

Members of Euphorbiaceae in primitive and advanced societies

R. E. SCHULTES

Botanical Museum, Harvard University, Cambridge, Massachusetts, U.S.A.

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SCHULTES, R. E., 1987. **Members of Euphorbiaceae in primitive and advanced societies.** The family contains a number of species used by man in a wide variety of ways. Often use is restricted to a small group of people, but in a few instances the plant has been a major crop and the product used throughout the world, e.g. *Hevea*, which yields rubber, used extensively in every civilized country. Cassava from *Manihot* is almost as widespread, being one of the staple foods of tropical regions. Species with more occasional use have constituents with interesting properties of potential future economic application.

ADDITIONAL KEY WORDS:—Amazon Indians — *Caryodendron* — cassava — *Croton* — *Elaeophorbia* — *Euphorbia* — *Hevea* — *Jatropha* — *Manihot* — rubber.

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INTRODUCTION

Considering the Euphorbiaceae's probable polyphyletic origin, cosmopolitan distribution, 300 genera with more than 6000 species and extreme botanical and chemical diversity, it is logical to expect that the family has given mankind numerous major economic plants, and that in primitive societies the uses of species number in the hundreds, if not thousands, and span an extraordinarily wide range of utilitarian applications.

The uses of euphorbiaceous plants in our own society run a broad gamut of

categories: foods, various kinds of poisons, medicines, sundry types of oils, waxes, rubbers, varnishes, compounds for paints and other industrial materials.

We may consider as major economic plants the following: *Aleurites fordii* Hemsl. (tung oil); *A. moluccana* Willd. (candlenut or lumbang oil); *A. montana* E. H. Wilson (mu tree); *Cnidioscolus* sp. (chilte rubber); *Croton tiglium* L. (croton oil); *Euphorbia antisyphilitica* Zucc. (candellila wax); *E. intisy* Drake (intisy rubber); *Hevea brasiliensis* (Willd. ex Adr. Juss.) Muell. Arg. (Pará rubber); *Manihot esculenta* Crantz (cassava, tapioca); *M. glaziovii* Muell. Arg. (Ceará rubber); *Ricinus communis* L. (castor bean); *Sapium sebiferum* Roxb. (vegetable tallow). (Hill, 1952; Purselove, 1968.)

This brief consideration of the economic botany and ethnobotany of the Euphorbiaceae is selective in so far as the thousands of ethnobotanical reports are concerned. As a consequence, several different categories of euphorbiaceous plants are discussed: 1, genera employed by Indians in the north-west Amazon; 2, species of *Elaeophorbia* and *Euphorbia*, with uses in primitive societies that suggest the practical need of chemical and pharmacological study for potential medicinal compounds; 3, *Caryodendron orinocense* Karst., a wild oil-rich tree worthy of domestication as a new tropical plantation crop; 4, *Croton* and *Jatropha* species, biodynamic plants with native uses that have recently yielded new chemical compounds of medicinal promise; and 5, the two most important economic plants of the family: *Manihot esculenta*, cassava or the source of tapioca, one of the 13 species of plants that feed the world population, and *Hevea brasiliensis*, the Pará rubber tree, that has changed the world in a century.

Scientists have long been interested in those toxic substances in the Euphorbiaceae, esters of the diterpene alcohols, phorbol, resiniferonol and ingenol, that have skin-irritant and tumour-inducing activities. They occur in a number of genera: *Aleurites*, *Baliospermum*, *Croton*, *Euphorbia*, *Exoecaria*, *Hippomane*, *Hura*, *Jatropha*, *Micrandra*, *Ostodes*, *Sapium*, *Stillingia* and *Synadenium*. More than 100 compounds structurally related to diterpene alcohols are known from these 13 euphorbiaceous genera. It is perhaps significant that these chemical irritants are known only from two sections of the Euphorbiaceae (in accord with the classification suggested by Webster, 1975).

It would seem logical to orientate chemical and pharmacological investigation not so much by random choice but more by taking advantage of the presumed knowledge of the properties of plants that primitive societies have discovered over the millennia by trial and error. In these primitive societies man is not usually going to utilize any plant that has no biodynamic activity: the fact that a plant is physiologically active indicates the presence of one or more active chemical constituents. Only a small percentage of the half-million species of plants have ever been even superficially examined as to their chemical constitution. If chemists were to attempt to procure and analyse the 80 000 species in the Amazon, for example, the task would never be finished. One effective short cut would be to concentrate on those species known to have native uses as medicines, toxins or narcotics. This ancient and intimate knowledge of plant properties is fast disappearing, even in one generation, with the ever encroaching acculturation and civilization of primitive societies the world over. Much of great value to our phytochemists and pharmacologists is rapidly disappearing, and the knowledge acquired over centuries will forever become extinct (Plotkin & Schultes, 1983).

USEFUL EUPHORBIACEOUS GENERA IN THE NORTH-WEST AMAZON

An example of the importance of biodynamic euphorbiaceous plants may be appreciated by the following noted genera which are employed by Indians in the small north-western part of the Amazon from which information has been gathered during 40 years of ethnopharmacological research in that region.

A species of *Alchornea* is believed to be effective in treating diarrhoea. The milky latex of *Chamaesyce* (often treated as a subgenus of *Euphorbia*) is applied to fungal infections between the toes ('athletes' foot'). The reddish juice from several species of *Croton* is applied to clean and help cure infected cuts and sores, ulcers and boils. One species of *Euphorbia* is considered to have purgative properties, and the latex of another is applied to fungal infections of the feet. *Hieronyma* is believed to be effective against a skin eruption called chandra. The sap of the petiole of a species of *Jatropha* is applied to sore gums of teething children, and another species is prepared as a bath used to reduce fevers and headache. The seed oil of *Mabea* is rubbed into the scalp to delay loss of hair. *Manihot* has, according to the natives, anti-diarrhoea properties. The latex of *Micrandra* is spread on sore gums and mucous membranes of the mouth and is valued as a styptic for the umbilical cord. *Nealchornia* is ichthyotoxic. *Phyllanthus* in cultivated as a fish poison, and several species are considered to be insect repellants, to be efficacious in decoction in treating kidney troubles and as a wash for reducing headaches (Schultes, unpublished field notes, 1941-1985).

