bracts enclosing a single dyad of a staminate and a hermaphroditic flower; the staminate flower opens and sheds long before exsertion of the hermaphroditic flower; petals woody, very large; stamens 21–70. Fruit ovoid, beaked, with very small, not clearly ordered scales, fibrous mesocarp and woody endocarp. Germination remote-ligular.

- *E. insignis*: stilt roots 1–3 m long; stem 2–5 m tall, bearing up to 9 spiny leaves which are 10–13 m long; inflorescence 6–10 m tall, flowers 8–9 cm long; fruit about 10 cm long, 6 cm in diameter. It occurs on steep slopes and cliffs of coastal forests near sea-level and in coastal mountains up to 700 m altitude.
- *E. utilis*: stilt roots short, numerous; stem up to 9 m tall and 20 cm in diameter; leaves large; inflorescence about 2 m long, flowers slender, up to 8–9 cm long; fruit 10 cm long, 5 cm in diameter. It is associated with poor soils with abundant humus, particularly on scarp faces or sharp ridgetops. Propagation from seed is easy; stems are harvestable 5 years after sowing in good soil (at the onset of flowering). The sago seems to be of a better quality than that of *Metroxylon sagu* Rottboell.

Selected sources 6, 13, 17, 18, 21, 32, 42, 83, 85.

Flemingia procumbens Roxburgh

LEGUMINOSAE

Synonyms *Flemingia vestita* Bentham ex Baker, *Moghania procumbens* (Roxburgh) Mukerjee, *M. vestita* (Bentham ex Baker) Kuntze.

Vernacular names Sohphlong (En, India).

Distribution From northern India through continental South-East Asia and southern China to the Philippines. Also cultivated in India (Assam).

Uses The tubers are edible and can be eaten raw; they are rich in starch.

Observations Small subshrub up to 1 m tall. Roots becoming tuberous, tubers fusiform, smooth, soft, 3–5 cm long. Leaves digitately trifoliolate; petiole 1–2 cm long; stipules lanceolate, 0.5 cm long; leaflets oblong, 4–6 cm × 2–3 cm, pubescent. Inflorescence a compact axillary raceme, 2 cm long; bracts lanceolate, 6–7 cm long; calyx tubular with 5 long lobes; petals unguiculate, red to purplish. Fruit an oblong, inflated legume, 7 mm long, containing two blackish reniform seeds 2 mm long. It occurs in savanna vegetation and on roadsides at 1000–3000 m altitude. In India, cultivated *F. procumbens* has a growing period of about 7 months and tuber yields amount to 10 t/ha.

Selected sources 13, 24, 26, 55, 63, 73, 78, 79, 94, 95.

Habenaria Willdenow

ORCHIDACEAE

Major species and synonyms
- *Habenaria multipartita* Blume ex Kränzlin.
- *Habenaria rumphii* (Brongniart) Lindley, synonyms: *Platanthera rumphii* Brongniart, *Habenaria stauroglossa* Kränzlin, *H. dahliana* Kränzlin.

Vernacular names *H. multipartita*: Indonesia: uwi-uwi (Javanese).

Distribution *Habenaria* comprises 600–800 species, occurring in all continents (except Antarctica). *H. multipartita* is only known from Java (Indonesia). *H. rumphii* is widespread all over South-East Asia but seems to be absent from Peninsular Malaysia and Sumatra.

Uses Although many *Habenaria* species have tuberous roots, only the 2 mentioned here are known to be used as food. In times of emergency many more tuberous orchid species could provide food.

All *Habenaria* species have ornamental value. *H. multipartita* has fragrant flowers that have an especially strong scent during the first part of the night.

Observations Erect, simple, terrestrial herbs, with tuberous roots or with a rhizome. Leaves not articulate, convolutive, acute, herbaceous. Flowers in a terminal erect raceme or spike; petals entire or 2-partite; lip spurred, 3-lobed or 3-partite; lateral lobes often divided into narrow segments along the outer margin; column very short, with a tubercular outgrowth on either side of the anther; anther erect, pollinia 2; rostellum usually small; stigmas 2.
- *H. multipartita*: 40–60 cm tall; roots tuberous; leaves 6–7, linear-lanceolate, 14–30 cm × 1.5–2.5 cm; raceme up to 18 cm long with many large, green, scented flowers. It occurs in sunny to slightly shaded, grassy locations, at 1300–2500 m altitude.
- *H. rumphii*: 20–70 cm tall; tubers terete, up to 4 cm long, 0.5 cm in diameter; leaves about 4, linear apiculate, 7–15.5 cm × 8–10 mm; raceme 3–6 cm long, with many white (seldom yellow or purplish) flowers. It is very variable, occurring in grassy vegetations up to 400 m altitude.

Selected sources 3, 7, 32, 46, 47, 49, 77.

Halopegia blumei (Koernicke) K. Schumann

MARANTACEAE

Synonyms *Maranta blumei* Koernicke, *Clinogyne blumei* (Koernicke) Bentham, *Donax blumei* (Koernicke) K. Schumann.

Vernacular names Indonesia: jelantir (Javanese), patat (Sundanese), langkuwas (Kangean). Laos: to:ng chi:ng (Xieng Khouang). Vietnam: dong nam.

Distribution Indonesia (Java, Madura, Kangean), Laos, Vietnam.

Uses The tubers are eaten cooked or roasted, especially in times of food scarcity, and said to be rather savoury, reminiscent of turnip (*Brassica rapa* L.). The leaves are occasionally used as wrapping material.

Observations Tillering, erect herb, 30–75 cm tall, with numerous horizontal rhizomes which are swollen at the top into 3–4-jointed tubers up to 2.5 cm long. Leaves 4–8, distichous; petiole 15–25 cm long, sheathed; blade elliptical, 12–28 cm × 5–11 cm, apex abruptly caudate, very thin. Inflorescence terminal or axillary, spiciform, pubescent; peduncle up to 15 cm long; spike 15–20 cm long, with about 10 bracts 5–10 cm long; flowers in pairs, one sessile, one on a 0.5 cm long, winged pedicel, white; calyx lobes very unequal; corolla lobes narrow; androecium with 1 fertile stamen and 4 petaloid staminodes; ovary trilocular. Fruit a 1-seeded caryopsis, about 8 mm long. It occurs in shady locations (e.g. teak forest) on heavy soil, up to 350 m altitude, often in groups together. In Java, aerial parts die off towards the end of the rainy season. Propagation is from tuber or from seed.

Selected sources 3, 32, 49, 66, 93.

Oxalis tuberosa Molina

OXALIDACEAE

Synonyms *Oxalis crenata* Jacquin, *O. crassicaulis* Zuccarini, *O. arracacha* G. Don.

Vernacular names Oca (En, Sp, South America). Truffette acide (Fr).

Distribution Oca is only known from cultivation; it was domesticated in ancient times in the Central Andes of Peru and Bolivia. At present it is cultivated in the Andes from Venezuela to Chile and occasionally elsewhere, e.g. in Mexico, New Zealand, southern Europe. It is most important in Colombia and Peru.

Uses The tubers form one of the principal carbohydrate foods for the Indians of the high Andes and are eaten boiled, roasted or candied. Oca is sometimes considered as the second most important root crop of the high Andes after Irish potato. For preservation, harvested tubers are dried. Dried tubers of bitter cultivars are called 'chuña', those of sweet cultivars are called 'cavi'. Chuña is usually soaked and then used as an ingredient in stews, cavi is eaten often cooked with honey or cane sugar syrup. The chemical composition of oca tubers on dry weight basis is approximately: protein 3–8%, fat 0.5%, carbohydrates 83–89%, fibre 4–5%, ash 2–3%. The energy value per 100 g edible portion is about 1550 kJ. Some cultivars contain calcium oxalate crystals in the tubers.

Observations Perennial, erect herb, often grown as an annual, pubescent, about 30 cm tall. Rhizome branched, the ends thickening into cylindrical tubers 5–7.5 cm long, 2–4 cm in diameter, white, yellow, red or purple. Leaves alternate, trifoliolate; petiole 7–10 cm long; leaflets obcordate, up to 25 mm × 22 mm, incised at apex. Inflorescence a 5–8-flowered umbel on peduncle 15–17 cm long; pedicel 7–20 mm long; flowers yellow, 5-merous, trimorphic, i.e. associated with 3 distinct tuber forms: long-styled with sweet tubers, mid-styled with white and short-styled with red tubers. Fruit a capsule with 1–3 seeds.

There are many cultivars. The best crop is grown at altitudes of 2700–4200 m. Propagation is by planting whole tubers or pieces with 1–3 eyes. Planting distance 50–90 cm between rows, 20–40 cm in the row. Tubers are harvestable 8 months after planting, yield is 4–5(–20) t/ha. Oca is a promising crop for the cooler parts of the tropical highlands of South-East Asia, suffering less from diseases and pests than Irish potato.

Selected sources 11, 20, 28, 31, 33, 40, 43, 44, 45.

Phoenix sylvestris (L.) Roxburgh

PALMAE

Synonyms *Elate sylvestris* L. (p.p.).

Vernacular names Wild date palm, date sugar palm (En). Thailand: inthaphalam-thai (south-western).

Distribution Wild in the Indus basin (Pakistan). Cultivated throughout the plains of India, Sri Lanka, Burma (Myanmar), south-western Thailand and occasionally elsewhere.

Uses Sap is extracted from the top of the palm. It can be drunk directly as palm juice, but is often boiled down into sugar or fermented and distilled to produce a strong alcoholic beverage. The leaves are used to make mats and baskets. The fruits and seeds are edible. A kind of sago can be extracted from the stem and the wood can be used for construction and fuel. *P. sylvestris* is also widely cultivated as an ornamental.

Observations A solitary, dioecious, glabrous, pleonanthic palm with stem up to 15 m tall and 30 cm in diameter, covered with persistent leaf bases. Leaves induplicate, pinnately compound, 2–4.5 m long; petiole short, bearing a few long sharp spines towards the apex; leaflets numerous, linear, 10–30 cm × 1–2.5 cm, glaucous, rigid, basal ones modified as spines. Inflorescence an interfoliar, branched spadix, up to 1 m long, male and female ones superficially similar; spikes numerous, in clusters, 10–30 cm long; male flowers angular, dense, with cupular 3-lobed calyx and 3 petals much exceeding the calyx, stamens 6; female flowers globose, distant, perianth as in male flowers, carpels 3. Fruit usually developing from 1 carpel, follicular, oblong-ellipsoid, 2–3 cm long, yellow to orange, exocarp smooth, mesocarp fleshy, endocarp membranous, 1-seeded. Germination remote-tubular.

P. sylvestris occurs in coastal plains, but is cultivated up to 1500 m altitude. It might be the wild ancestor of the date palm *P. dactylifera* L. Sap extraction from the side of the crown may start when the palm is 7–10 years old (trunk 1.20 m tall) and can continue for 20–25 years. Annual yield per palm amounts to 100 l juice, which can be converted into about 3 kg sugar. *P. acaulis* Buch.-Ham. ex Roxburgh (India, Burma (Myanmar), Thailand, Laos) and *P. rupicola* T. Anderson (eastern Himalayas) may have uses similar to *P. sylvestris*.

Selected sources 4, 13, 16, 25, 27, 30, 37, 40, 42, 48, 57, 73, 81, 85, 94.

Pholidocarpus ihur (Giseke) Blume

PALMAE

Synonyms *Borassus ihur* Giseke.

Vernacular names Indonesia: woka hutan (Moluccas), ihur (Ambon), ibul (Buru).

Distribution Indonesia (Sulawesi, Moluccas). Occasionally cultivated elsewhere (e.g. in Java).

Uses The stem is sometimes used for sago extraction, but its quality seems to be inferior. The leaves may be used for thatch, wrapping and water containers. The wood is hard and is sometimes used as timber.

Observations Robust, solitary, armed, pleonanthic, hermaphroditic tree palm with erect stem ringed with inconspicuous close leaf scars. Leaves fan-like, induplicate, costapalmate; petiole 1–3 m long, along the margins with robust, bulbous-based, horizontal spines; blade divided by deep splits into 3–4-fold segments which are further divided by shallower splits into single-fold segments. Inflorescence interfoliar, arching out of the crown, much-branched, about 1.5 m long; flowers sessile, yellow, bisexual; calyx cup-shaped, shallowly 3-lobed; corolla deeply divided into 3 lobes; stamens 6, filaments united into a tube; gynoecium 3-carpellate with slender style. Fruit developing from 1 carpel, globose, drupaceous, about 6 cm in diameter, brown; exocarp cracked into numerous low corky brown warts, mesocarp subfleshy, endocarp crustaceous with short fibres outside. Seed with massive endosperm. Germination remote-tubular. It occurs in the lowlands, often in waterlogged soils. The genus *Pholidocarpus* Blume is closely related to *Livistona* R. Brown; it is distinguished by the deeply divided leaves with compound segments and the very large, often corky-warted fruits.

Selected sources 3, 32, 42, 46, 85.

Psoralea esculenta Pursh

LEGUMINOSAE

Synonyms *Pediomelum esculentum* (Pursh) Rydberg.

Vernacular names Indian breadroot, prairie potato, Indian turnip (En, Am). Navet de prairie, pomme blanche, pomme de prairie (Fr).

Distribution North America (southern Canada, United States), occasionally cultivated elsewhere.

Uses The tubers were used by the American Indians like Irish potatoes. Flesh of the tuber dries quickly in the sun, producing a hard cake that can be stored safely for long periods. The cake is ground into a flour and can be used year-round to make bread or for thickening soups.

Observations Rather stout erect, slightly branched, pubescent, perennial herb, up to 50 cm tall with roots thickening to potato-like tubers or to fusiform, large carrot-like tubers with white flesh. Leaves palmately compound, 5-foliolate; petiole usually much longer than blade; leaflets ovate or obovate, 2–6 cm × 0.8–2 cm. Inflorescence a dense, oblongoid spike, up to 10 cm long; flowers bluish. Fruit an oblongoid glabrous legume, up to 0.5 cm long, slightly wrinkled, enclosed in the calyx tube. Seed brown. *P. esculenta* occurs on marginal soils in prairies and plains. Propagation is from seed. It might be of interest for the drier highlands of South-East Asia. The tubers have a protein content of more than 7% (dry weight basis) and are said to have an agreeable flavour and texture. Other *Psoralea* species might have similar properties, e.g. *P. patens* Lindley and *P. cinerea* Lindley (from Australia; growing under adverse, dry conditions; tubers contain 5–7% protein on dry weight basis), *P. hypogaea* Nutt. (from central to southern United States; similar to *P. esculenta* but smaller). Tuber-bearing *Psoralea* species certainly deserve more scientific attention.

Selected sources 2, 30, 40, 62.

Pueraria lobata (Willdenow) Ohwi

LEGUMINOSAE

Synonyms

- var. *lobata*: *Pueraria thunbergiana* (Sieb. & Zucc.) Bentham, *P. hirsuta* (Thunb.) Matsumura, *P. triloba* (Houtt.) Makino;
- var. *montana* (Lour.) van der Maesen: *Dolichos montanus* Lour., *Pueraria tonkinensis* Gagnepain, *P. montana* (Lour.) Merrill;
- var. *thomsoni* (Bentham) van der Maesen: *Pue-*

raria thomsoni Bentham.