ELAEOPHORBIA

In Africa and Madagascar, a common custom involves the administration of justice—that is, the establishment of guilt or innocence—through the use of preparations based on highly toxic plants. At least 25 species in eight families are known to be so employed. The most important sources are leguminous and apocynaceous species, but two of the minor ordeal poisons belong to the Euphorbiaceae (Robb, 1957).

The introduced South American *Manihot esculenta* is used to a certain extent throughout tropical Africa, but especially in the Congo Basin. The active principle may be the cyanogenic glycoside which, when the root is prepared for food, must be removed.

However, perhaps the more interesting euphorbiaceous ordeal poison is *Elaeophorbium drupifera* (Thonn.) Stapf. This plant is abundant in parts of western Africa, but it seems to be used in criminal trials only in the Ivory Coast. The natives express the caustic white latex and mix it with water, or they prepare the plant as a decoction. The usual manner of use is ingestion, but occasionally it may be spread on the eyes of the accused and rubbed in with the fingers, in which case damage to the cornea constitutes evidence of guilt. The latex contains the toxic constituent, but the active principle has not yet been elucidated.

While it would seem rather futile to investigate such an apparently dangerous ordeal poison, the discovery of the medicinally extremely useful cholinergic alkaloid physostigmine from an even more pernicious African ordeal poison, *Physostigma venenosum* Balf., the Calabar bean of Nigeria, should indicate that we cannot prejudge the cause of any biodynamism in plants was of no value in



modern medicine. Consequently, this toxic euphorbiaceous species deserves chemical and pharmacologic study.

EUPHORBIA

A promising ethnopharmacological lead that should be more thoroughly investigated is the use by Mayan Indians of Guatemala of *Euphorbia lancifolia* Schlecht. The vernacular name *ixbut* comes from early Mayan languages of the Pokom group, *ix* meant woman, but indicated an increase in the flow or volume of liquid, in other words a galactagogue. The leaves and branchlets are boiled in water which is allowed to cool, sugar is added, and the drink is taken thrice daily. *Ixbut* tea should not be used, the natives state, when it starts to ferment (Rosengarten, 1978).

In 1949, experiments were carried out in collaboration with Merck & Co. Of 86 postpartem women tested, 45 showed increased milk production, and in several cases mothers who had previously been unable to nurse were able to do so after several days of drinking *ixbut* tea. The plant was introduced to Cuba in 1945 as a galactagogue and it was reported that *ixbut* could increase lactation in nursing mothers up to 100%. A study carried out in Mexico between 1949 and 1951 gave inconclusive and somewhat negative results, but the plant material used was about a week old and so may have lost its active ingredient(s). The report on this Mexican study suggested that the lactogenic properties may have been exaggerated, but the striking effects claimed in Guatemala by lay people cannot be totally denied on the basis of the material tested in Mexico.

Ixbut has been employed in Guatemala as a supplement to cattle feed, and a commercially available cattle galactagogue called Galac-Latex, in which the principal ingredient was *ixbut*, enjoyed a brief period on the market. Studies carried out in El Salvador and in south-eastern Mexico indicated substantial increase in milk productions in cows; experiments in Guatemala on goats showed no signs of toxicity and a modest increase in milk production.

The active principle in *Euphorbia lancifolia* has never been isolated and until it is found any decisions concerning its value in human or veterinary medicine cannot be made. Yet *ixbut* remains, on the basis of native use for centuries and on the evidence of preliminary experiments, a promising ethnopharmacological subject worthy of further phytochemical and pharmacological investigation.

CARYODENDRON

The euphorbiaceous genus *Caryodendron* has three species, all from tropical South America, one of which, *C. orinocense*, represents a most promising neotropical plant for domestication as new oil-rich crop. Growing wild in the Orinoquia of Venezuela and Colombia, and the westernmost Amazonia of Colombia, Ecuador and Peru, this tree attains a height in forests, where it must compete with thick vegetation, of 70 ft and possesses a dense crown that may measure some 40 ft in diameter. It also grows in open plains or grassland areas or llanos. It is known by a number of vernacular names, principally *inchi* (from the Ketchwa term for the groundnut, *Arachis hypogaea* L.) in Colombia, Ecuador and Peru (Martínez, 1970); and *palo de nuez* (nut tree) and *tacay* in Venezuela (Schnee, 1973). One especially oil-rich variety with particularly large fruits and seeds is called *ninacuru inchi* (fire-fly inchi, because fire-flies congregate in its crown).

The fruit is a typical trilocular capsule. The epicarp is greyish and chartaceous. The epicarp and mesocarp, when ripe and dry, make up a single layer that is easily removed. The endocarp is hard and woody. The seeds are ivory-coloured when fresh, but turn dark cream when rancidity sets in. The endosperm tastes like groundnuts, but when rancid it becomes both bitter and pungent. Most of the endosperm comprises oil-bearing cells. The seeds (without husk) constitute up to 35.8% of the weight of the fruit.

The seeds are viable for only a short period. One experimental planting in Colombia gave 97% germination, whereas another had only 5%. The trees grow approximately $3\frac{1}{2}$ ft a year, and they begin to bear fruit in 6 or 8 years. In the humid tropics, the seeds rapidly become rancid but, if collected immediately upon falling from the trees and taken to a cool, dry climate, a year will pass before they become rancid (Pérez-Arbeláez, 1956; Patiño, 1967).

Caryodendron orinocense is deemed superior to the African oil palm (*Elaeis guineensis* Jacq.) in its ecological adaptability, its agronomic characteristics and in the quantity and quality of its oil.

Caryodendron has been neglected and is not included in the major books on oleaginous plants. Historically, the earliest report appears to be that of an explorer of the Orinoco River (Gumilla, 1745) who wrote that the fruit known as *cumana* and which the Indians called *aboy* yielded an oil like that of olives in colour and taste.

CROTON

With 750 tropical and subtropical species in both hemispheres, *Croton* is ethnobotanically one of the most fascinating genera of the Euphorbiaceae. The extraordinary spectrum of uses to which its species are put in primitive societies offers a cogent argument for intensive phytochemical research (Altschul, 1973).

The tumour-inducing properties of the fixed oil in the seed of *Croton tiglium* were discovered in the 1940s. It has been suggested that the unusual frequency of oesophageal cancer in China may possibly be due to the common use of this species in folk medicine for a variety of ills. Another species, *C. flavens* L., has been indicated in the same kind of cancer in Curacao.

One chemical compound, phorbol myristate acetate (PMA), a phorbol diester and a constituent of croton oil, has been found to be the most active skin-irritant, inducing skin tumours in mice. However, croton oil itself is not carcinogenic, but when applied together with a subeffective carcinogen, cancer can be induced. Therefore, phorbol esters represent one of the most valuable agents in studying the carcinogenic process at the cellular level (Berenblum, 1941). Fourteen different phorbol diesters are known from *C. tiglium*. These compounds appear to be found only in the Euphorbiaceae; and they are well represented in *Croton*, particularly in *Euphorbia* (Kinghorn, 1979).

This use of phorbol diesters as a tool in pharmacological studies represents an example of one valuable application of a toxic substance from a species employed for a very different purpose in primitive societies, one of the hallmarks of ethnopharmacological research (Kinghorn, 1985; Reis & Lipp, 1982).

Several species have become important economic plants in advanced societies: *Croton cascarilla* Benn. and *C. eluteria* Benn. of the West Indies, the bark of which yields a tonic; the Asiatic *C. tiglium*, source of the strongest known purgative, croton oil, from the seed; *C. lacciferus* L. of Sri Lanka and India, from the lac of

which a varnish is made; and several Brazilian species that produce a red dragon's-blood resin (Le Cointe, 1934; Uphof, 1968).

But this list of commercially valuable uses of *Croton* cannot compare with the uses provided by a great number of species in primitive societies in both the Old and New Worlds:

Croton alamosanus N. E. Rose: the resin relieves toothache (Mexico) and the leaves are made into a kind of tea (south-east Asia). *C. cajucara* Benth.: the plant is considered to be febrifugal (Brasil). *C. caudatus* Geisel: a preparation of the roots is taken to relieve constipation (India, Malaysia). *C. ciliato-glandulosus* Ort.: valued as a febrifuge and purgative for man and as a galactogogue for goats (Mexico). *C. cortesianus* HBK.: the caustic sap is applied for treating skin diseases (Mexico). *C. crassifolius* Geisel: the root is used to heal wounds by mixing with wine (Hainan). *C. dioidus* Char.: the plant is believed to be anti-rheumatic and to calm hysteria (Mexico). *C. draco* Schlecht: the red sap is thought to heal ulcers and is applied as a remedy for a disease of horses' hoofs (Mexico). *C. echinocarpus* Muell. Arg.: this species is a strong drastic and anthelmintic and is also used in treating eye diseases (Brazil). *C. glabellus* L.: the Witoto Indians crush the leaves to poultice infected cuts and sores (Colombia). *C. gossypifolius* Vahl: the red sap is spread on cuts (Venezuela). *C. guatemalensis* Lotsy: the bark is valued as a remedy for chills and to prepare a bath for treating rheumatism (Guatemala). *C. humilis*: employed in treating skin and urinary diseases (Brazil). *C. macrostachyus* Hochst. ex Del.: the juice of the leaves is anthelmintic (Ethiopia). *C. niveus* Jacq.: a tea is tonic for intermittent fevers (tropical America). *C. oblongifolius* Roxb.: the powdered seeds are utilized as an insecticide and for stupefying fish (India). *C. oligandrum* Pierre ex Hutchinson: the scented bark is a remedy for colic (Gabon); *C. palanostigma* Klotzsch: the sap is applied to ulcers and boils to reduce pain (Brazil). *C. populifolius* Mill.: an alcoholic maceration of the bark is considered to be anti-rheumatic (Venezuela). *C. poilanei* Gagnep.: the bark is reputedly used to treat eye diseases (Cambodia). *C. reflexifolius* HBK.: this plant is said to be febrifugal and tonic and to relieve symptoms of colds. *C. repens* Schlecht.: this species is accepted as a treatment for dysentery and stomach-ache (Central America). *C. seligerus* Hook.: the stems and leaves are macerated for ichthyotoxic use (south-western U.S.A.). *C. texensis* (Klotzsch) Muell. Arg.: the Pawnee Indians bathe sick babies in a decoction; the Zuni drink a tea of the whole plant for upset stomach; the Hopi value it as an emetic and other tribes ascribe insecticidal properties to it (south-western U.S.A.). *C. tiglium*: the seeds are employed as a fish poison (tropical Asia). *C. xalapensis* HBK.: the mucilage is applied for tooth-ache, sore gums, cleaning teeth and the sap is considered good for dressing wounds (Mexico, Guatemala).

By far the greater number of species are employed in the form of resin or sap to hasten the healing of wounds and ulcers. Other frequent uses in primitive medicine are as purgatives, anthelmintics and fish poisons.