Vernacular names General: kudzu (En).
- var. *lobata*: Kudzu, Japanese arrowroot (En). Koudzou (Fr). Indonesia: bitok (Madurese), tobi (Sundanese), tebi (Kangean). Papua New Guinea: owitu (Asaro), kopitu (Kainantu), oka moi (Medlpa). Philippines: baai (Igorot), tahaunon (Manubo). Thailand: tamyakhrua. Vietnam: cu nang, cu s[aws]n d[aa]y.
- var. *montana*: Taiwan kudzu (En). Laos: chüa tau kung (northern), khauz pièd (northern). Vietnam: d[aa]y cae lan, d[aa]y dan, s[aws]n d[aa]y.
- var. *thomsoni*: Thomson's kudzu (En). Thailand: phakphit. Vietnam: d[aa]y c[as]t c[aw]n, s[aws]n d[aa]y.

Distribution From eastern India throughout South-East Asia, China, Japan and Pacific Islands. Now widespread in other tropical and subtropical areas, cultivated and often naturalized. Var. *lobata*, originally from China and Japan, is the main variety introduced elsewhere. Var. *montana* originates from Indo-China, southern China, Taiwan and the Philippines, var. *thomsoni* from north-eastern India to Indo-China and the Philippines.

Uses Kudzu produces edible tubers, useful stem fibres, its leaves, shoots and flowers can be used as vegetable and for silage or hay, and it is a useful erosion-controlling soil cover, shade plant and medicinal plant. The tuber is esteemed for its fine starch, used especially in China, Japan and Papua New Guinea for sauces, soups, jelled salads, noodles, porridges, jelly puddings, confectionary and beverages. Japan produces over 300 t per year. Elsewhere in South-East Asia the tubers are used in times of famine. The stem fibres are used for binding (ropes), weaving (clothes, fishing lines, baskets) and for paper production. It is excellent for fodder and silage, if mixed with grass. It is effective for erosion control, provided its growth is controlled well; its aggressive growth may lead to entire forests being covered and trees dying, as has been experienced in the United States. Medicinally the starch is used in Japan to restore intestinal and digestive disorders, taken in soups or teas. Tea from the tubers is used in China against colds, influenza, diarrhoea, dysentery and hangovers. The flowerbuds are used as a diaphoretic and febrifuge medicine. Kudzu is also popular as an ornamental climber with fragrant flowers.

Observations Perennial, pubescent, woody climber with very large oblongoid tubers up to 2 m long, 18–45 cm in diameter, weighing up to 180 kg when old. Branches strong, up to 30 m long and up to 10 cm in diameter. Leaves alternate, pinnately trifoliolate; petiole 8–13(–21) cm long, rachis 1.5–7 cm long, petiolules 4–10 mm; leaflets ovate to orbicular, 8–26 cm × 5–22 cm, entire to trilobed. Inflorescence usually an unbranched elongate pseudoraceme up to 35 cm long with 3 flowers per node; calyx campanulate with 5 unequal teeth; petals purplish to blue or pink, often with a yellow or green spot, up to 25 mm long; stamens 10, monadelphous or with one free stamen. Fruit a flattened oblongoid pod, straight to falcate, 4–13 cm × 0.6–1.3 cm, golden-brown hairy, with 5–15 seeds. Seed flattened-ovoid, 4–5 mm × 4 mm × 2 mm, red-brown with black mosaic. Germination epigeal, first two leaves simple and opposite.

P. lobata occurs in thickets, forests, roadsides, pastures, hedges, on dry or moist, poor or rich soils, more common in the lowlands but up to 2000 m altitude. Outside its native area, seed is not usually formed. Propagation is mainly by planting young stem cuttings almost horizontally. Tubers can be harvested about 1 year after planting the cuttings. If left longer in the soil they can become very large. For fodder production, first harvest is possible in the second year, full production is reached from the third year onwards.

P. lobata is extremely variable and 3 varieties have been distinguished, although intermediates occur. The main distinguishing characteristics are flower size, leaflet form and fruit size.
- var. *lobata*: flowers 12–20 mm long, leaflets usually trilobed, fruits 5–13 cm × 7–12 mm;
- var. *montana*: flowers up to 12 mm long, leaflets usually entire, fruits 4–10 cm × 6–9 mm;
- var. *thomsoni*: flowers 20 mm or longer, leaflets usually trilobed, fruits 8–13 cm × 9-13 mm.

Other tuberous *Pueraria* species have or might have similar possibilities (e.g. *P. candollei* Graham ex Bentham from India, Bangladesh, Burma (Myanmar) and Thailand; *P. edulis* Pampanini from India and China; *P. mirifica* Airy Shaw & Suvat. from Thailand; *P. tuberosa* (Roxb. ex Willd.) DC. from India, Nepal and Pakistan).

Selected sources 1, 3, 8, 13, 17, 23, 24, 30, 32, 40, 43, 62, 67, 68, 79, 90, 91.

Sagittaria trifolia L.

ALISMATACEAE

Synonyms *Sagittaria sinensis* Sims, *S. hirundinacea* Blume, *S. sagittifolia* L. subsp. *leucopeta-*

la (Miquel) Hartog [*sagittifolia* also erroneously written as *sagittaefolia*].

Vernacular names Arrowhead, arrow-weed, swamp potato (En). Fléchière, sagittaire (Fr). Indonesia: bea-bea (general), eceng genjer (Sundanese), kalopak (Sulawesi). Malaysia: ubi keladi, keladi chabang. Philippines: gauai-gauai (Bisaya), tikog (Bikol). Cambodia: slök lumpaèng. Laos: phak sôb. Thailand: khakhiat, taokiat (central), phakkhangkai (northern). Vietnam: rau m[as]c, t[uwf] c[oo], c[ur] ch[os]c.

Distribution Asia, from the Black Sea to Japan and throughout South-East Asia. In Malesia it is only indigenous in Sumatra, Sulawesi and the Philippines, elsewhere it has been introduced. Also introduced in other warm temperate to tropical areas (e.g. in Australia, Pacific Islands). Most important in China.

Uses The tubers are edible but should be consumed boiled (when raw they are poisonous). Young leaves are used as a vegetable and aboveground parts are used as fodder, especially for pigs. In Vietnam the tubers are used medically as a tonic and a laxative.

Observations Perennial aquatic herb, about 1 m tall, glabrous, laticiferous, with slender 15–35 cm long rhizomes, thickening at the tip into tubers of 3–6 cm length and 2–5 cm diameter. Leaves in a radical rosette, emerged ones erect, sagittate, with linear to lanceolate lobes up to 19 cm × 3 cm; petiole sharply triangular, ribbed, 20–60 cm long, containing air-channels, sheathing at the base; submerged leaves linear, up to 80 cm × 2 cm; floating leaves lanceolate to ovate. Inflorescence a raceme, with triangular peduncle, together 25–50(–90) cm long, with 2–6 whorls of 3 flowers, 1–3 lower whorls female and often laterally branched, other flowers male; pedicel up to 1.5 cm long; sepals and petals 3; petals white, suborbicular, 12–15 mm in diameter, unguiculate. Fruit a globular head, about 1 cm in diameter, consisting of numerous obovate achenes 3–5 mm × 1.5–3 mm, with a broad dorsal and ventral wing. In the wild, *S. trifolia* is of very local occurrence and quite rare in Malesia, up to 1000 m altitude. It is more common in cultivation, in swamps and wetrice fields. Propagation is by planting tubers whole or as pieces. First harvesting can take place 6–7 months after planting. *S. trifolia* has long been considered as a subspecies or a variety of the widespread temperate European and Asian species *S. sagittifolia* L., which has white petals with a distinct purple or carmine basal spot, purplish anthers, and blunt basal leaf lobes.

Selected sources 3, 9, 13, 22, 30, 32, 40, 43, 51, 66, 68, 79, 81.

Schismatoglottis wallichii Hook.f.

ARACEAE

Distribution Peninsular Malaysia, Singapore.

Uses The rhizome is said to be edible. It is also a rare ornamental in tropical greenhouses.

Observations Robust herb with thickened rhizomes and a short, 2.5–5 cm long stem. Leaves simple, broadly lanceolate; petiole 15–23 cm long, sheathing in lower part; blade 15–28 cm × 2.5–7.5 cm. Inflorescence a spadix; peduncle up to 13 cm long; spathe-tube 3–4 cm long, limb 5–7.5 cm long, including a 1.5 cm long point, white; spadix up to 7 cm long, female and sterile part each 2.5 cm long, male part (at top) shorter and clavate. Fruit a small globose berry. It occurs in lowland rainforest.

Selected sources 13, 20, 37.

Smilax zeylanica L.

SMILACACEAE

Synonyms *Smilax australis* R. Br. sensu Heyne and Burkill.

Vernacular names Indonesia: kayu cina hutan (Moluccas), saihe maruani (Seram), asaihe tuni (Ambon).

Distribution India, Burma (Myanmar), Thailand, Malesia (Indonesia; other countries not well known).

Uses Boiled young roots are edible, possibly only used in times of famine. The stems are very tough and used for baskets and wickerwork. Young stem tips are used as a vegetable. Medicinally, the roots are used as an adulterant of the famous roots of *Smilax china* L. (chinaroot, gadung cina), active against venereal diseases and skin problems.

Observations Robust woody climber, up to 6 m long, dioecious, extremely variable. Branches terete to angular, zigzag to straight, sparingly prickly to unarmed. Leaves alternate, ovate, oblong, or lanceolate or orbicular, 5–24 cm × 1–13 cm, thinly to thickly coriaceous, with 3–5 main veins. Inflorescences of both sexes consisting of 1–5 umbels; common axis up to 5 cm long, peduncle up to 3.5 cm long, rays 1.5–2 cm long; umbels 10–40-flowered; staminate perianth 3–5.5 mm long, pistillate one 3–4.5 mm. Fruit a globose berry, 6–9 mm in diameter, dirty yellow to shiny black. Seeds 2–3 per berry, planoconvex or globose, brown. It occurs in jungles, brushwood, primary and secondary forests, bamboo-thickets, up to 1600 m altitude.

The *S. zeylanica* complex has not yet been studied well; sometimes it is divided into 3 species, based on leaf differences, sometimes into different subspecies, on the basis of number and size of umbels, form and size of leaves and form of branches.

S. australis R. Br. is endemic to Australia. Most *Smilax* species have a considerable medicinal value.

Selected sources 3, 32, 57, 79, 80, 86, 94.

Tropaeolum tuberosum Ruiz & Pavon

TROPAEOLACEAE

Synonyms *Tropaeolum mucronatum* Meyen, *Trophaeum tuberosum* (Ruiz & Pavon) Kuntze.

Vernacular names Tuberous nasturtium, anyu (En). Capucine tubéreuse (Fr). Añu, isaña, mashua (Sp, South America).

Distribution South America, in the high Andean region from Venezuela to Argentina, wild and cultivated. Occasionally, it is grown elsewhere (e.g. in New Zealand).

Uses An ancient food crop from the high Andes. The tubers are eaten boiled and resemble turnips. The flowers are consumed as a salad. Medicinally the tubers are used to treat kidney, liver and skin diseases and they also possess sedative and anaphrodisiac properties.

Observations Herbaceous climber, 2–3 m long, glabrous. Rhizomes thickening to tubers, conical to ellipsoid, 5–15 cm long, 3–6 cm in diameter, furrowed or roughened by numerous nodes and scaly leaves. Leaves alternate, simple; petiole long, twining on surrounding vegetation; blade peltate, ovate in outline, 5–20 cm long, 3–5(–7)-lobed. Flowers axillary, solitary, 5-merous; pedicel 10–19 cm long; sepals red, fused at base into a long spur; petals yellow-orange to red or scarlet. Fruit a 3-seeded schizocarp, each mericarp rugose, remaining indehiscent.

T. tuberosum occurs in high mountain areas, at 2700–4200 m altitude, mostly known from cultivation, but wild forms exist in Ecuador, Peru and Bolivia. Numerous local cultivars (over 100) are known, varying greatly in tuber colour from dirty-white or yellow to red or purple. Propagation is from tubers, usually planted in rows 70–100 cm apart and 40–70 cm between plants. Tubers reach maturity in about 7 months under short daylength. Tubers can be stored well up to 6 months without special requirements. Yields can reach 20–30 t/ha. The tubers contain about 18% starch, 2% sugar and 4% protein. *T. tuberosum* might be an interesting crop for the cooler parts of the tropical highlands of South-East Asia.

Sometimes, *T. tricolor* Sweet is considered as the wild ancestor of the domesticated *T. tuberosum*.

Selected sources 11, 20, 28, 31, 33, 40, 43, 44, 45.

Typhonium roxburghii Schott

ARACEAE

Synonyms *Arum diversifolium* Blume, *Typhonium divaricatum* Blume, *T. trilobatum* auct., non (L.) Schott.

Vernacular names Indonesia: trenggiling mentik (Javanese), ileus (Sundanese), bira kecil (Moluccas). Malaysia: keladi puyoh, birah kechil.

Distribution Southern India, Sri Lanka, Malaysia, Indonesia, Papua New Guinea. Introduced elsewhere (e.g. in the Philippines, Tanzania, Brazil).

Uses It has been reported from Indonesia that the corms are edible after several boilings. However, they are very acrid and cause swellings on tongue and lips. Medicinally, the corms are used against eruptions on the skin and their sap is used against yaws.

Observations Herb, 10–45 cm tall, with subglobose corm up to 3.5 cm in diameter and rooting at the top. Leaves usually shallowly trilobed, usually broader than long; petiole up to 30 cm long. Inflorescence a spadix; peduncle up to 10 cm long; spathe 30 cm long, limb dark red to purple inside; spadix with pistillate part 0.5 cm long, sterile part 1 cm long covered with acicular downturned rudiments, naked interstice 1.5 cm long, staminate part 1 cm long, appendix 8–15 cm long and dark red. Fruit a 1–2-seeded berry.

It is a weed of preferably damp waste places, up to 1000 m altitude.

Selected sources 3, 13, 15, 20, 32, 37, 40, 65.

Typhonium trilobatum (L.) Schott

ARACEAE

Synonyms *Arum trilobatum* L., *A. orixense* Roxburgh ex Andrews, *Typhonium orixense* (Andrews) Schott.

Vernacular names Malaysia: keladi puyuh. Laos: bo:n biѐw. Thailand: mahora (south-eastern), uttaphit (central), thithe (Karen). Vietnam: c[ur] ch[os]c, ch[os]c, b[ar]n h[aj] ba th[uf]y.

Distribution From India through Indo-China to Peninsular Malaysia. Elsewhere believed to have been introduced (e.g. in the Philippines, Borneo, Singapore, West Africa, Trinidad).

Uses The dried sliced corms are locally eaten in Indo-China. The leaves are said to be useful as fish food. In traditional medicine in Indo-China the corms are used against cough, asthma and nausea. In Thailand, the leaves are used as a poultice for boils after being softened over a fire.

Observations Herb with corm of several cm in diameter and roots from the top. Leaves with petiole up to 40 cm long, blade usually deeply trilobed, central lobe up to 20 cm × 10 cm. Inflorescence a spadix; peduncle 5 cm long; spathe 10–20 cm, with dark red limb; spadix with 1 cm pistillate part, sterile part 1–2 cm long and covered with whitish intertwined filamentous sterile flowers, naked interstice 1–2.5 cm, staminate part 2–3 cm long, appendix 5–10 cm long and dark red. *T. trilobatum* is a weed occurring in the lowlands, in Peninsular Malaysia often around towns.

Selected sources 13, 15, 20, 37, 38, 40, 49, 65, 81, 93.

Ullucus tuberosus Lozano

BASELLACEAE

Synonyms *Basella tuberosa* (Lozano) Kunth, *Melloca tuberosa* (Lozano) Lindley, *Ullucus kunthii* Moquin-Tandon.

Vernacular names Ulluco, papa lisa, ruba (En). Olloco, melloco, timbos (Sp, South America).

Distribution In the South American Andes, cultivated from Venezuela to Argentina; the wild ancestor occurs from central Peru to northern Argentina and is sometimes considered a separate species (*Ullucus aborigineus* Brücher). Occasionally, *U. tuberosus* is cultivated elsewhere.

Uses The tubers are an ancient food of the Andes, consumed fresh like boiled potatoes in stews or they are dried (chuña) and ground into flour and consumed whenever needed. The green parts can be used as a vegetable.

Observations Twining, procumbent, fleshy, glabrous herb, 20–30(–60) cm tall with ridged stems 5–7 cm in diameter; wild forms are more creeping with branches up to several m long producing much smaller tubers. Tubers are normally formed underground at the end of rhizomes, occasionally also in leaf axils aboveground on stolons; they resemble small potatoes, cylindrical, ellipsoidal or globose with shallow eyes, 4–6 cm in diameter, smooth, soft-skinned, white, orange, yellow, red or green, or mixed-coloured, flesh yellowish and mucilaginous. Leaves alternate, fleshy, simple; petiole erect, grooved; blade cordate to reniform, 5–20 cm × 5–12 cm, shiny. Inflorescence an axillary raceme, but in cultivation flowering is rare; flowers bisexual, star-shaped, small, with 2 circular red sepals and a 5-lobed, small, green-yellow corolla. Fruit a subglobose capsule, 2–2.5 mm long, 1-seeded, indehiscent.

U. tuberosus occurs in high, wet, mountain regions, at altitudes of 2000–3300 m. Propagation is from small tubers, planted in rows 80–100 cm apart and 40–60 cm in the row. Tubers mature in about 4–6 months, normally at a daylength of about 12 hours. Diseases and pests are not serious. Yields may amount to 5–9 t/ha. On a fresh weight basis the tubers contain 10–14% carbohydrates and 1% protein. Many people consider ulluco tubers or chuña a delicacy, also outside its region of origin. Possibly, it is of interest for the cooler parts of the tropical highlands of South-East Asia.

Selected sources 10, 11, 28, 31, 33, 40, 43, 45, 54, 72.

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4 Plants yielding non-seed carbohydrates, but with other primary use

(List of species in other commodity groups, which are used also for their carbohydrates (starch, sugars, pectin) or derived products (alcohol, vinegar).

Acrocomia aculeata (N.J. Jacquin) Loddiges (ornamental plants)
  Acrocomia sclerocarpa Martius
Anacardium occidentale L. (edible fruits and nuts)
Ananas comosus (L.) Merr. (edible fruits and nuts)
Antidesma bunius (L.) Sprengel (edible fruits and nuts)
  Antidesma dallachyanum Baillon
  Antidesma rumphii Tulasne
Apium graveolens L. (vegetables)
Aponogeton fenestralis Hook. f. (ornamental plants)
Arctium lappa L. (vegetables)
Artocarpus altilis (Parkinson) Fosberg (edible fruits and nuts)
  Artocarpus camansi Blanco
  Artocarpus communis J.R. & G. Forster
Artocarpus heterophyllus Lamk (edible fruits and nuts)
Artocarpus integer (Thunb.) Merr. (edible fruits and nuts)
  Artocarpus champeden (Loureiro) Stokes
Baccaurea dulcis (Jack) Muell. Arg. (edible fruits and nuts)
Baccaurea motleyana (Muell. Arg.) Muell. Arg. (edible fruits and nuts)
Baccaurea racemosa (Reinw. ex Blume) Muell. Arg. (edible fruits and nuts)
  Baccaurea wallichii Hook.f.
Baccaurea ramiflora Lour. (edible fruits and nuts)
  Baccaurea sapida (Roxburgh) Muell. Arg.
  Baccaurea wrayi King ex Hook.f.
Bactris gasipaes Kunth (edible fruits and nuts)
  Bactris utilis Benth. & Hook.f. ex Hemsley
Benincasa hispida (Thunberg ex Murray) Cogniaux (vegetables)
  Benincasa cerifera Savi
Beta vulgaris L. (vegetables)
Brassica juncea (L.) Czernjaew (vegetables)
  Brassica integrifolia (West) Rupr.
Brassica napus L. (vegetables)
Brassica oleracea L. (vegetables)
Brassica rapa L. (vegetables)
Bruguiera gymnorhiza (L.) Savigny (dye and tannin-producing plants)
  Bruguiera conjugata Merrill
Ceratonia siliqua L. (forages)
Cheilosa malayana (Hook.f.) Corner ex Airy Shaw (edible fruits and nuts)
  Baccaurea malayana King ex Hook.f.
Citrullus lanatus (Thunberg) Matsum. and Nakai (vegetables)
  Citrullus vulgaris Schrader ex Ecklon & Zeyher

Citrus reticulata Blanco (edible fruits and nuts)
Citrus chrysocarpa Lushington
Citrus deliciosa Tenore
Citrus nobilis Andrews et auct., non Loureiro
Citrus sinensis (L.) Osbeck (edible fruits and nuts)
Citrus aurantium L. (var.) *sinensis* L.
Clausena lansium (Lour.) Skeels (edible fruits and nuts)
Clausena wampi (Blanco) Oliver
Cocos nucifera L. (vegetable oils and fats)
Coscinium blumeanum Miers ex Hook.f. & Thomson (medicinal and poisonous plants)
Cucumis sativus L. (vegetables)
Cucurbita ficifolia Bouché (vegetables)
Cucurbita maxima Duchesne ex Lamk (vegetables)
Cucurbita mixta Pangalo (vegetables)
Cucurbita moschata (Duchesne ex Lamk) Duchesne ex Poiret (vegetables)
Cucurbita pepo L. (vegetables)
Curcuma aeruginosa Roxburgh (medicinal and poisonous plants)
Curcuma heyneana Valeton & Van Zijp (medicinal and poisonous plants)
Curcuma longa L. (spices)
Curcuma domestica Valeton
Curcuma mangga Valeton & Van Zijp (vegetables)
Curcuma purpurascens Blume (medicinal and poisonous plants)
Cycas rumphii Miq. (edible fruits and nuts)
Cycas circinalis L.
Cycas siamensis Miq. (edible fruits and nuts)
Daucus carota L. (vegetables)
Diospyros lolin Bakh. (edible fruits and nuts)
Durio zibethinus Murray (edible fruits and nuts)
Eriobotrya japonica (Thunb.) Lindley (edible fruits and nuts)
Eugeissona tristis Griffith (fibre plants)
Eugenia uniflora L. (edible fruits and nuts)
Eugenia michelii Lamk
Euterpe oleracea Martius (edible fruits and nuts)
Fortunella hindsii (Champ.) Swingle (edible fruits and nuts)
Fortunella japonica (Thunb.) Swingle (edible fruits and nuts)
Citrus inermis Roxburgh
Citrus japonica Thunberg
Fortunella margarita (Lour.) Swingle (edible fruits and nuts)
Furcraea foetida (L.) Haw. (ornamental plants)
Furcraea gigantea Vent.
Gnetum tenuifolium Ridley (edible fruits and nuts)
Hedychium coronarium Koenig (medicinal and poisonous plants)
Imperata cylindrica (L.) Raeuschel (forages)
Jatropha multifida L. (medicinal and poisonous plants)
Litchi chinensis Sonn. (edible fruits and nuts)
Euphoria didyma Blanco
Litchi philippinensis Radlk.
Nephelium litchi Cambess.

Malus domestica Borkh. (edible fruits and nuts)
Pyrus malus L. (in part)
Mammea americana L. (edible fruits and nuts)
Manilkara zapota (L.) P. van Royen (edible fruits and nuts)
Achras zapota L.
Melia azedarach L. (medicinal and poisonous plants)
Melia dubia Cav.
Merremia mammosa (Loureiro) H. Hallier (medicinal and poisonous plants)
Ipomoea gomezii Clarke
Merremia peltata (L.) Merrill (medicinal and poisonous plants)
Merremia nymphaeifolia H. Hallier
Monochoria vaginalis (N.L. Burman) Kunth (vegetables)
Morus nigra L. (edible fruits and nuts)
Musa L. (dessert bananas) (edible fruits and nuts)
Musa acuminata Colla (vegetables)
Musa malaccensis Ridley
Musa zebrina Van Houtte ex Planchon
Musa balbisiana Colla (vegetables)
Musa brachycarpa Backer
Nephrodium sieboldi Hook. (lower plants)
Nymphaea nouchali Burm.f. (vegetables)
Nymphaea stellata Willd.
Pandanus leram Jones ex Fontana (edible fruits and nuts)
Parartocarpus venenosus (Zoll. & Moritzi) Becc. (edible fruits and nuts)
Parartocarpus woodii (Merrill) Merrill
Parartocarpus triandra (J.J. Smith) J.J. Smith
Pastinaca sativa L. (vegetables)
Phoenix dactylifera L. (edible fruits and nuts)
Physalis peruviana L. (edible fruits and nuts)
Pouteria campechiana (Kunth) Baehni (edible fruits and nuts)
Lucuma nervosa A. DC.
Prunus persica (L.) Batsch (edible fruits and nuts)
Prunus salicina Lindley (edible fruits and nuts)
Prunus triflora Roxburgh
Psidium friedrichsthalianum (O. Berg) Niedenzu (edible fruits and nuts)
Psidium guajava L. (edible fruits and nuts)
Psophocarpus tetragonolobus (L.) DC. (vegetables)
Pueraria phaseoloides (Roxb.) Benth. (forages/auxiliary plants in agriculture and forestry)
Raphanus sativus L. (vegetables)
Raphanus caudatus L.
Rollinia mucosa (Jacq.) Baillon (edible fruits and nuts)
Rollinia deliciosa Safford
Rollinia orthopetala A. DC.
Rubus niveus Thunb. (edible fruits and nuts)
Rubus lasiocarpus J.E. Smith
Schismatoglottis calyptrata (Roxburgh) Zollinger & Moritzi (vegetables)
Scirpus grossus L.f. (fibre plants)
Scorzonera hispanica L. (vegetables)

Sechium edule (Jacq.) Swartz (vegetables)
Smilax megacarpa A. DC. (vegetables)
Sorghum bicolor (L.) Moench (cereals)
   Andropogon sorghum Brot.
   Sorghum vulgare Pers.
Stemona tuberosa Loureiro (medicinal and poisonous plants)
   Stemona moluccana (Blume) Wright
Syzygium cumini (L.) Skeels (edible fruits and nuts)
   Eugenia cumini (L.) Druce
Syzygium curranii (C.B. Robinson) Merr. (edible fruits and nuts)
   Eugenia curranii C.B. Robinson
Syzygium jambos (L.) Alston (edible fruits and nuts)
   Eugenia jambos L.
Taraxacum officinale Weber (vegetables)
Tinospora crispa (L.) Hook.f. & Thomson (medicinal and poisonous plants)
   Tinospora rumphii Boerl.
   Tinospora tuberculata (Lamk) Beumee ex Heyne
Trichosanthes ovigera Blume (vegetables)
   Trichosanthes cucumeroides (Seringe) Maxim.
Vaccinium whitfordii Merr. (edible fruits and nuts)
Vigna vexillata (L.) A. Richard (auxiliary plants in agriculture and forestry)
Vitis flexuosa Thunb. (edible fruits and nuts)
Vitis pentagona Diels & Gilg (edible fruits and nuts)
Vitis vinifera L. (edible fruits and nuts)
Zea mays L. (cereals)

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Acronyms of organizations

- ACIAR: Australian Centre for International Agricultural Research (Canberra, Australia).
- AVRDC: Asian Vegetable Research and Development Center (Shanhua, Taiwan).
- CGIAR: Consultative Group on International Agricultural Research.
- CIAT: Centro Internacional de Agricultura Tropical [International Centre for Tropical Agriculture] (Cali, Columbia).
- CIP: Centro Internacional de la Papa [International Potato Centre] (Lima, Peru).
- CIRAD-FLHOR: Centre of International Cooperation and Agronomical Research for Development–Department of Fruits and Horticultural Products (Montpellier, France).
- CSIRO: Commonwealth Scientific and Industrial Research Organization (Canberra, Australia).
- DGIS: Directorate-General for International Cooperation (The Hague, the Netherlands).
- FAO: Food and Agriculture Organization of the United Nations (Rome, Italy).
- FINNIDA: Finnish International Development Agency (Helsinki, Finland).
- FRIM: Forest Research Institute of Malaysia (Kuala Lumpur, Malaysia).
- IARPCB: International Association for Research on the Plantain and other Cooking Bananas.
- IBPGR: International Board for Plant Genetic Resources (now IPGRI) (Rome, Italy).
- IDRC: International Development Research Center (Ottawa, Canada).
- IEBR: Institute of Ecology and Biological Resources (Hanoi, Vietnam).
- IFPRI: International Food Policy Research Institute (Washington, D.C., United States).
- IITA: International Institute of Tropical Agriculture (Ibadan, Nigeria).
- INIBAP: International Network for the Improvement of Banana and Plantain (Montpellier, France).
- IPB: Institut Pertanian Bogor [Bogor Agricultural University] (Bogor, Indonesia).
- IPGRI: International Plant Genetic Resources Institute (Rome, Italy).
- IRRI: International Rice Research Institute (Los Baños, Philippines).
- ISSCT: International Society of Sugar Cane Technologists.
- ISTRC: International Society for Tropical Root and Tuber Crops.
- JIRCAS: Japan International Research Center for Agricultural Sciences.
- LIPI: Indonesian Institute of Sciences (Jakarta, Indonesia).
- MARDI: Malaysian Agricultural Research and Development Institute (Ser-

dang, Malaysia).
- MITA: Mayaguez Institute of Tropical Agriculture (Mayaguez, Puerto Rico)
- PCARRD: Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (Los Baños, Philippines).
- PGRC: Plant Genetic Resources Centre.
- PROSEA: Plant Resources of South-East Asia (Bogor, Indonesia).
- PUDOC-DLO: Centre for Agricultural Publishing and Documentation–Agricultural Research Department (Wageningen, the Netherlands).
- RDCB: Research and Development Centre for Biology (Bogor, Indonesia).
- ROTREP: Roots and Tuber Research Project (Alabama, Normal, United States).
- SAPPRAD: South-East Asian Programme for Potato Research and Development.
- TISTR: Thailand Institute of Scientific and Technological Research (Bangkok, Thailand).
- TPI: Tropical Products Institute (London, United Kingdom).
- UNITECH: Papua New Guinea University of Technology (Lae, Papua New Guinea).
- UPLB: University of the Philippines at Los Baños (Los Baños, Philippines).
- USDA: United States Department of Agriculture (Washington, D.C., United States).
- VISCA: Visayas State College of Agriculture (Leyte, Philippines).
- WAU: Wageningen Agricultural University (Wageningen, the Netherlands).