JATROPHA

The genus *Jatropha*, native to tropical and sub-tropical regions of both hemispheres as well as to North America and South Africa, comprises some 175 species of herbs, shrubs and small trees.

Numerous species find a wide spectrum of folk uses in the many regions where this genus occurs. *Jatropha curcas* L., an American species early introduced to the Old World, is the source of curcas oil, but is also valued as a strong purgative and for use in making candles and soap and in illumination and lubrication. In El Salvador, the latex is applied for eruptions on the lips (herpes?) and in front of the ears to treat eye inflammation (conjunctivitis?) (Burkill, 1935; Uphof, 1968). The related, *J. gossypifolia* L. has been employed in various parts of the world in treating leprosy, venereal diseases and ulcers, as a cataplasm for swollen breasts, an emetic, emmenagogue, stomachic and febrifuge. In Mexico and the south-western U.S.A. bark of *J. spathulata* (Ortega) Muell. Arg. is employed in tanning leather and is the source of a red dye; another species is used to clean and tighten teeth and to invigorate the hair; in Yucatan the roots of *J. gaumeri* Greenman have been employed in treating snakebite. The latex and sap of numerous members of the genus are applied to wounds and cuts to hasten healing. A Peruvian species has the wide reputation of being an aphrodisiac. The roots of a Brazilian species are valued in treating dropsy. The ancient Mayan Indians boiled the young leaves of a local species, *J. aconitifolia* Mill., and ate them as a vegetable. Many representatives of *Jatropha* are caustic and toxic, causing severe dermatitis (Altschul, 1973; von Reis & Lipp, 1982).

It is obviously of interest to note that extracts of *Jatropha gossypifolia* and related species have enjoyed folk uses in sundry areas in treating 'cancer'. Recent chemical and biological investigations have indicated that a novel macrocyclic diterpenoid, which has been called jatrophone, displays inhibitory activity *in vitro* against cells from human carcinoma and against four animal tumour systems and that it was significantly effective against lymphocytic leukaemia. Jatrophone is currently being considered as a candidate for Phase I human testing in cancer patients (Kupchan *et al.*, 1970).

MANIHOT

The human race is fed mainly by 12 or 13 plants: rice, wheat, maize, soybean, common bean, groundnut, sugar cane, sugar beet, white potato, sweet potato, cassava, banana (including the plaintain) and coconut. The cassava plant not only enjoys outstanding popularity, but it also ranks as one of the most complex cultigens known; an allotetraploid, it has never been found in the wild. It is also the only toxic plant that has become a major food plant (Burkill, 1935; Schery, 1947; Cook, 1982).

All 171 species of *Manihot* are American, and there is no doubt that *M. esculenta* is a New World plant. But there is little agreement concerning its background or its place of origin, and it is not even possible to say whether this plant originated from one or several species (Sauer, 1952; Jennings, 1976).

During its long history, this cultigen has developed nearly one hundred races. Customarily, these races are divided into two large assemblages, bitter cassava and sweet cassava, depending upon the amount and location of the toxic constituent, a cyanogenic glycoside related to hydrocyanic (prussic) acid; free hydrocyanic acid may occasionally also be present.

In the races called sweet cassava, the toxic constituents are localized in the bark of the underground parts of the plant, and this bark is naturally peeled off in preparing the tuberous root for food. The bitter cassavas have the poisonous

elements present, often in relatively high concentrations, throughout the plant, particularly in the starch component of the root. It is impossible to establish a demarcation between these two vague races, since the cyanogenic content may vary with individual cultivars. The plants of sweet cassava usually have light green leaves, whereas those of the bitter races tend to have dark green leaves, often somewhat reddish or purplish. The sweet cassavas tend to be more widespread than the bitter types and appear to be more closely associated with the older civilizations.

But the many races developed have other characteristics, differing in length of growth, mealiness, size and colour of the root, colour of the stems and even parts of the leaves, shape and hairiness of the leaves, and a host of other easily visible differences. Because of this great diversity, the botanical synonymy of *Manihot esculenta* has grown to be extensive; two of the most commonly used binomials are *M. aipi* Pohl for the strains with low concentrations of the glycoside, and *M. utilissima* Pohl for the strains with high concentrations of the poisonous constituents. The vernacular terminology for this most useful plant is extraordinarily extensive; for, as the plant spread to the Old World tropics, the New World names were rarely adopted. The most frequently employed common names in the non-aboriginal South and Central American languages are cassava, manioc and yuca in Spanish-speaking parts; *macaxera* and *mandioca* in Brazil (Rogers & Appan, 1973).

Cassava obviously has a very long history as a food crop in the Americas. There is evidence that cassava flour was traded in north-west South America in the second and third millennia BC. Ancestral types of our modern cassava may have been amongst the first food plants of tropical America (Mangelsdorf *et al.*, 1964). Archaeological evidence indicates that it was cultivated at least 2500 years ago in Mexico; starch grains from caves in Tamaulipas (Mexico) which are dated from 900–200 BC (MacNeish, 1958; Callen, 1967) appear to be from cassava. Specimens have been found in profusion in many archaeological sites in coastal Peru, suggesting that it was a major food crop in ancient times in that region. There are also representations of the tuber on clay pottery and textiles, and remains have often been found in Peruvian mummy bundles (Towle, 1961). Griddles and other indirect evidence has placed cassava at the mouth of the Amazon in AD 1300, but it must be borne in mind that in hot humid areas such as the Amazon the preservation of plant material in archaeological form is very rare (Schultes, 1984b).