Glossary

abaxial: on the side facing away from the axis or stem (dorsal)

abscission: the natural detachment of leaves, branches, flowers or fruits

acaulescent: lacking a visible stem

accession: in germplasm collections: plant material of a particular collection, usually indicated with a number

accrescent: increasing in size with age

achene: a small dry indehiscent one-seeded fruit

acicular: needle-shaped; sharp pointed

acropetal: from the base toward the apex

actinomorphic: radially symmetrical; applied to flowers which can be bisected in more than one vertical plane

aculeate: furnished with prickles; prickly

acuminate: ending in a narrowed, tapering point with concave sides

acute: sharp; ending in a point with straight or slightly convex sides

adaxial: on the side facing the axis (ventral)

adjacent-ligular: in germination, the new shoot developing next to the seed and enclosed by a ligule

adnate: united with another part; with unlike parts fused, e.g. ovary and calyx tube

adpressed (appressed): lying flat for the whole length of the organ

adventitious: not in the usual place, e.g. roots on stems, or buds produced in other than terminal or axillary positions on stems

air layering: a form of layering in which soil (rooting medium) is brought to the branch to be layered; the ball of soil in a polyethene cover is wrapped around the girdled branch; after adventitious roots grow out above the girdle, the layer can be separated

albumen: the nutritive material stored within the seed, and in many cases surrounding the embryo (endosperm)

alkaloid: large group of organic bases containing nitrogen and usually oxygen that occur for the most part in the form of salts with acids; usually optically and biologically active

allopolyploid (alloploid): a polyploid with more than two sets of chromosomes, derived from different species; allotriploid with three sets, allotetraploid with four sets, etc.

alluvium: soil material deposited by running water in recent geological time

alternate: leaves, etc., inserted at different levels along the stem, as distinct from opposite or whorled

amplexicaul: stem-clasping, when the base of a sessile leaf or a stipule is dilated at the base, and embraces the stem

amylose: a component of starch characterized by its straight chains of glucose units and by the tendency of its aqueous solutions to set to a stiff gel

amylograph: an instrument that measures and records the gelatinization temperature and viscosity of pastes of starch and flour

amylopectin: a branch-chained polysaccharide found in starch with a structure similar to glycogen; it does not tend to gel in aqueous solutions

anastomosis: cross connection of branches or roots; union of one vein or parenchyma band with another, the connection forming a reticulation

anatropous: a reversed ovule with the micropyle close to the hilum

androecium: the male element; the stamens as a unit of the flower

andromonoecious: having perfect and male flowers, but no female flowers

androphore: a stalk supporting the androecium or stamens

annual: a plant which completes its life cycle in one year

annular: used of any organs disposed in a circle

annulate: ring-shaped

annulus: a ring or a ring-like part

anterior: of time, previous; of place, position in front, or turned away from the axis

anthelmintic: a drug or agent that destroys or causes expulsion of intestinal worms

anther: the part of the stamen containing the pollen
anthesis: the time the flower is expanded, or, more strictly, the time when pollination may take place
anthocyanin: the blue, sometimes red, colouring of plant parts
anthracnose: a disease characterized by distinctive limited lesions on stem, leaf or fruit, often accompanied by dieback and usually caused by a *Gloeosporium* or a *Colletotrichum*, imperfect fungi. The perfect state of the fungus, when known, is *Gnomonia* or *Glomerella*
antiseptic: inhibits or retards or prevents the growth and reproduction or arrests the development of bacteria and other micro-organisms that cause infection or other deleterious processes
antrorse: directed upwards (opposed to retrorse)
apetalous: without petals or with a single perianth
apex (plural: *apices*): tip or summit of an organ
aphrodisiac: a food or drug stimulating sexual desire
apical: at the apex of any structure
apiculate: ending abruptly in a short point
apocarpous: carpels free from each other
apomict: an organism reproducing by apomixis
apomixis: reproduction by seed formed without sexual fusion (apomictic)
appendage: a part added to another; attached secondary or subsidiary part, sometimes projecting or hanging
appendix (botany): a name given to appendages of any kind, e.g. in *Araceae* the sterile top part of the spadix
applanate: flattened out or horizontally expanded
appressed (adpressed): lying flat for the whole length of the organ
arborescent: attaining the size or character of a tree
arcuate: curved
areole: irregular squares or angular spaces marked out on a surface, e.g. of a fruit; a small cell or cavity
aril: an expansion of the funicle enveloping the seed, arising from the placenta; sometimes occurring as a pulpy cover (arillus)
arillate: possessing an aril
arillode: a false aril, a coat of the seed not arising from the placenta
aristate: awned
armed: bearing some form of spines
arthritis: inflammation of a joint or joints
articulate: jointed, or with places where separation takes place naturally
articulation: a joint, popularly applied to nodes of grasses
ascending: curving or sloping upwards
asexual: sexless; not involving union of gametes
asthma: a chronic disorder characterized by paroxysms of the bronchi, shortness of breath, wheezing, a suffocating feeling, and laboured coughing to remove tenacious mucus from the air passages
astringent: an agent or substance causing shrinkage of mucous membranes or raw or exposed tissues
attenuate: gradually tapering
auricle: a small lobe or ear
auriculate: eared, having auricles
autopolyploid (autoploid): polyploid with more than two sets of similar chromosomes derived from the same species
auxin: an organic substance characterized by its ability in low concentrations to promote growth of plant shoots and to produce other effects such as root formation and bud inhibition
awn: a bristle-like appendage, especially occurring on the glumes of grasses
axil: the upper angle between the leaf and the stem
axillary: arising from the axil
axis: the main or central line of development of a plant or organ
baccate: berry-like; pulpy or fleshy
bark: the tissue external to the vascular cambium collectively, being the secondary phloem, cortex and periderm
basifixed: attached or fixed by the base
basipetal: developing from the apex toward the base
beak: a long, prominent and substantial point, applied particularly to prolongations of fruits
berry: a juicy indehiscent fruit with the seeds immersed in pulp; usually several-seeded without a stony layer surrounding the seeds
bifid: divided in two, usually equal parts
bijugate: used for a pinnate leaf with 2 pairs of leaflets
bilabiate: two-lipped
bilocular: with two compartments or cells
biotype: a population in which all the individuals have the same genetic constitution
bipinnate: when the primary divisions (pinnae) of a pinnate leaf are themselves pinnate
biseriate: arranged in two rows
bisexual: having both sexes present and functional in the same flower

blade: the expanded part, e.g. of a leaf or petal
blotched: see variegated
bole: the main trunk of a tree, generally from the base up to the first main branch
bract: a reduced leaf subtending a flower, flower stalk or the whole or part of an inflorescence
bracteole: a secondary bract on the pedicel or close under the flower
breeding: the propagation of plants or animals to improve certain characteristics
bristle: a stiff hair or a hair-like stiff slender body
bulb: an underground storage organ with a much-shortened stem bearing fleshy leaf bases or scale leaves enclosing the next year's bud
bulbil: an aerial bulb or bud produced in a leaf axil or replacing the flower, which, on separation, is capable of propagating the plant
bullate: surface much blistered or puckered
bunch: cluster, growing together
bush: a low thick shrub without a distinct trunk
cabbage (of palms): a terminal bud of a palm tree that resembles a head of a cabbage and is eaten as a vegetable
caducous: falling off early
caespitose: forming mats or spreading tufts
callus: small hard outgrowth at the base of spikelets in some grasses; tissue that forms over cut or damaged plant surface
calyx: the outer envelope of the flower, consisting of sepals, free or united
cambium: a layer of nascent tissue between the wood and bark, adding elements to both
campanulate: bell-shaped
campylotropous: applied to an ovule or seed, one side of which has grown faster than the other so as to bring its true apex (micropyle) near the hilum
canaliculate: channeled, with a longitudinal groove
canopy: the uppermost leafy layer of a tree, forest or crop
capitate: headed, like the head of a pin in some stigmas, or collected into compact head-like clusters as in some inflorescences
capsule: a dry dehiscent fruit composed of two or more carpels and either splitting when ripe into valves, or opening by slits or pores
carminative: expelling gas from the stomach and intestines; a carminative medicine
carpel: one of the foliar units of a compound pistil or ovary; a simple pistil has only one carpel
cartilaginous: hard and tough
caruncle: an outgrowth of a seed near the hilum
caryopsis: the fruit of a grass, in which the outer layer (testa) of the seed proper is fused to the ovary wall
cataphyll: reduced or scale-like leaf present in certain seedlings on the lower stem nodes and sometimes elsewhere on the seedling stem
catkin: a close bracteate, often pendulous spike, usually with unisexual flowers
caudate: with a tail-like appendage
chalaza: basal part of the ovule or seed where it is attached to the funicle and the point at which vascular tissues enter and spread into the ovule
channeled: grooved, hollowed out like a gutter
chartaceous: papery
cholera: any of several diseases of man and domestic animals usually marked by severe gastrointestinal symptoms
chromosome: a structural unit in the nucleus which carries the genes in a linear constant order; the number is typically constant in any species
ciliate: with a fringe of hairs along the edge
cincinnus (plural: *cincinni*): a flower cluster wherein each successive flower arises in the axil of a bracteole borne on the stalk of the previous flower
circumnutation: the phenomenon of the apical portions of stem, tendril, root, turning to various quarters of the compass
cirrus: a climbing organ, structurally a whip-like extension of the leaf rachis, armed with reflexed spines
cladode: a branch of a single internode simulating a leaf
clavate: club-shaped or thickened towards the end
clavellate: diminutive of clavate
claw: the narrow part of a petal or sepal
cleft: cut halfway down
cleistogamous: pollination and fertilization taking place within the unopened flower
clone: a group of plants originating by vegetative propagation from a single plant and therefore of the same genotype
clustered: with several stems
coleoptile (coleoptilum, coleophyllum): the first leaf in germination of monocotyledons, which sheathes the succeeding leaves
coleorhiza: the sheath of a monocotyledonous embryo, when pierced by the true radicle
column: a tube of connate stamen filaments
coma: the hairs at the end of some seeds; a tuft of leafy bracts or leaves at the top of an inflorescence (e.g. pineapple, *Curcuma* inflorescence)
compound: of two or more similar parts in one organ, as in a compound leaf or compound fruit

concave: hollow
concoction: a combination of crude materials that are prepared (cooked) together
conduplicate: folded lengthwise
conical: having the shape of a cone (cone-shaped)
connate: united or joined
connective (botany): tissue between the pollen sacs of an anther
conspecific: belonging to the same species
convex: having a more or less rounded surface
convolutive: when one part is wholly rolled up in another
cordate: heart-shaped, as seen at the base of a leaf, etc., which is deeply notched
core: central part; the seeds and integuments of a pome, such as an apple; pith in dicotyledonous plants
coriaceous: of leathery texture
corm: a solid, short, swollen underground stem, usually erect and tunicated, of one year's duration, with that of the next year at the top or close to the old one
cormel: diminutive of corm, often indicating a secondary corm or tuberous side-rhizome
corolla: the inner envelope of the flower consisting of free or united petals
corona: any appendage or extrusion that stands between the corolla and stamens; crown; the remains of the calyx limb on e.g. apples or pears
corrugate(d): wrinkled
cortex: the bark or rind
corymb: a flat-topped indeterminate inflorescence in which the branches or pedicels sprout from different points, but attain approximately the same level, with the outer flowers opening first
corymbose: flowers arranged to resemble a corymb
costa: a rib, when single, the midrib or vein
costapalmate: shaped like the palm of a hand and having a short midrib or costa
cotyledon: seed-leaf, the primary leaf; dicotylous embryos have two cotyledons and monocotylous embryos have one
cover crop: a crop planted to prevent soil erosion and to provide humus and/or fodder
crenate: the margin notched with blunt or rounded teeth
crenulate: slightly crenate, with small teeth
crop-weed complex: an aggregate of culta and taxa, of cultivated and wild plants belonging to the same species and which are morphologically difficult to distinguish
cross-pollination: the transfer of pollen from one flower to the stigma of a flower of another plant which is not of the same clone
crown: the aerial expanse of a tree, not including the trunk; corona; a short rootstock with leaves; the base of a tufted, herbaceous, perennial grass
crustaceous: of brittle texture
culm: the stem of grasses and sedges
cultigen: a plant species or race that has arisen or is known only in cultivation
cultivar (cv., plural: *cvs)*: an agricultural or horticultural variety that has originated and persisted under cultivation, as distinct from a botanical variety; a cultivar name should always be written with an initial capital letter and given single quotation marks (e.g. banana 'Gros Michel')
*culton (*plural: *culta)*: same meaning as taxon (plural: taxa) but for cultivated plants (comprising usually a cultivar or a cultivar group)
cuneate: wedge-shaped; triangular, with the narrow end at the point of attachment, as the bases of leaves or petals
cupule: a small cup-like structure; the cup of such fruits as the acorn, consisting of an involucre composed of adherent bracts
cuspidate: abruptly tipped with a sharp rigid point
cuticle: the outermost skin of plants, consisting of a thin continuous fatty film
cutting: portion of a plant, used for vegetative propagation
cyme: a determinate inflorescence, often flat-topped, in which each growing point ends in a flower and the central flowers open first
cymose: bearing cymes or inflorescences related to cymes
cystitis: inflammation of the urinary bladder
damping-off: a disease of seeds or seedlings caused by fungi which cause various effects, from failure to germinate to the dying off of the seedling
deciduous: shedding or prone to shedding, applied to leaves, petals, etc.
decoction: a preparation made by boiling a medicinal plant in water
decompound: several times divided or compounded
decumbent: reclining or lying on the ground, but with the summit ascending
decurrent: extending down and adnate to the petiole or stem, as occurs in some leaves
decussate: of leaves, arranged in opposite pairs on the stem, with each pair perpendicular to the preceding pair
deflexed (reflexed): abruptly recurved; bent downwards or backwards
dehiscent: opening spontaneously when ripe, e.g. capsules, anthers

deltoid: shaped like an equal-sided triangle
demulcent: a medicine or ointment having a soothing or emollient effect on inflamed body surfaces
dendroid (hairs): tree-like in form, or branching
dentate: margin prominently toothed with the pointed teeth directed outwards
denticulate: minutely toothed
depurative: removes impurities or waste materials; 'purifies' the blood
determinate: of inflorescences, when the terminal or central flower of an inflorescence opens first and the prolongation of the axis is arrested
dextrorse: twining to the right (clockwise)
diaphoretic: an agent inducing sweating, having the power to increase perspiration
dichotomous: forked, parted by pairs
dicotyledon: angiosperm with two cotyledons or seed-leaves
digitate: a compound leaf whose leaflets diverge from the same point like the fingers of a hand
dimorphic: of two forms, as may occur with branches, etc.
dioecious: with unisexual flowers and with the staminate and pistillate flowers on different plants (dioecy)
diosgenin: a complex steroid obtained from certain species of yam and which can be converted into 16-dehydropregnenolone, one of the main active ingredients in oral contraceptives
diploid: with two sets (genomes) of chromosomes, as occurs in somatic or body cells; usually written $2n$, having twice the basic chromosome number of the haploid germ cells
discoid: resembling a disk or discus, being flat and circular with a round thickened lamina and rounded margins
disk: a fleshy or elevated development of the receptacle within the calyx, corolla or stamens, often lobed and nectariferous
dispersal: the various ways by which seeds are scattered, e.g. by wind, water or animals
distal: situated farthest from the place of attachment
distichous: regularly arranged in two opposite rows on either side of an axis
diuretic (diureticum): an agent increasing the urinary discharge
divaricate: extremely divergent
domatium (plural: *domatia*): a modified projection that provides shelter for other organisms
dormancy: a term used to denote the inability of a resting plant or plant part (e.g. the seed, bulb, tuber, or in tree crops usually the buds) to grow or to leaf out, even under favourable environmental conditions
dorsal: back; referring to the back or outer surface of a part or organ (abaxial)
dorsifixed: attached by the back, as in the case of the attachment of anthers to a filament
drupaceous: resembling a drupe, whether actually a drupe or not
drupe: a fleshy one-seeded indehiscent fruit with the seed enclosed in a strong endocarp
dyad: a pair (e.g. of flowers)
dysentery: any of various intestinal diseases characterized by inflammation, abdominal pain, toxaemia, and diarrhoea with bloody, mucous faeces
ecbolic: agent increasing uterine contractions and aids in or hastens expulsion or delivery of child during birth; agent producing abortion
echinate: bearing spines or bristles
edema, oedema: an abnormal excess accumulation of serous fluid in connective tissue or in a serous cavity
ellipsoid: a solid which is elliptic in outline
elliptic(al): oval in outline but widest about the middle
emarginate: notched at the extremity
embryo: the rudimentary plant within a seed, developed from a zygote (sexual) or from other nuclei in the embryo sac or cells of the nucellus or integuments (apomictic)
emmenagogue: substance promoting flow of menstrual discharge
endemic: exclusively native to a specified or comparatively small region; also used as a noun for a taxon thus distributed
endo-: prefix, referring to the inside or the inner surface or part
endocarp: the innermost layer of the pericarp or fruit wall
endosperm: the starchy or oily nutritive material stored within some seeds, sometimes referred to as albumen; it is triploid, having arisen from the triple fusion of a sperm nucleus and the two polar nuclei of the embryo sac
energy value: the heat produced by the combustion of a unit weight of a fuel or food (= calorific value)
entire (botany): with an even margin without teeth, lobes, etc.
eophyll: the first fully developed foliar leaf in a seedling above the cotyledons
epicalyx: an involucre of bracts below the flower, resembling an extra calyx
epidermis: the true cellular skin or covering of a plant below the cuticle

epigeal: above the ground; in epigeal germination the cotyledons are raised above the ground
epiphyll: the upper portion of a leaf, from which the petiole and blade are developed
evapotranspiration: loss of water from the soil by evaporation from the surface and by transpiration from the plants growing thereon
evergreen: bearing foliage all year long; a plant that changes its leaves gradually
ex situ: in an artificial environment or unnatural habitat
exocarp: the outer layer of the pericarp or fruit wall
exsert, exserted: protrude beyond, as stamens beyond the tube of the corolla
extra-axillary: beyond or outside the axil
falcate: sickle-shaped
fasciate(d): coalesced (e.g. stems, tubers, etc.)
fascicle: a cluster of flowers, leaves, etc., arising from the same point
febrifuge: an agent serving to reduce fever
fermentation: a chemical change accompanied by effervescence and suggestive of changes produced in organic materials by yeasts
fertile (botany): capable of completing fertilization and producing seed; producing seed capable of germination; having functional sexual organs
fertilization: union of the gametes (egg and sperm) to form a zygote
fibre: any long, narrow cell of wood or bark other than vessel or parenchym elements
fibrous: having much woody fibre composed of or including fibres
filament: thread; the stalk supporting the anther
filiform: slender; thread-like
fimbriate: fringed
flabellate: fan-shaped, dilated in a wedge-shape, sometimes plaited (folded)
flagellum: a whip-like climbing organ derived from an inflorescence, bearing reflexed spines
fleshy: succulent
floret: a small flower, one of a cluster as in grasses or *Compositae*
flowering branch: a leafy or leafless segmented axis that bears one or more inflorescences
fodder: something fed to domesticated animals, especially coarse, dried food from plants (hay, straw, leaves)
foliaceous: leaf-like
foliolate (2-, 3-, 4- etc.): with 2-, 3-, 4- leaflets
follicle: a dry, unicarpellate fruit, dehiscing by the ventral suture to which the seeds are attached
forage: grassland and fodder plants suitable as feed for herbivores, usually with lower nutrient concentration and digestibility than concentrates such as grain
frambesia: see yaws
free: neither adhering nor united
frond: the foliage of ferns and other cryptogams; also used for the leaves of palms
fruit: the ripened ovary with adnate parts
fugaceous: withering or falling off rapidly or early
fungicide: an agent that destroys fungi or inhibits their growth
funicle (funiculus): the little cord which attaches the ovule or seed to the placenta
galactagogue: agent stimulating secretion or flow of milk
gamopetalous: with united petals either throughout their length or at the base
gamosepalous: with united sepals either throughout their length or at the base
gene: the unit of inheritance located on the chromosome
geniculate: abruptly bent so as to resemble the knee-joint
genome: a set of chromosomes as contained within the gamete and corresponding to the haploid chromosome number of the species
genotype: the genetic makeup of an organism comprising the sum total of its genes, both dominant and recessive; a group of organisms with the same genetic makeup
genus (plural: *genera*): the smallest natural group containing distinct species
geotropic: relating to the influence of gravity on growing organs; positive geotropic: growing towards the earth's centre (e.g. roots); negative geotropic: growing away from the earth (e.g. most stems)
germplasm: the genetic material that provides the physical basis of heredity; also a collection of genotypes of an organism
glabrescent: becoming glabrous or nearly so
glabrous: devoid of hairs
glandular: having or bearing secreting organs or glands
glaucous: pale bluish-green, or with a whitish bloom which rubs off
globose: spherical or nearly so
glomerule: a condensed head of almost sessile flowers; a cluster of heads in a common involucre
glucoside: compound that is an acetal derivative of sugars and that on hydroloysis yields glucose
glume (plural: *glumes*): the chaffy or membranous two-ranked members of the inflorescence of grasses and similar plants; lower glume and up-

per glume, two sterile bracts at the base of a grass spikelet

granulose (granular): composed of or covered with grain-like minute particles

gynoecium: the female part or pistil of a flower, consisting, when complete, of one or more ovaries with their styles and stigmas

gynophore: a stalk supporting the gynoecium formed by elongation of the receptacle

habit: external appearance or way of growth of a plant

habitat: the kind of locality in which a plant grows

haemoptysis: expectoration of blood from some part of the respiratory tract

hangover: disagreeable physical effects following heavy consumption of alcohol or from the use of drugs

hapaxanthic: describing plants (e.g. some palms) having a single flowering period after which the plant dies (cf. pleonanthic)

haploid: having a single set (genome) of chromosomes in a cell or an individual, corresponding to the chromosome number (n) in a gamete

harvest-index: the total harvestable produce as a fraction of the total biomass produced by the crop in a given year

hastate: with more or less triangular basal lobes diverging laterally

head: a dense inflorescence of small crowded often stalkless flowers (a capitulum)

hemi-: prefix, meaning half

hepatitis: inflammation of the liver

herb: any vascular plant which is not woody

herbaceous: with the texture, colour and properties of a herb; not woody

hermaphrodite: bisexual; in flowers, with stamens and pistil in the same flower

herpes: any of several inflammatory virus diseases of the skin characterized by clusters of vesicles

heterogamous: with two or more kinds or forms of flowers

heterogeneous: lacking in uniformity; exhibiting variability

heteromorphic: varying in number or form

heterophyllous: bearing leaves of different shape

hilum: the scar left on a seed indicating its point of attachment

hirsute: with rather coarse stiff hairs

hispid: covered with long rigid hairs or bristles

homogeneous: uniform as to kind; showing no variability

husk: the outer covering of certain fruits or seeds

hyaline: almost transparent

hybrid: the first generation offspring of a cross between two individuals of different species

hybridization: the crossing of individuals of different species

hypanthium: a cup-like receptacle usually derived from the fusion of the floral envelopes and androecium on which are seemingly borne the calyx, corolla and stamens

hypocotyl: the young stem below the cotyledons

hypogeal: below ground; in hypogeal germination the cotyledons remain below ground within the testa

imbricate: overlapping like tiles; in a flower bud when one sepal or petal is wholly external and one wholly internal and the others overlapping at the edges only

imparipinnate: of leaves, pinnate with an unpaired terminal leaflet

impressed: marked with slight depressions

in situ: in the natural environment

in vitro: outside the living body and in an artificial environment

incised: cut deeply

incompatibility: in floral biology: not capable of cross- or self-fertilization; in plant propagation: not capable to make stock–scion combinations resulting in a lasting union

incrassate: thickened

indehiscent: not opening when ripe

indeterminate: of inflorescences, a sequence in which the terminal flowers are the last to open, so that the floral axis may be prolonged indefinitely by the terminal meristem; of shoot growth: when the shoot apex forms and unfolds leaves during extension growth, so that shoot growth can continue indefinitely

indigenous: native to a particular area or region

indumentum: a covering, as of hairs, scales, etc.

induplicate: with the margins bent inwards and the external face of these edges applied to each other without twisting; V-shaped in cross section, trough-shaped

inequilateral: unequal-sided

inferior: beneath, lower, below; an inferior ovary is one which is below the sepals, petals and stamens

inflexed: bent or curved inward toward the centre

inflorescence: the arrangement and mode of development of the flowers on the floral axis; the branch that bears the flowers, including all its bracts and branches

influenza: an acute highly contagious virus disease characterized by sudden onset, fever, prostration, severe aches and pains, and progressive inflammation of the respiratory mucous membrane

infrafoliar: borne below the leaves
infructescence: a ripened inflorescence in the fruiting stage
insecticidal: destroying or controlling insects
insecticide: an agent that destroys insects
insulin: polypeptide hormone produced by β-cells of the islets of Langerhans in the pancreas, which decreases the amount of glucose in the blood by promoting glucose uptake by cells and increasing the capacity of the liver to synthesize glycogen; its action is antagonistic to glucagon, adrenal glucocorticoids and adrenaline, and its deficiency or reduced activity produces diabetes with a raised blood sugar level
integument: the envelope of an ovule
intercostal: between the veins of a leaf or a leaf-like structure
interfloral: between the flowers
interfoliar: borne among the leaves
internode: the portion of the stem (culm) between two nodes
interstitial: occurring in interstices or spaces
intramarginal: of a vein, running near and parallel with the margin
intraspecific: occurring within a species or involving members of one species
intrastaminal: within the stamens
introrse: turned inward, towards the axis, as the dehiscence of an anther
inulin: linear polysaccharide made up of fructose units; a storage carbohydrate in the roots, rhizomes and tubers of many *Compositae*
involucre: a ring of bracts (involucral bracts) surrounding several flowers or their supports, as in the heads of *Compositae* or the umbels in *Umbelliferae*
irregular flower: in which parts of the calyx or corolla are dissimilar in size and shape; asymmetrical or zygomorphic
jaundice: a disease characterized by yellowish pigmentation of the skin, tissues and body fluids caused by the deposition of bile pigments
joint; jointed: an articulation (e.g. a node); articulated, falling apart at the joints
jugate: connected or yoked together; e.g. in leaves 1–n jugate: with 1–n pairs of leaflets
juvenile phase (stage): the period between germination and the first signs of flowering, during which vegetative processes preclude flower initiation even under the most favourable conditions
keel (carina): a ridge like the keel of a boat; the two anterior and united petals of a papilionaceous corolla; the principal vein of a sepal or glume
keeled (carinate): having a keel or carina
kernel: the nucellus of an ovule or of a seed, that is, the whole body within the coats
labellum: lip; the lowest petal of an orchid; petaloid anterior staminode in *Zingiberaceae*
lacerate: torn; irregularly cleft or cut
lactogenic: inducing lactation
LAI (leaf area index): a measure of the photosynthetic area over a given area of ground
lamina: see blade
lanceolate: lance-shaped; much longer than broad, being widest at the base and tapering to the apex
landrace: a locally developed kind of cultivar, without formal recognition, and usually much more variable than an official registered cultivar and from which usually several cultivars can be selected
LAR (leaf area ratio): the ratio of the photosynthetic surface area of a leaf to its dry weight
lateral: on or at the side
latex: a juice, usually white and sometimes sticky, exuding from broken surfaces of some plants
laticiferous: latex-bearing
lax: loose, distant
laxative: having a tendency to loosen or relax; a drug making the bowels loose and relieving constipation
leaflet: one part of a compound leaf
lemma: the lower of the two glumes which surround each floret in the spikelet of grasses
leucoderma: a skin abnormality that is characterized by a usually congenital lack of pigment in spots or bands and produces a patchy whiteness
liana: a woody climbing vine
ligulate: with or possessing a ligule; possessing an elongated flattened strap-shaped structure
ligule: a membranous outgrowth on the upper surface of a grass leaf at the junction of the sheath and the blade, which may be presented by a ridge or by a line of hairs; an elongated flattened strap-shaped structure; in palms it is a distal projection of the leaf sheath, often coriaceous
limb: the expanded part of a tubular corolla, as distinct from the tube or throat; the lamina of a leaf or of a petal; the branch of a tree
linear: long and narrow with parallel sides
lobe: any division of an organ or specially rounded division
lobed: divided, but not to the base
locular: divided by internal partitions into compartments as in anthers and ovaries
locule: the cavity of an ovary or anther