One indication of the great age of cassava as a major food source is found in the appearance of this plant in the origin myths of many Indian tribes. For example, one myth of the natives of north-west Amazon, holds that the tribe originated in the Milky Way. One man and one woman came down in a dug-out canoe drawn by an anaconda. With them, they had three plants: coca (*Erythroxylon coca* Lam. var. *ipadu* Plowman, the source of cocaine) caapi (*Banisteriopsis caapi* (Spruce ex Griseb.) Morton, a sacred hallucinogen) and cassava.

All early European explorers and travellers to tropical America mentioned cassava, which, at least in the humid forested areas, was the mainstay of the carbohydrate intake in regions where cereals could not be cultivated. As early as the late 17th century, a long bibliography had grown up concerning the crop; and Sir Hans Sloane in his *Catalogus Plantarum in Insula Jamaica* (1696) and his

Natural History of Jamaica (1707–1725), extolled cassava as offering “the most general use of any provision all over the West Indies, especially the hotter parts, and used to victual ships”. But it was not the favourite provision for ships stores: there is associated with the toxic glycoside an enzyme that, upon wilting of the tuber, can liberate free hydrocyanic acid; this action rarely occurs in growing or fresh material, but a stale tuber can become poisonous, deterring many sea-voyagers from storing them in preference to white potatoes, sweet potatoes and yams. This peculiarity may have been one reason for the relatively slow spread of *Manihot esculenta* to the Old World tropics. If ships’ masters had stored cassava meal, the chemical reaction would not have been possible; but meal could not give rise in new locations to living plants.

How did natives circumvent the toxicity of this plant, the carbohydrate basis of many of their diets? Little needs to be done beyond peeling in the case of sweet cassavas. The Amazon natives grate the tuber, soak the mash overnight in a dug-out canoe; in the morning the wet mash is pressed into a tubular wicker squeezer called a *tipi-tipi*, which is squeezed under pressure. The resulting partly dried residue is crushed, broken up, spread on a flat stone or metal plate and subjected to a hot fire. The result is a coarse meal (the consistency of sawdust) known as *farinha* or *fariña*. It is eaten in this form or else as unleavened bread. The heat is apparently sufficient to break down the toxic materials that might have survived the overnight soaking. The toxic milky juice that is squeezed out of the overnight mash is concentrated by boiling to a thick syrup. This syrup is widely employed as a condiment in many sauces in the West Indies, and known as *tucupí* amongst the Amazonian Indians.

The starch content of the tubers averages about 26%, but in some strains it may reach 74%; they are 1.5–2.0% protein, but have practically no fat. Consequently, a diet made primarily of cassava tends to be unbalanced (unless well supplemented with other plant or animal elements), a situation that is widespread, especially in the humid tropics.

Cassava is used as a food in many ways, especially in the Old World tropics. Sweet cassavas may be boiled, mashed or fried—much like potatoes. In the Amazon and other humid, forested parts of the American tropics, the most frequent method of using bitter cassava, once it is detoxified, is as a coarse meal which may be eaten in dry form or mixed with water or fruit juices; or it can be baked into an unleavened bread on a flat ‘oven’, usually a large stone. Small pieces of the tuber may be salivated, collected in a dug-out canoe and left to ferment. In Africa and south-east Asia, there are many other ways, some of them rather sophisticated, of preparing the tuber as a food. The product known in western cultures as tapioca is one of these products. To make tapioca, the tubers are peeled, washed and grated; this preliminary procedure is followed by repeated washings and changes of the water with squeezing until no more starch can be removed; the starch contained in the collected waters is allowed to settle, and the water is drained off, leaving pure starch. All traces of cellulose are removed in the process. The starch is made into small flakes which are slightly heated. Tapioca is a Brazilian invention, but it seems that it is now more frequently prepared in home culinary in south-east Asia. Commercial tapioca factories follow exactly the same steps, but machinery is used.

If we go beyond the applications of *Manihot esculenta* as human food, we encounter many additional uses of this plant: as an animal food, as a source of



glucose and alcohol, added to mal in brewing, in preparing a seasoning for rice. An ethnobotanically most interesting food-use amongst the Brazilian Indians was reported by many European travellers: eating the *leaves* of some of the strains as food. It appears to have died out now in Brazil, or at least to be extremely rare, but it is a very common custom today in Malaysia, where the leaves are sold in many native markets.

Manihot esculenta did not spread rapidly in the Old World. It arrived at the end of the 16th Century on the west coast of Africa, and towards the end of the 18th Century on the east coast, an event due primarily to Portuguese shipmasters plying between Brazil and Africa. It was introduced into Sri Lanka in 1796 and into India about 1800. It had apparently reached Java somewhat earlier. There has been a suggestion that it had earlier reached the Philippine Islands from Mexico (Burkill, 1935). Until about 1850, the importance of cassava in south-east Asia was not significant, but from that time onwards its place as an accepted plant steadily grew, until now in Malaysia and Indonesia it has taken its place as a major crop. It was accepted in this region first as a famine reserve plant: it was drought resistant, did not suffer unduly from locust attack and, most important of all, tolerated poor husbandry.

We meet a much more confused picture concerning the origin and local spread of *Manihot esculenta* and its many strains in the New World tropics. All species of the genus can be intercrossed, but some may be productively isolated under natural conditions. All species apparently have 36 chromosomes, but there is evidence of polyploidy in *M. esculenta*.

Older writers on the origin of cultivated plants all indicated a South American origin. One modern student (Renvoize, 1972), on the basis of ecological and anthropological data, suggested that the savannahs of Venezuela should be considered. A Brazilian botanist (Ducke, 1946), thoroughly familiar with the Amazon, stated that nothing is known with certainty, while Renvoize (1972) suggests that Mexico and Central America must be considered the place of origin of the species. Still other investigators believe that several species have been involved in the origin of cassava: possibly *Manihot aesculifolia* Pohl, *M. pringlei* S. Wats. and *M. rubricaulis* I. M. Johnston, its closest relatives (Rogers, 1963, 1965). *Manihot ringlei* is unusual in wild species in having the toxic glycosides. Variability in the cultivated *M. esculenta* is very extensive and may have resulted from hybridization with several wild species. Many of these colonize disturbed areas near cultivated plots where the opportunities for gene exchanges would be available, leading to hybrids that could have produced new cultivated and wild forms.

A recent meticulous and critical evaluation of the numerous theories on the origin of *Manihot esculenta* by Mangelsdorf *et al.* (1964) has concluded that the sweet cassava strains were probably first domesticated in Central America, where there is no evidence of early cultivation of bitter cassava. On the other hand, bitter cassava appears to have first been cultivated in northern South America. There is much 'varietal' diversity in Brazil, where, with the centre of diversity of other *Manihot* species, there could have been favourable conditions for hybridization and the creation of new types of cassava. But this study suggests that there is little evidence that bitter cassava was first domesticated in that region (Renvoize, 1972).

Perhaps the most thorough modern study is by Rogers & Appan (1973) who

propose two geographical centres of origin and diversification: they suggest that the two types of cassava have come from one or from several species. The proponents of this opinion seemed later to renounce it, but other writers on the origin of cultivated plants have seemed to accept the idea that the sweet and bitter strains of cassava originated separately and developed independently. It has further been suggested that the great food value of cassava was early recognized in both putative centres of origin: Central America and the Amazon. It has even been postulated that before the food value of the starchy tuber was recognized the bitter cassava might possibly have been employed as a fish poison, utilizing the ichthyotoxic properties of the water with which the natives extracted the cyanogenic glycoside.

If cassava originated in two centres, there would probably have been no need to postulate long routes of early migration from South America to Mexico or vice versa. Intercommunication and trade amongst pre-colonial American Indians was well established: both types of cassava could therefore have diffused over wide areas.

After careful evaluation of the evidence offered to date, it is still not possible to state definitely where *Manihot esculenta* or the two general types originated and were domesticated. It is hoped that future interdisciplinary studies of such an important plant may shed more light on this enigma.

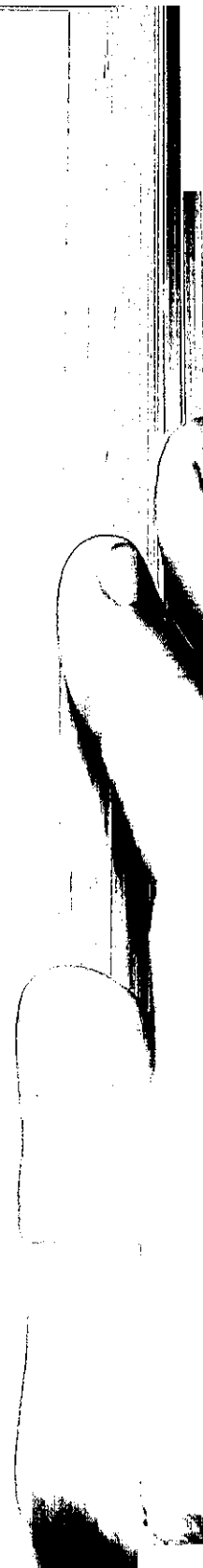
HEVEA

By whatever measure is used, *Hevea brasiliensis*, one of the most recently domesticated economic plants, stands out significantly from at least two points of view. Firstly, there can be little doubt that no other species has so drastically changed human life around the world in the short space of a century (Schultes, 1984a,b). The domestication of this Amazonian tree literally altered the course of civilization. Secondly, this single species now furnishes 98% of all the world's needs of natural rubber, an achievement not duplicated by any other plant source of an economic product (Polhamus, 1962; Compagnon, 1986).

Rubber has certainly been known to man since he began to roam the fields and forests, for this polymerized isoprene is found in the latex of at least 7000 species in sundry families. However, it seems that rubber had few if any significant uses in any of the Old World civilizations. And even in the New World, its utilization by aboriginal peoples was minor. In Peru, Yucatan and Mexico, the Indians esteemed rubber from the moraceous genus *Castilla* in magico-religious ceremonies. Early European chroniclers, especially Columbus, spoke of the use of rain capes, balls and syringes. Amazon Indians valued *Hevea brasiliensis* primarily as the source of edible, carbohydrate-rich seeds, not for its latex (Schultes, 1956).

As early as 1755, King John of Portugal tried to encourage a rubber shoe industry at Belém at the mouth of the Amazon River but, because the process of vulcanization had not been discovered, the product was so useless that the industry failed.

In 1832, MacIntosh found that rubber could be dissolved in naphtha, a discovery that led to the establishment of small industries in Europe and the U.S.A. Most of these industries failed, because the rubber was sticky in heat and brittle in cold.



Then in the late 1830s, Goodyear in the U.S.A. and Hancock in England independently discovered vulcanization, the chemical insertion of sulphur molecules into the isoprene chain. Rubber immediately became a truly useful product, no longer sticky but plastic and elastic; and demand for it grew vertiginously. The only practical source was the wild *Hevea* in Amazonian forests, supplies were frequently scarce and the quality was poor. Yet from the 31 tons produced in 1827, the world market used 2600 tons in 1857. This dramatic increase in demand was fulfilled by the virtual enslavement of the Indians.

The work of tapping wild trees, separated one from the other at usually appreciable distances in the inhospitable jungle, required the rubber-workers to live for 4 or 5 months a year in shacks far from their homes and agricultural plots, suffering from exposure and malnutrition, falling prey to tropical diseases and, in very many areas, enduring mistreatment and even torture or death for not bringing in an assigned quota of latex (Hardenburg, 1912; Collier, 1968). They lived in perpetual debt to unscrupulous 'rubber barons' who resided in cities and towns, often in sumptuous luxury. This nefarious forest industry survived until the Asiatic plantations came into production in the early years of the 20th Century. When the supply of rubber from plantations, cheap and of high quality, became available, the forest industry was killed, and a multitude of Indians and other tappers were freed from the inhuman conditions under which they had had to live and die for nearly a century.