loculicidal: the cavity of a pericarp dehiscent by the back, the dorsal suture
lodicule: one of the small, usually thin, delicate and transparent structures inserted usually in a single whorl of 3, immediately below the stamens in the grass and bamboo flower
longitudinal: lengthwise
macronutrients: chemical elements of which relatively large quantities are essential for the growth of a plant (such as N, P, Ca, Mg)
Malesia: the biogeographical region including Malaysia, Indonesia, the Philippines, Singapore, Brunei and Papua New Guinea
mangrove: a brackish-water coastal swamp of tropical and subtropical areas that is partly inundated by tidal flow
membranous: thin and semi-transparent, like a fine membrane
mericarp: one of the separate halves or parts of a fruit, as in *Umbelliferae*
meristem: undifferentiated tissue of the growing point whose cells are capable of dividing and developing into various organs and tissues
merous (4–, 5– etc.): with 4, 5 etc. parts or numbers of sepals, petals etc.
mesocarp: the middle layer of the pericarp or fruit wall which is often fleshy or succulent
micropyle: a minute opening in the integument of an ovule through which the pollen tube penetrates
midrib: the main vein of a leaf which is a continuation of the petiole
monadelphous: of stamens, united into one group by their filaments
monocarpic: only flowering and fruiting once (said of an annual or other plant)
monochasium: a cymose inflorescence where a pattern of a single lateral branch arising below the terminal flower is repeated
monocotyledon: angiosperm having a single cotyledon or seed-leaf
monoecious: with unisexual flowers, but male and female flowers borne on the same plant
monopodial: of a primary axis which continues its original line of growth from the same apical meristem to produce successive lateral branches
mucilage (mucilaginous): a gelatinous substance that is similar to gum but that swells in water without dissolving and forms a slimy mass
mucous: secreting or containing a viscous or slimy matter
mucro: a sharp terminal point
mucronate: ending abruptly in a short stiff point
multifid: cleft into many lobes or segments
multiseriate: arranged in several rows
muricate: rough, with short and hard tubercular excrescences
mycorrhiza: a symbiotic association of roots with a fungal mycelium which may form a layer outside the root (ectotrophic) or within the outer root tissue (endotrophic)
narcotic: a drug that in moderate doses dulls the senses, relieves pain and induces profound sleep, but in excessive doses causes stupor, coma or convulsions
naturalized: introduced into a new area and established there, giving the impression of wild growth
nausea (nauseous): an uncomfortable feeling in and about the stomach associated with aversion to food and a need to vomit
necrosis: death of a portion of tissue often characterized by a brown or black discoloration
nectar: a sweet fluid extruded from various parts of the plant (e.g. by the flower to attract pollinators)
nectary: a group of modified subepidermal cells in flowers or leaves (extrafloral) secreting nectar
nematode: small elongated cylindrical worm-like micro-organism, free-living in soil or water, or parasitic in animals or plants
nerve: a strand of strengthening and/or conducting tissue running through a leaf, which starts from the midrib and diverges or branches throughout the blade
neuter: sexless, neither male or female; having neither functional stamens nor pistils
node: the point on the stem or branch at which a leaf or lateral is borne
nodule: a small knot or rounded body, often in roots of leguminous plants, where bacteria of the genus *Rhizobium* are active in the fixation of nitrogen from the air
nucellus: the nutritive tissue in an ovule
nucleus (plural: *nuclei)*: an organized proteid body of complex substance in the protoplasm of cells; the central point in a starch granule
nut: a one-seeded indehiscent fruit with a hard dry pericarp or shell
nutlet: a little nut
ob-: prefix, indication inverse or opposite condition (obtriangular, obcordate, etc.)
oblanceolate: reverse of lanceolate
oblate: more or less spherical but flattened at the poles
obligate: necessary, essential; the reverse of facultative
oblique: slanting; of unequal sides

oblong: longer than broad, with the sides parallel or almost so
oblongoid: a solid object which is oblong in section
obovate: reverse of ovate
obovoid: a solid object which is obovate in section
obpyriform: pear-shaped but attached at the broad end
obtuse: blunt or rounded at the end
ocrea: a tubular stipule or pair of opposite stipules so combined; an extension of the leaf sheath beyond the petiole insertion
offset (offshoot, rhizome cutting): a lateral shoot used for propagation
offshoot: see offset
ontogenetic: relating to or appearing in the course of development of an individual organism
opaque: neither shining nor transparent
operculum: a lid or cover which separates by a transverse line of division
opposite: of leaves and branches when two are borne at the same node on opposite sides of the stem
orbicular: flat with a more or less circular outline
order (and its extensions, first, etc.): a sequence, as of branching: a first order branch branches to produce a second order branch, etc.
orthotropic: having a more or less vertical direction of growth
ovary: that part of the pistil, usually the enlarged base, which contains the ovules and eventually becomes the fruit
ovate: egg-shaped in outline or in section; a flat surface which is scarcely twice as long as broad with the widest portion below the middle
ovoid: a solid object which is egg-shaped (ovate in section)
ovule: the immature seed in the ovary before fertilization
palea: the upper of two membranous bracts enclosing the flower in grasses
palmate: of leaflets, leaf lobes or veins, with the different elements arising from the same point
palmatifid: cut about half way down in a palmate manner; palmately lobed
pancreas: a compound glandular organ associated with the gut in most vertebrates, and secreting the hormones insulin and glucagon from endocrine glands and digestive enzymes from exocrine glands
panicle: an indeterminate branched racemose inflorescence
paniculate: resembling a panicle
pantropical: distributed throughout the tropics
papilionaceous flower: butterfly-like, pea-like flower, with standard, wings and keel
papillae: soft superficial glands or protuberances
papillate: having minute nipple-like protuberances
papillose: covered with minute nipple-like protuberances
pappus: the various tufts of hairs on achenes or fruits; the limb of the calyx of *Compositae* florets
papyraceous: papery, like paper
parasitic: deriving nourishment from some other organism
paripinnate: a pinnate leaf with all leaflets in pairs
parthenocarpy: the production of fruit without true fertilization
partite (parted): cleft, but not quite to the base
patent: spreading out widely
pedate: palmately divided or parted with the lateral divisions two-cleft
pedatisect: pedately veined, the divisions nearly reaching the midrib
pedicel: stalk of each individual flower of an inflorescence
pedicellate: furnished with a pedicel
peduncle: the stalk of an inflorescence or partial inflorescence
pedunculate: furnished with a peduncle
pellucid: translucent
peltate: of a leaf, with the stalk attached to the lower surface, not at the edge
pendent, pendulous: drooping; hanging down from its support
penninerved: pinnately veined, parallel veins arise at an angle from a midvein (as in *Musa*)
perennial: a plant living for many years and usually flowering each year
perfect flower: a flower possessing both male and female organs
perianth: the floral leaves as a whole, including both sepals and petals if both are present
pericarp: the wall of the ripened ovary or fruit whose layers may be fused into one, or may be more or less divisible into exocarp, mesocarp and endocarp
persistent: remaining attached; not falling off, not deciduous; applies to organs that remain in place after they have fulfilled their natural functions
petal: a member of the inner series of perianth segments which are often brightly coloured
petaloid: petal-like
petiolar: borne on, or pertaining to a petiole
petiolate: having a petiole

petiole: the stalk of a leaf
petiolule: the stalk of a leaflet
phloem: the principal food-conducting tissue of vascular plants; the bast element of a vascular bundle and basically composed of sieve elements, parenchyma cells, fibres and sclereids
photoperiod: length of day favouring optimum functioning of an organism
phyllotaxy: the arrangement of leaves or floral parts on their axis
phytosanitary: of or relating to health or health measures of plants
pilose: hairy with rather long soft hairs
pilosity: hairiness
pinna (plural: *pinnae*): a primary division or leaflet of a pinnate leaf
pinnate: arranged in pairs along each side of a common axis
pinnatifid: pinnately cleft
pistil: the female part of a flower (gynoecium) of one or more carpels, consisting, when complete, of one or more ovaries, styles and stigmas
pistillate: a unisexual flower with pistil, but no stamens
pistillode: a sterile, often reduced pistil
pith: the soft core occurring in the structural centre of a log; the tissue, sometimes soft, in the centre of the stem of a non-woody dicotyledon
placenta: the part of the ovary to which the ovules are attached
placentation: the way in which the placentae are arranged in the ovary
plagiotropic: having an oblique or horizontal direction of growth
pleonanthic: describing plants (e.g. some palms) flowering continuously, not dying after flowering (cf. hapaxanthic)
plicate: folded to and fro, like a fan
ploidy: degree or repetition of the basic number of chromosomes
plumose: feather-like with fine hairs
plumule: the primary bud of an embryo or germinating seed
plywood: a structural material consisting of sheets of wood glued or cemented together with the grains of adjacent layers arranged at right angles or at a wide angle
pneumatophore: used of air vessels of any description; a root often functioning as a respiratory organ in a marsh plant
pod: a general term for a dry dehiscent fruit; a dry fruit composed of a single carpel and dehiscing by sutures, like in legumes
pollen: spores or grains borne by the anthers containing the male element (gametophyte)
pollination: the transfer of pollen from the dehiscing anther to the receptive stigma
pollinia: regularly shaped masses of pollen formed by the cohesion of a large number of pollen grains, as in orchids
polyembryony: the production of two or more embryos within an ovule
polygamous: with unisexual and bisexual flowers in the same plant
polymorphic: polymorphous, with several or various forms; variable as to habit
polyploid: with more than two sets (genomes) of chromosomes in the somatic cells
poricidal: opening by pores
posterior: next to or towards the main axis
poultice: a soft, usually heated and sometimes medicated mass spread on cloth and applied to sores or other lesions
praemorse: jaggedly toothed, as if bitten
precocious: exceptionally early in development; flowering and fruiting at an early age
prickle: a sharp, relatively stout outgrowth from the outer layers
primordium: a group of undifferentiated meristematic cells, usually of a growing point, capable of differentiating into various kinds of organs or tissues
procumbent: lying along the ground
propagule: a part of a plant that becomes detached and grows into a new plant
prophyll: the bracteole at the base of an individual flower; the first bract borne on the inflorescence
prostrate: lying flat on the ground
protandrous: of flowers, shedding pollen before the stigma is receptive
protogynous: of flowers, the stigma is receptive before the pollen is shed
protuberance: projection, an extension beyond the normal surface
proximal: the part nearest the axis (as opposed to distal)
pruning: cutting off the superfluous branches or shoots of a plant for better shaped or more fruitful growth
pseudopetiole: a structure resembling a petiole, but not being one
pseudoraceme: raceme-like inflorescence but not a true raceme
pseudostem: an axis with the appearance of a stem but made up of other organs, e.g. leaf sheaths in *Musa* and *Curcuma*
puberulent: covered with down or fine hairs
puberulous: minutely pubescent

pubescent: covered with soft short hairs
pulp: the soft fleshy part of the fruit; mechanically ground or chemically digested wood used in manufacturing paper and allied products
pulvinate: cushion-shaped
pulvinule: the swollen base of a petiolule
pulvinus: a minute gland or swollen petiole base.
punctate: marked with dots or translucent glands
punctiform: in the form of a point or dot
pungent: bearing a sharp point; causing a sharp or irritating sensation
purgative: a medicine causing vigorous evacuation from the bowels
pyrene: a nutlet or kernel; the stone of a drupe or similar fruit
pyriform: resembling a pear in shape
quadrangular: four-cornered or four-edged
qualitative short-day plant: to flower, the plant needs short days (often with quantitative response); if the daylength surpasses a certain value (the critical daylength) the plant does not flower
quantitative short-day plant: plant flowers sooner under short-day conditions, but short days are not absolutely necessary to flower
raceme: an unbranched elongated indeterminate inflorescence with stalked flowers opening from the base upwards
racemose: raceme-like
rachilla: a diminutive or secondary axis, as the stalk of the spikelet in grasses; the branch that bears the flowers
rachis (plural: *rachides*): the principal axis of an inflorescence or a compound leaf beyond the peduncle or petiole
radical: arising from the root, or its crown
radicle: the first root of an embryo or germinating seed
ramification: branching
raphid (plural: *raphides*): a needle-shaped crystal occurring typically as one of a closely packed, sheaf-like bundle and consisting of calcium oxalate
ratoon: shoots in perennial crops such as the pineapple, left on the plants after harvest to produce the subsequent crop (ratoon crop)
ray: the radiating branch of an umbel; the outer floret of an inflorescence of the *Compositae* with strap-like perianth which differs from those in the centre or disk
receptacle: the flat, concave or convex part of the axis from which the parts of the flower arise
recurved: bent or curved downward or backward
reduplicate: of leaflets inversed V-shaped in cross section
reflexed: abruptly bent or turned downward or backward
regular: of a radially symmetrical flower; actinomorphic
remote-ligular: in germination, the young plant connected to the seed by a long tubular cotyledonary petiole, bearing a ligule
remote-tubular: in germination, the young plant connected to the seed by a long tubular cotyledonary petiole, lacking a ligule
reniform: kidney-shaped
restorative: capable of restoring health, strength, consciousness
reticulate: netted, as when the smallest veins of a leaf are connected together like the meshes of a net
retrorse: turned or directed backward or downward (opposed to antrorse)
retuse: with a shallow notch at a rounded apex
revolute: of leaves with the margins, rolled downwards towards the midrib
rheumatism: any of various painful conditions of the joints and muscles
rhizoid: root-like
rhizome: an underground stem which is distinguished from a root by the presence of nodes, buds, and leaves or scales
rhombic: shaped like a rhomb, an equilateral oblique-angled figure
rhomboid (botany): quadrangular, diamond-shaped with the lateral angles obtuse
rind: the tough outer layer of the fruit
root-nodules: small dwellings on roots of leguminous and other plants, containing nitrogen-fixing bacteria (rhizobia)
root sucker: a shoot originating from adventitious buds on the roots
rootstock: see rhizome; a stock for grafting consisting of a root and part of the main axis
rosette: a cluster of leaves or other organs in a circular form
rostellum: a small beak; in orchids a projection of the upper edge of the stigma in front of the anthers
rostrate: beaked
rotate: wheel-shaped; circular and flat
rotund: rounded in outline, somewhat orbicular, but a little inclined towards oblong
rubefacient: causes reddening of the skin, due to dilation of blood vessels, when applied locally
rudimentary: of organs, imperfectly developed and non-functional
rufous: reddish

rugose: wrinkled
rugulose: somewhat wrinkled
ruminate (endosperm): mottled in appearance, due to the infolding of a dark inner layer of the seed-coat into the paler coloured endosperm
runner: a specialized stem that develops from a leaf axil at the crown of a plant, grows horizontally along the ground, and forms a new plant at one of the nodes, usually at or near the tip (as in strawberry)
sagittate: shaped like an arrowhead; of a leaf base with two acute straight lobes directed downwards
samara: an indehiscent winged fruit
saponin: a glycoside with soap properties
saprophyte: a plant which derives its food from dead organic matter
sarcotesta: the fleshy outer seed-coat
scaberulous: somewhat rough
scabrid, scabrous: rough to the touch
scalariform: having markings suggestive of a ladder
scale: a thin scarious body, often a degenerate leaf or a trichome of epidermal origin
scandent: climbing
scape: a leafless floral axis or peduncle arising from the ground
scarification (seed): scarifying, to cut or soften the wall of a hard seed to hasten germination
scarify: to treat a hard-coated seed by mechanical abrasion or with acid to facilitate germination
schizocarp: a pericarp which splits into one-seeded portions, mericarps or 'split fruits'
sclerenchymatous: of tissue, composed of thick-walled cells
scrub: vegetation whose growth is stunted because of lack of water coupled with strong transpiration
scurfy: bearing small scales on the surface (lepidote; scaly)
secondary venation: the collection of veins of a leaf blade branching off from midrib in pinnately veined leaves, or from the main veins in palmately veined ones
section (botany): a taxonomic rank between the genus and the species accomodating a single or several related species
sedative: a drug that tends to calm, moderate or tranquillize nervousness or excitement
seed: the reproductive unit formed from a fertilized ovule, consisting of embryo and seed-coat, and, in some cases, also endosperm
seedling: the juvenile plant, grown from a seed
segment: the division of a palmate or costapalmate leaf
self-compatible: capable of fertilization and setting seed after self-pollination
self-pollination: pollination with pollen from the same flower or from other flowers of plants of the same clone
self-sterile: failure to complete fertilization and obtain seed after self-pollination
semi-: prefix, meaning half or incompletely, e.g. semi-inferior
semi-aquatic: a water-plant which roots in the soil, but produces aquatic leaves, otherwise living as land-plants
sepal: a member of the outer series of perianth segments
sepaloid: sepal-like
septate: divided by one or more partitions
septum (plural: *septa*): a partition or cross-wall
seral: a temporary or developing vegetation type
seriate: serial, disposed in series of rows
sericeous: silky
serrate: toothed like a saw, with regular pointed teeth pointing forwards
serrulate: serrate with minute teeth
sessile: without a stalk
seta (plural: *setae*): a bristle-like body
setose: set with bristles or bristle-like elements
setulose: set with small bristles or bristle-like elements
sheath: a tubular structure surrounding an organ or part, as the lower part of the leaf clasping the stem in grasses
shoot: the ascending axis, when segmented into dissimilar members it becomes a stem
shrub: a woody plant which branches from the base, all branches being equivalent
simple (botany): not compound, as in leaves with a single blade
sinistrorse: twining to the left (anti-clockwise)
sinuous: wavy
solitary: single stemmed, not clustering
spadix: a flower spike with a fleshy or thickened axis, as in aroids and some palms
spat(h)ulate: spoon-shaped
spathe: a large bract enclosing a spadix, or two or more bracts enclosing a flower cluster
spermatorrhoea: abnormally frequent or excessive involuntary emission of semen without orgasm
spherical: globular
spicate: spike-like
spiciform: with the form of a spike
spicule: a fine, fleshy or brittle, needle-like spine
spike: a simple indeterminate inflorescence with sessile flowers along a single axis
spikelet: a secondary spike, one of the units of

which the inflorescence is made in grasses, consisting of one or more florets on a thin axis, subtended by a common pair of glumes

spine: a short stiff straight sharp-pointed hard structure usually arising from the wood of a stem

spinescent: ending in a spine or sharp point

spinose: having spines (spinous)

spinulescent: slightly spiny or having small spines

spiral: as though wound round an axis

spur (botany): a hollow and slender extension of some part of the flower, usually nectariferous; a small reproductive shoot

squamose: scaly

stamen: one of the male reproductive organs of a flower; a unit of the androecium

staminate: a flower bearing stamens but no pistil

staminode: an abortive or rudimentary stamen without or with an imperfect anther

standard (flower part): the fifth, posterior or upper petal of a papilionaceous corolla

starch: polysaccharide made up of a long chain of glucose units joined by α-1,4 linkages, either unbranched (amylose) or branched (amylopectin) at a α-1,6 linkage; the storage carbohydrate in plants, occurring as starch granules in amyloplasts, and which is hydrolyzed during digestion by amylases, maltase and dextrinases to glucose via dextrins and maltose

stellate: star-shaped, as of hairs with radiating branches, or of petals arranged in the form of a star

stem: the main ascending axis of a plant; in bamboos usually named culm, in other plant groups occasionally

sterile: failing to complete fertilization and produce seed as a result of defective pollen or ovules; not producing seed capable of germination; lacking functional sexual organs (sterility)

stigma: the portion of the pistil which receives the pollen

stilt roots: the oblique adventitious roots of the mangrove and similar forms

stimulant: an agent that produces a temporary increase of the functional activity or efficiency of an organism or any of its parts

stipe: the stalk supporting a carpel or gynoecium

stipel: small secondary stipule at the base of a leaflet

stipitate: borne on a stipe or short stalk

stipule: a scale-like or leaf-like appendage at the base of a petiole

stolon: a trailing stem usually above the ground which is capable of producing roots and shoots at its nodes

stoloniferous: bearing a stolon or stolons

stone: the hard endocarp of a drupe containing the seed or seeds

straggling: extremely divergent, spreading very far apart

strain: a group of individuals of a common origin, usually a more narrowly defined group than a cultivar

striate: marked with fine longitudinal parallel lines, as grooves or ridges

strigose: with short stiff hairs lying close along the surface

style: the part of the pistil connecting the ovary with the stigma

stylodium (stylode): a style-like stigma (e.g. in grasses, *Compositae*) or a false style (e.g. glands on top of an ovary)

sub-: prefix, meaning somewhat or slightly (e.g. subacute), or below (e.g. subterranean) or less than, imperfectly

subfamily: a taxonomic rank between the family and the tribe denoting a part of a family

subglobose: nearly globular

subspecies: a subdivision of a species, in rank between a variety and a species

subulate: awl-shaped, sharply pointed

succulent: juicy, fleshy

sucker: a shoot, usually originating from adventitious buds on the roots or basal stem parts, which does not fit in the architectural model, but is capable of repeating the model

sudorific: causing or inducing sweat

sulcate: grooved or furrowed

superior (ovary): an ovary with the perianth inserted below or around its base, the ovary being attached at its base only

suture: the line of junction of two carpels; the line or mark of splitting open

sympetalous: with united petals

sympodial: of a stem in which the growing point either terminates in an inflorescence or dies, growth being continued by a new lateral growing point

synandrium: the cohesion of the anthers of each male flower in certain *Araceae*

syncarp: a multiple or fleshy aggregate fruit, including fruit produced from a more or less entire inflorescence (as in *Artocarpus*, *Ananas*, *Morus*)

syncarpous: of an ovary composed of two or more united carpels

syphilis: a disease communicated by sexual contact, or via the blood or bite of an infected person, caused by a spirochete (*Treponema pallidum*) and characterized by a clinical course in

3 stages continued over many years
tail (botany): any long and slender prolongation
taproot: the primary descending root, forming a direct continuation of the radicle
taxon (plural: *taxa)*: a term applied to any taxonomic unit irrespective of its classification level, e.g. variety, species, genus, etc.
taxonomy: the study of principles and practice of classifying living organisms (systematics)
tendril: a thread-like climbing organ formed from the whole or part of a stem, leaf or petiole
tepal: a segment of a perianth, applied when no distinction between sepals and petals can be made
terete: cylindrical; circular in transverse section
terminal: borne at the end or apex
ternate: in threes
terrestrial: on or in the ground
tertiary venation: generally the collection of the smallest veins of a leaf blade
testa: the outer coat of the seed
tetraploid: having four times ($4n$) the basic number of chromosomes or twice the diploid number ($2n$)
theca (plural: *thecae)*: a spore- or pollen-case
thorn: a woody sharp-pointed structure formed from a modified branch
throat: of corolla, the orifice of a gamopetalous corolla
tiller: a shoot from the axils of the lower leaves, e.g. in some grasses and palms (making such shoots: tillering)
tissue culture: a body of tissue growing in a culture medium outside the organism
tomentellous: minutely tomentose
tomentose: densely covered with short soft hairs
tomentulose: slightly tomentose
tomentum: pubescence
tonic: medicinal preparation believed to have the power of restoring normal activity
transverse: of tertiary veins, connecting the secondary veins, not necessarily in a perpendicular way
tree: a perennial woody plant with a single evident trunk
triad: a special group of 2 lateral staminate and a central pistillate flower, structurally a short cincinnus
trichome: any hair, bristle or scale-like outgrowth of the epidermis
trifoliate: three-leaved
trifoliolate: with three leaflets
trigonous: three-angled, with plane faces
trijugate: bearing 3 pairs of leaflets
trilocular: having 3 chambers, each usually bearing an ovule or seed
triovulate: gynoecium with 3 ovules, one in the locule of each carpel
tripartite: divided into 3 parts
triploid: having three times the basic number of chromosomes, usually written $3n$
trisect(ed): divided into 3, three-cleft to the base
tristichous: in 3 vertical ranks
truncate: cut off more or less squarely at the end
trunk: the main stem of a tree apart from its limbs and roots
tuber: the swollen portion of an underground stem or root which acts as a storage organ and propagule; it is usually of one year's duration, those of successive years not arising directly from the old ones nor bearing any constant relation to them
tubercle: a small tuber-like excrescence
tuberculate: covered with warty protuberances
tuberous: producing tubers or resembling a tuber
tufted: growing in tufts (caespitose)
tunicated: provided with a dry papery covering round a bulb or corm
twining: winding spirally
ulcer: an open sore on the skin or a mucous membrane, characterized by the disintegration of the tissue and, often, the discharge of pus
umbel: an indeterminate, often flat-topped inflorescence whose divergent peduncles (rays) and pedicels arise from a common point; in a compound umbel each ray itself bears an umbellule (small umbel)
unarmed: devoid of thorns, spines or prickles
uncinate: hooked
undulate: wavy, said for instance of a leaf margin if the waves run in a plane at right angles to the plane of the leaf blade
unguiculate: contracted at the base into a claw
unifoliolate: with one leaflet only, but in origin a compound leaf
unilateral: one-sided
unilocular: one-celled
uniseriate: in one horizontal row or series
unisexual: of one sex, having stamens or pistils only
urceolate: urn-shaped
valvate: of perianth segments with their edges in contact, but not overlapping in the bud
variegated: irregularly coloured in patches, blotched
variety: botanical variety which is a subdivision of a species; an agricultural or horticultural variety is referred to as a cultivar

vein: a strand of vascular tissue in a flat organ, such as a leaf
velutinous: see velvety
velvety: with a coating of fine soft hairs; the same as tomentose but denser so that the surface resembles (and feels like) velvet
venation: the arrangement of the veins in a leaf
venereal disease: a contagious disease (as gonorrhoea or syphilis) that is typically acquired in sexual intercourse
ventral: faces central axis (adaxial), opposed to dorsal (abaxial)
ventricose: with a swelling or inflation on one side
verrucate: covered with warts
verrucose: warty
verruculose: very warty, much covered with warts
versatile (botany): turning freely on its support, as many anthers on their filaments
verticil: whorl
verticillaster: a false whorl, composed of a pair of opposed cymes, as in *Labiatae*
verticillate: in a whorl with several elements arising at the same node
vestigial: small and imperfectly developed
viability: ability to live, grow and develop
villose (villous): with long weak hairs
vine: a plant having a stem that is too slender to hold itself erect and therefore supports itself by climbing over an object
viny: trailing or climbing
violaceous: violet-coloured
viscid: sticky
viscous: glutinous, or very sticky
viviparous: germinating or sprouting from seed or bud while attached to the parent plant
warty: covered with firm roundish excrescences
waterlogged: flooded with water, generally for a period of at least a few weeks
whip: general term for cirrus and flagellum
whorl: arrangement with more than two organs of the same kind arising at the same level
wing: any membraneous expansion attached to an organ; a lateral petal of a papilionaceous corolla
woolly: referring to an indumentum, clothed with long and tortuous or matted hairs
xylem: the main water-conducting tissue in vascular plants which extends throughout the plant and is also involved in transport of minerals, food storage and support; primary xylem is derived from the procambium, secondary xylem (e.g. the wood of trees and shrubs) from the vascular cambium; xylem is composed of tracheary elements: tracheids and (in angiosperms) vessel elements; both are elongated hollow cells, with thickened, usually heavily lignified walls, and lacking protoplasts when mature; they are joined end to end to form a continuous conducting tube
yaws: an infectious contagious tropical disease caused by a spirochete (*Treponema pertenue*) and marked by ulcerating lesions with later bone involvement (also called frambesia)
zygomorphic: irregular and divisible into equal halves in one plane only
zygote: the cell formed from the fusion of two gametes; a fertilized egg

Sources of illustrations

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Nypa fruticans: Sastrapradja, S. et al., 1978. Palem Indonesia. Proyek Sumber Daya Ekonomi (SDE 54), Lembaga Biologi Nasional (LBN 13), LIPI, Bogor, Indonesia. p. 46 (habit); Corner, E.J.H., 1966. The natural history of palms. Weidenfeld & Nicholson, London, United Kingdom. p. 131, Fig. 69 (inflorescence); Koorders, S.H., 1913–1937. Exkursionsflora von Java. Vol. 4, Atlas. Gustaf Fischer Verlag, Jena, Germany. p. 164, Fig. 355 (infructescence). Redrawn and adapted by P. Verheij-Hayes.

Pachyrhizus erosus: Westphal, E. & Jansen, P.C.M. (Editors), 1989. Plant Resources of South-East Asia. A selection. Pudoc, Wageningen, the Netherlands. p. 214 (habit, mature fruit); Sastrapradja, S. et al., 1981. Root and tuber crops (translation of 'Ubi-ubian', 1977). International Board for Plant Genetic Resources (IBPGR), Rome, Italy. p. 86 (tuber). Redrawn and adapted by P. Verheij-Hayes.

Plectranthus rotundifolius: Sastrapradja, S. et al., 1981. Root and tuber crops (translation of 'Ubi-ubian', 1977). International Board for Plant Genetic Resources (IBPGR), Rome, Italy. p. 26. Redrawn and adapted by P. Verheij-Hayes.

Saccharum officinarum: Westphal, E. & Jansen, P.C.M. (Editors), 1989. Plant Resources of South-East Asia. A selection. Pudoc, Wageningen, the Netherlands. p. 244.

Solanum tuberosum: Correll, D.S. (Editor), 1962. The potato and its wild relatives. Texas Research Foundation, Renner, Texas, United States. p. 529, Fig. 208. Redrawn and adapted by P. Verheij-Hayes.

Stachys sieboldii: Herklots, G.A.C., 1972. Vegetables in South-East Asia. George Allen & Unwin, London, United Kingdom. p. 471, Fig. 139 (habit); Fritz, D. et al., 1989. Gemüsebau. 9th revised edition. Ulmer, Stuttgart, Germany. p. 315, Fig. 127 (stolon with tubers); Buishand, T. et al., 1986. Groenten uit alle windstreken. Spectrum, Utrecht, the Netherlands. p. 101 (tuber). Redrawn and adapted by P. Verheij-Hayes.