The botanical source of *Hevea* rubber was elucidated when, in 1775, the French botanist Fusée Aublet (1775) described the genus and a species *H. guianensis* Aubl. from French Guiana. He detailed its exploitation and added significant ethnobotanical observations, such as the native use of the seeds as food. Forty-nine years later, Carl Willdenow (in Jussieu, 1824: 40, t.12, fig. 38B, 1-6) described a second species, *H. brasiliensis* (Willd. ex Andr. Juss.) Muell. Arg., from a collection made at the mouth of the Amazon. The epoch explorations of the British plant-collector Richard Spruce in the Brazilian Amazon between 1849 and 1855 provided a number of species new to science: *H. benthamiana* Muell. Arg., *H. lutea* (Benth.) Muell. Arg. (now considered to be a variety of *H. guianensis*), *H. pauciflora* (Spruce ex Benth.) Muell. Arg., *H. rigidifolia* (Spruce ex Benth.) Muell. Arg., and *H. spruceana* (Bth.) Muell. Arg. Spruce's Amazonian collecting coincided with the period during which the 'rubber boom' began. Later studies by several botanists have added still other species to *Hevea*: *H. camargoana* Murça Pires, *H. camporum* Ducke, *H. microphylla* Ule and *H. nitida* Muell. Arg. Of the 10 species now recognized, only three, *H. guianensis* and its varieties *lutea* (Spruce ex Benth.) Ducke & Schultes and *marginata*, *H. benthamiana* and *H. brasiliensis*, yield usable rubber, the latex of all of the other species being too rich in resins or too low in caoutchouc. *Hevea brasiliensis* is the source of the highest grades of rubber. Some of the local variants or strains of this species, the only species domesticated and the basis of all plantations, yield rubber superior to others.

Domestication of *Hevea brasiliensis* came almost fortuitously at just the right time. The success in domesticating the quinine tree in India in the 1850s convinced the British government that rubber should be considered as a candidate for a new crop for the humid tropical colonies. The dynamo behind the pro-*Hevea* campaign was a government geographer. Sir Clement Markham,

who in the 1870s enlisted the enthusiastic support of Sir Joseph Hooker, director of the Royal Botanic Gardens, Kew.

Several early attempts to introduce *Hevea* seed from the Amazon failed: in 1871 and twice in 1875. The long, slow trip from the Amazon to Kew proved too much for the viability of these delicate seeds rich in sugars that rapidly fermented, killing the embryos.

Henry Wickham, an Englishman who had travelled widely for a number of years in the Amazon and Orinoco, had sent rubber seeds to Kew without success. But he was well known to Sir Joseph Hooker, who encouraged him to continue his efforts. Wickham realized that the earlier failures were the result of slow transportation. In 1876, a steamer bringing industrial material to Manáos in the Brazilian Amazon found no return cargo. According to Wickham: "I determined to plunge for it. I had no cash on hand. The seed was even then beginning to ripen. I knew that Capt. Murry must be in a fix, so I wrote chartering the ship." He had Indians collect 70 000 seeds near Santarém at the mouth of the Rio Tapajóz in the eastern Amazon. The steamer picked up the seeds, raced downstream, called at the Brazilian customs official who, realizing the delicacy of plants for delivery to "Her Britannic Majesty's own Royal Botanic Gardens" immediately despatched the ship. Of the 70 000 seeds, 2800 germinated at Kew, a rate which would be considered astonishingly high even in the native home of the rubber tree.

There had been apathy or even opposition in certain governmental circles to the plan to domesticate *Hevea brasiliensis*, but the enthusiasm of Markham and Hooker and the devastation in Asia at that time of the *Coffea arabica* L. plantations by the fungal disease *Hemilea vastatrix* must receive much credit for the attempt to go ahead with the project (Wycherly, 1968).

Young trees were eventually sent from Kew to Ceylon, whence they later went to Singapore and other tropical parts of the Empire. The domestication of the tree that has so thoroughly revolutionized life styles around the world would not have been possible without a chain of botanical gardens throughout the British possessions. So far as is known, all cultivated trees of *Hevea brasiliensis* in Asia and Africa are descendants from the Wickham introduction (Burkill, 1935; Barlow, 1978).

Tales concerning the 'British seed steal' are rife. The story, endlessly repeated in the population literature and accepted as absolute truth in Brazil, is wholly without foundation, even though Wickham himself, who lived to a great age, mischievously enjoyed the circulation of the story in England in his later years. Sir Henry Wickham, knighted for his efforts, broke no Brazilian law, since at that time there was no law prohibiting the export of seeds, and several prior exportations had been effected. Furthermore, the ship's cargo was duly passed by Brazilian customs, and there had been no attempt in the Amazon to conceal the collection of the rubber seeds.

The whole history of economic botany has been one of exchange of useful plants, and most of the world's principal plantation crops are produced in regions far from their original homes. In fact, Brazil's major agricultural industries are based on plants introduced from other areas: soybean from China, rice and jute from India, sugar from south-eastern Asia, the African oil palm, cacao from Colombia and Ecuador and, above all, coffee from Ethiopia.

Coming from a single locality in an area occupied by *Hevea brasiliensis* half the

size of the U.S.A., the Wickham seeds represented but one of many variants or ecotypes; and of this single ecotype, the seed came from a limited number of trees. Thus, the germ plasm on which plantation scientists had to work was extremely limited. Yet the improvements in yield that have been brought about in less than a century are almost unbelievable: the first plantations (from seed material) in Sri Lanka yielded 450 pounds of dry rubber per acre per year. Since clonal grafting was instituted, yields greater than 3000 pounds per acre are now not uncommon.

The story of the rubber tree's domestication includes the names of many famous personages: Aublet, Spruce, Macintosh, Goodyear, Hancock, J. D. Hooker, Markham and Wickham. But once the tree was planted in Asia, the names of two other scientists are outstanding in the creation of the great plantations: Ridley and Cramer. Fortunately, Wickham lived long enough to see the results of his endeavours establish a new and vast industry, and he also saw how it re-shaped the world.

Ridley (1928, 1955), director of the Botanic Gardens in Singapore, found only eight of the original nine trees and 1000 young plants from the original introduction still in existence when he assumed directorship of the Garden in 1888. He immediately raised 8000 additional plants from seed imported from Sri Lanka. He was an indefatigable experimenter, and his earliest innovations had to do with tapping methods. Trees in the Amazon were slashed in a great variety of makeshift techniques, usually to the detriment of the trees. It was Ridley who instituted the cutting off of thin layers of the bark every 2 or 3 days to make a slanting channel for the latex to travel down to a cup, avoiding injury to the cambium, since in *Hevea* the latex-bearing vessels are external to the cambium. With numerous modifications over the years, this is still the practice in all plantations. Amongst other discoveries, he demonstrated the advantages of tapping in the early morning, instead of in the afternoon. It was Ridley's enthusiasm and constancy that, aided by the fall in world prices of tea, poor results with cacao, the coffee disease and especially the advent of the motor car, convinced planters to go into rubber (Fairchild, 1928).

The Dutch, in the meanwhile, were busy with innovations in the Dutch East Indies. Cramer, whose total stock was likewise descended from the Wickham seeds, made several unsuccessful attempts to introduce material of other species from Brazil, looking ahead to the need for genetic experiments. With great opposition from planters, he managed to substitute bud-grafting of clonal material instead of planting seeds; the best of the first clones almost doubled the average yield of trees planted from seed, and the best of the first generation of bred clones almost doubled the yield again. He carried out analysis of variation in yield of latex, predicting that vegetative selection, cloning and genetic selection or breeding, would inevitably lead to increases in yield, all aspects basic to today's plantation management and scientific efforts toward improvement (Wilson, 1943; Dijkman, 1951).

Rubber research institutes in several countries are actively experimenting along avenues of research, especially in view of the fast-developing new applications of natural rubber which portend greatly increased demands in the not-too-distant future. Amongst some of the goals that are sought are a search for dwarfism, induced mutations, artificial polyploids and the use of tissue culture. Naturally, an interest in still higher yields and disease resistance remain major goals in the improvement programme.

There was a brief and sporadic resurgence of the silvatic Amazon rubber industry in the 1940s, when the Japanese overran most of south-east Asia, cutting off the greater part of the world's supply of natural rubber. The governments of the U.S.A. and of the South American countries where *Hevea* grows stimulated the extraction of rubber for the war effort. Natural rubber was necessary for many war-related operations such as the manufacture of tyres for heavy aircraft, for which the artificial elastomers available were inferior.

Several generations of Amazonian natives had had no experience in rubber tapping. Foresters and botanists were sent in to teach modern methods of cutting. Navigation and, in more remote areas, small airstrips were provided to supply the urgent need for natural rubber. Food, clothing, medicines and other necessities were made available for the tappers who were not mercilessly exploited, as in earlier years. In comparison with the pre-war production of rubber from south-east Asia, the amount procured in the few years of duration of the fighting was very small, but it represented a very important contribution to the war effort, even though the quality of the rubber was far inferior to that produced by the Old World plantations. Three species were exploited: *Hevea brasiliensis* (which gave the best rubber); *H. benthamiana* (the rubber was usually as good as that from *H. brasiliensis*) and *H. guianensis* (yielding an inferior, yet still usable rubber), the most widespread species (Schultes, 1970).

When peace was restored, south-east Asia again rapidly fulfilled the world's needs, and in most parts of South America, the production of rubber from wild trees gradually diminished or disappeared.

One of the fortunate by-products of this short-lived revival of the Amazon rubber tapping was that the technical people who were sent in to stimulate the industry were able to study *Hevea* in great detail, to collect germ plasm of many of the non-commercial species for future genetic work and to find in the forest wild, élite trees of *H. brasiliensis* that potentially seemed to be high yielders of latex and/or to exhibit possible disease resistance (Schultes, 1977). A search for alternative sources of natural rubber in the Euphorbiaceae and in other families was also stimulated at this time.

What will the future of natural rubber be now that germ plasm of the whole spectrum of the genus *Hevea*, material from the 10 species and all of the many ecotypes from the wild, is available for scientifically directed programmes of improvement? The domestication of *Hevea brasiliensis* marks a revolutionary milestone in human history. What applied science and human ingenuity have accomplished on such a limited germ plasm base is astounding, although perhaps not widely recognized by the world population that has been so drastically affected by the event.

One of the great Colombian novels describes the misery and suffering of the poor Amazonian rubber tappers of the early part of this century. It should be read by every modern scientist and planter concerned with today's plantation industry (Rivera, 1946). The title, *La Voragine (The Vortex)*, refers to the mysterious swallowing up of man in the often nefarious vastness of the Amazon jungle. One magnificent passage describes the magnetic hold of the rubber tree in those days: "I have been a rubber tapper. I am a rubber tapper. I have lived in the muddy swamps in the solitude of the forests with my crew of malaria-ridden men cutting the bark of the trees that have white blood like that of the gods".



Considering what changes *Hevea brasiliensis* latex has wrought for the good of mankind, perhaps we can call it the "blood of the gods".

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