Tacca leontopetaloides: Limpricht, W., 1928. Taccaceae. In: Engler, A. (Editor): Das Pflanzenreich. Vol. 4, 42. W. Engelmann Verlag, Leipzig, Germany. p. 27, Fig. 5 (habit of flowering plant); Hepper, F.N., 1968. Taccaceae. In: Hepper, F.N. (Editor): Flora of West tropical Africa. 2nd edition. Vol. 3. Crown Agents for Oversea Governments and Administrations, London, United Kingdom. p. 177, Fig. 379 (tuber and basal plant part, part of leaf segment, inflorescence); Carter, S., 1962. Taccaceae. In: Hubbard, C.E. & Milne-Redhead, E. (Editors): Flora of tropical East Africa. Crown Agents for Oversea Governments and Administrations, London, United Kingdom. p. 2, Fig. 1 (inner side of perianth segment with top of stamen, seed surrounded by aril, seed). Redrawn and adapted by P. Verheij-Hayes.

Xanthosoma nigrum: Koorders, S.H., 1913–1937. Exkursionsflora von Java. Vol. 4, Atlas. Gustaf Fischer Verlag, Jena, Germany. p. 203, Fig. 407 (habit, inflorescence with spatha partly removed); Sastrapradja, S. et al., 1981. Root and tuber crops (translation of 'Ubi-ubian', 1977). International Board for Plant Genetic Resources (IBPGR), Rome, Italy. p. 94 (lower plant part with roots and developing tuberous rhizomes, large tuber, small tuber). Redrawn and adapted by P. Verheij-Hayes.

Map of South-East Asia for Prosea: original design of R. Boekelman.

Index of scientific plant names

Page numbers printed in bold refer to main treatment.

Index of vernacular plant names

Page numbers printed in bold refer to main treatment. For transcriptions of Vietnamese names, see at the end of the index.

Transcriptions of Vietnamese characters

[aa] = â	[ar] = ả	[ax] = ã	[ej] = ẹ	[oo] = ô	[ow] = ơ	[uj] = ụ	[uwx] = ữ
[aaf] = ầ	[as] = á	[ee] = ê	[er] = ẻ	[oof] = ồ	[owf] = ờ	[ur] = ủ	[ux] = ũ
[aaj] = ậ	[aw] = ă	[eef] = ề	[es] = é	[ooj] = ộ	[ooj] = ợ	[us] = ú	
[aar] = ẩ	[awf] = ằ	[eej] = ệ	[ex] = ẽ	[oor] = ổ	[owr] = ở	[uw] = ư	
[aas] = ấ	[awj] = ặ	[eer] = ể	[if] = ì	[oos] = ố	[ows] = ớ	[uwf] = ừ	
[aax] = ẫ	[awr] = ẳ	[ees] = ế	[is] = í	[oox] = ỗ	[owx] = ỡ	[uwj] = ự	
[af] = à	[aws] = ắ	[eex] = ễ	[of] = ò	[or] = ỏ	[ox] = õ	[uwr] = ử	
[aj] = ạ	[awx] = ẵ	[ef] = è	[oj] = ọ	[os] = ó	[uf] = ù	[uws] = ứ	

The Prosea Foundation
(Plant Resources of South-East Asia)

Name, location, legal status and structure

- Prosea is a Foundation under Indonesian law, with an international charter, domiciled in Bogor. It is an autonomous, non-profit, international agency, governed by a Board of Trustees. It seeks linkage with existing regional and international organizations;
- Prosea is an international programme focusing on the documentation of information on plant resources of South-East Asia;
- Prosea consists of a Network Office in Bogor (Indonesia) coordinating 6 Country Offices in South-East Asia, and a Publication Office in Wageningen (the Netherlands).

Participating institutions

- Forest Research Institute of Malaysia (FRIM), Karung Berkunci 201, Jalan FRI Kepong, 52109 Kuala Lumpur, Malaysia;
- Indonesian Institute of Sciences (LIPI), Widya Graha, Jalan Gatot Subroto 10, Jakarta 12710, Indonesia;
- Institute of Ecology & Biological Resources (IEBR), Nghia Do, Tu Liem, Hanoi, Vietnam;
- Papua New Guinea University of Technology (UNITECH), Private Mail Bag, Lae, Papua New Guinea;
- Philippine Council for Agriculture, Forestry and Natural Resources Research & Development (PCARRD), Los Baños, Laguna, Philippines;
- Thailand Institute of Scientific and Technological Research (TISTR), 196 Phahonyothin Road, Chatuchak, Bangkok 10900, Thailand;
- Wageningen Agricultural University (WAU), Costerweg 50, 6701 BH Wageningen, the Netherlands.

Objectives

- to document and make available the existing wealth of information on the plant resources of South-East Asia for education, extension work, research and industry;
- to make operational a computerized data bank on the plant resources of South-East Asia;
- to publish the results in the form of an illustrated, multi-volume handbook in English;
- to promote the dissemination of the information gathered.

Target groups

- those professionally concerned with plant resources in South-East Asia and working in education, extension work, research and commercial production (direct users);
- those in South-East Asia depending directly on plant resources, obtaining relevant information through extension (indirect users).

Activities

- the establishment and operation of data bases;
- the publication of books;
- the sponsorship, support and organization of training courses;
- research into topics relevant to Prosea's purpose;
- the publication and dissemination of reports and the research results.

Implementation

The programme period has been tentatively divided into 3 phases:
- preliminary phase (1985–1986): publication of 'Plant Resources of South-East Asia, Proposal for a Handbook' (1986);
- preparatory phase (1987–1990): establishing cooperation with South-East Asia through internationalization, documentation, consultation and publication; reaching agreement on the scientific, organizational and financial structure of Prosea;
- implementation phase (1991–2000): compiling, editing and publishing of the handbook; making operational the computerized data bank with the texts and additional information; promoting the dissemination of the information obtained.

Documentation

A documentation system has been developed for information storage and retrieval called Prosea Data Bank. It consists of 6 data bases:
- BASELIST: primarily a checklist of more than 6200 plant species;
- CATALOG: references to secondary literature;
- PREPHASE: references to literature from South-East Asia;
- ORGANYM: references to institutions and their research activities;
- PERSONYM: references to specialists;
- TEXTFILE: all Prosea publications and additional information.

Publication

The handbook in blue cover (hardbound) is distributed by Backhuys Publishers, Leiden, the Netherlands (formerly by Pudoc, Wageningen, the Netherlands). The handbook in green cover (paperback) is distributed in two price-classes: a low-price paperback, distributed by Prosea South-East Asia for all developing countries; a medium-price paperback, distributed by Backhuys Publishers, Leiden, the Netherlands, for developed countries (becoming available two years after publication of the hardbound edition). The bibliographies are distributed by Prosea South-East Asia.

The handbook

- No 1. Pulses. L.J.G. van der Maesen and Sadikin Somaatmadja (Editors). Pudoc, Wageningen. 1989/ESCAP CGPRT Centre, Bogor. 1990 (out of print)/Prosea, Bogor. 1992.
- No 2. Edible fruits and nuts. E.W.M. Verheij and R.E. Coronel (Editors). Pudoc, Wageningen. 1991/Prosea, Bogor. 1992.
- No 3. Dye and tannin-producing plants. R.H.M.J. Lemmens and N. Wulijarni-Soetjipto (Editors). Pudoc, Wageningen. 1991/Prosea, Bogor. 1992.
- No 4. Forages. L. 't Mannetje and R.M. Jones (Editors). Pudoc, Wageningen. 1992/Prosea, Bogor. 1992.
- No 5(1). Timber trees. Major commercial timbers. I. Soerianegara and R.H.M.J. Lemmens (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 5(2). Timber trees. Minor commercial timbers. R.H.M.J. Lemmens, I. Soerianegara and Wong Wing Chong (Editors). Backhuys Publishers, Leiden. 1995/Prosea, Bogor. 1995.
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- No 6. Rattans. J. Dransfield and N. Manokaran (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 7. Bamboos. S. Dransfield and E.A. Widjaja (Editors). Backhuys Publishers, Leiden. 1995/Prosea, Bogor. 1995.
- No 8. Vegetables. J.S. Siemonsma and Kasem Piluek (Editors). Pudoc, Wageningen. 1993/Prosea, Bogor. 1994.
- No 9. Plants yielding non-seed carbohydrates. M. Flach and F. Rumawas (Editors). Backhuys Publishers, Leiden. 1996/Prosea, Bogor. 1996.
- No 10. Cereals. G.J.H. Grubben and S. Partohardjono (Editors). (expected publication date 1996).
- No 11. Auxiliary plants in agriculture and forestry. F.H. Ibrahim and L.J.G. van der Maesen (Editors). (expected publication date 1996).
- No 12. Medicinal and poisonous plants.
- No 13. Spices.
- No 14. Vegetable oils and fats.
- No 15. Cryptogams. W.F. Prud'homme van Reine and M.A. Rifai (Editors). (expected publication date 1997).
- No 16. Stimulants.
- No 17. Fibre plants.
- No 18. Plants producing exudates.
- No 19. Essential-oil plants.
- No 20. Ornamental plants.

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- Bibliography 2: Edible fruits and nuts. Edition 1. Part 1 and part 2. N. Wulijarni-Soetjipto and J.S. Siemonsma (Editors). Prosea, Bogor/Pudoc, Wageningen. 1993.

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- A Selection. E. Westphal and P.C.M. Jansen (Editors). Pudoc, Wageningen. 1989/Prosea, Bogor. 1993.
- Basic list of species and commodity grouping. Version 1. R.H.M.J. Lemmens, P.C.M. Jansen, J.S. Siemonsma, F.M. Stavast (Editors). Prosea Project, Wageningen. 1989. (out of print).
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- Proceedings of the First Prosea International Symposium, May 22–25, 1989. Jakarta, Indonesia. J.S. Siemonsma and N. Wulijarni-Soetjipto (Editors). Pudoc, Wageningen. 1989. (out of print).
- Proceedings of the Second Prosea International Workshop, November 7–9, 1994. Jakarta and Cisarua, Indonesia. Rusdy E. Nasution and N. Wulijarni-Soetjipto (Editors). Prosea, Bogor. 1995.

In brief, Prosea is

- an international programme, focused on plant resources of South-East Asia;
- interdisciplinary, covering the fields of agriculture, forestry, horticulture and botany;
- a research programme, making knowledge available for education and extension;
- ecologically focused on promoting plant resources for sustainable tropical land-use systems;
- committed to conservation of biodiversity;
- committed to rural development through diversification of resources and application of farmers' knowledge.

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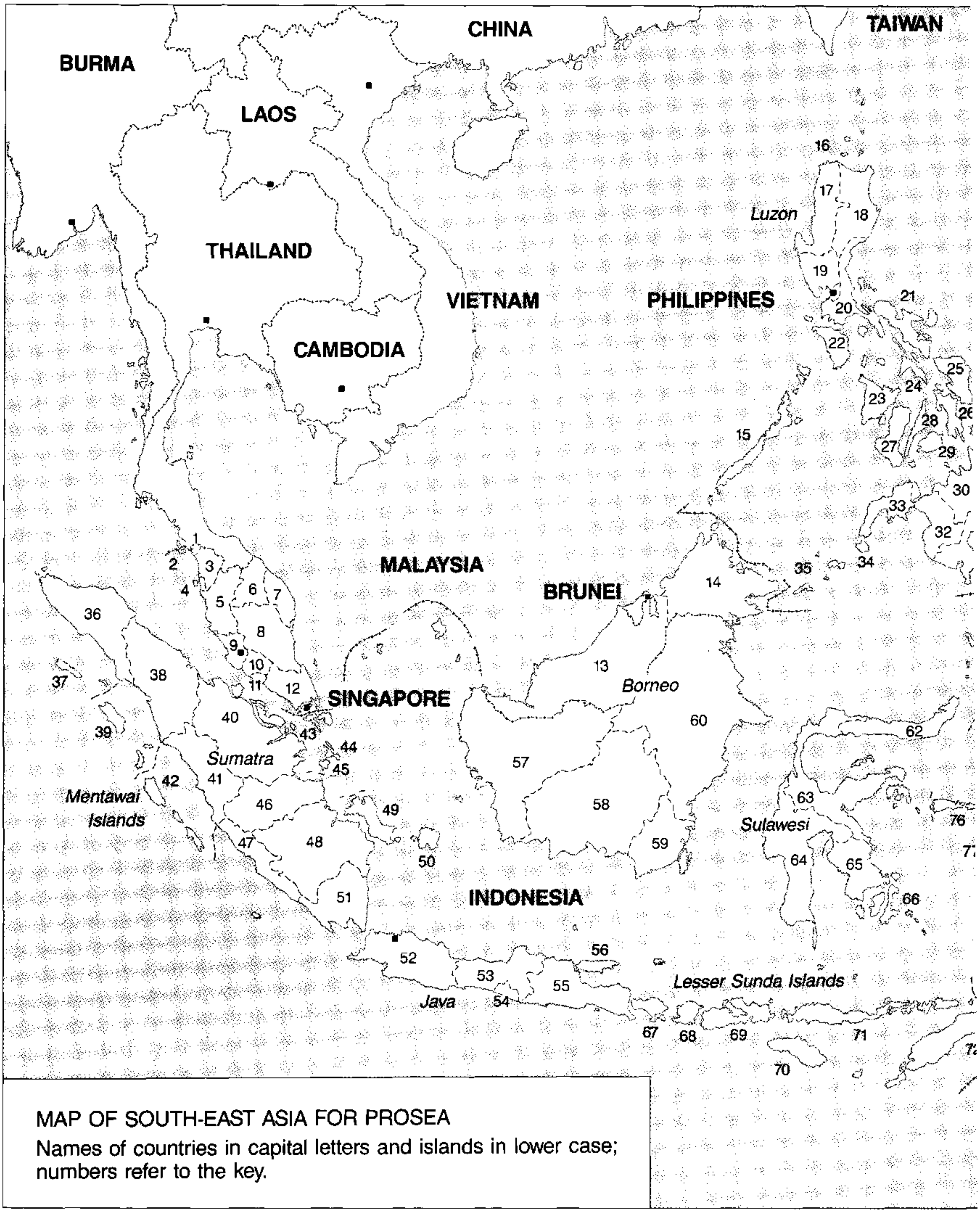

MAP OF SOUTH-EAST ASIA FOR PROSEA

Names of countries in capital letters and islands in lower case; numbers refer to the key.

Key of islands (*i*), states (*s*), regions (*r*) and provinces (*p*).

MALAYSIA
East Malaysia *r* 13-14
Johor *s* 12
Kedah *s* 3
Kelantan *s* 6
Langkawi *i* 2
Melaka *s* 11
Negeri Sembilan *s* 10
Pahang *s* 8
Peninsular Malaysia (West Malaysia) *r* 1-12
Perak *s* 5
Perlis *s* 1
Pinang *s* 4
Sabah *s* 14
Sarawak *s* 13
Selangor *s* 9
Terengganu *s* 7

PHILIPPINES
Babuyan Islands *i* 16
Basilan *i* 34
Bicol *r* 21
Bohol *i* 29
Cagayan Valley *r* 18
Cebu *i* 28
Central Mindanao *r* 32
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