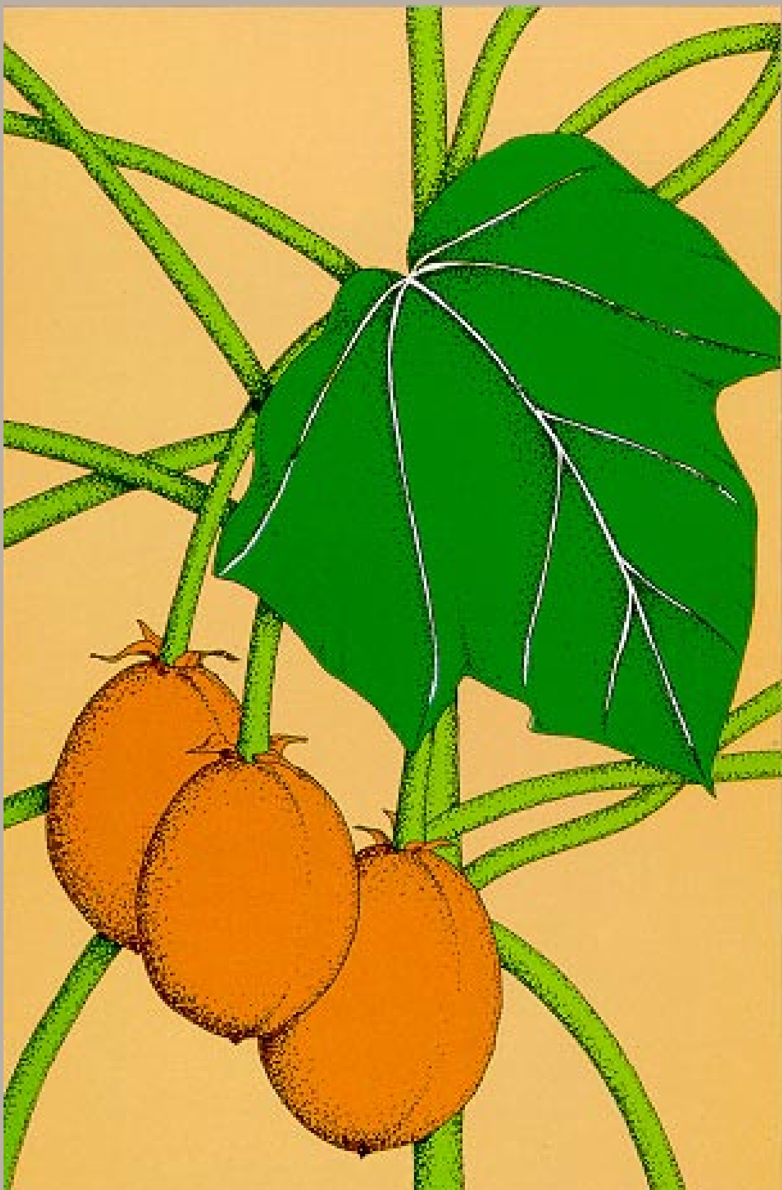
Promoting the conservation and use of underutilized and neglected crops. 1.

Physic nut

Jatropha curcas L.



Joachim Heller

IPK
Institut für Pflanzengenetik
und Kulturpflanzenforschung
GATERSLEBEN

International Plant Genetic Resources Institute
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IPGRI
Via delle Sette Chiese 142
00145 Rome
Italy

IPK
Corrensstraße 3
06466 Gatersleben
Germany

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Foreword

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

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

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Series editors:

Dr Joachim Heller, Institute of Plant Genetics and Crop Plant Research (IPK)

Dr Jan Engels, International Plant Genetic Resources Institute (IPGRI)

Prof. Dr Karl Hammer, Institute of Plant Genetics and Crop Plant Research (IPK)

1. Introduction

The use of trees and shrubs in arid and semi-arid regions is of vital importance for the human population in developing countries (Ben Salem and Palmberg 1985). The exhaustive exploitation of these resources in conjunction with droughts, especially in the Sahel, has caused an alarming reduction in tree cover. This has resulted in increased desertification, soil erosion caused by wind and water, and droughts and floods as well as reduced water supply and decreasing soil fertility. Trees also play an important role in the CO_2 cycle of the earth as they assimilate carbon dioxide.

Traditionally, shrubs (and trees) serve many purposes. Le Houérou (1989) distinguished 13 groups according to how they are used:

1. food and drink for humans
2. browse for livestock and wildlife
3. beekeeping and honey production
4. source of energy – firewood and charcoal
5. building and fencing material
6. fibre for cloth, rope and handicrafts
7. tools for agriculture and cottage industry
8. handicraft, art and religious objects
9. dye and tanning
10. drugs, medicinal and veterinary uses
11. shade and shelter for plants, animals and humans (‘palaver’ trees)
12. protection against erosion, maintenance of soil fertility and productivity
13. water storage.

Attempts are now being made to promote the cultivation of crops previously grown only regionally or to a low extent. Comprehensive surveys exist, especially of crops which adapt well to arid and semi-arid conditions (Davis *et al*. 1983; Weiss 1989). In order to identify interesting plant species, not only for use as raw material in industry but also as an energy source, a number of comprehensive surveys have been carried out in the United States of America (Nielsen *et al*. 1977; Buchanan *et al*. 1978; Wang and Hufman 1981; McLaughlin and Hoffmann 1982; Carr *et al*. 1985).

Plant species which can be processed to provide a diesel fuel substitute have captured the interest of scientists more in temperate than in tropical zones. In this plant category, the following properties of the tropical physic nut (*Jatropha curcas* L., Euphorbiaceae) have won over the interest of various development agencies: it adapts well to semi-arid marginal sites, its oil can be processed for use as a diesel fuel substitute and it can be used for erosion control. Although the physic nut is of Mexican and Central American origin, it is cultivated in many other Latin American, Asian and African countries as a hedge and it was an important export product from the Cape Verde Islands during the first half of this century. The aim of this monograph is to make information more easily available to those interested in the potential uses and the genetic resources of the physic nut.

2. Names of the species and taxonomy

The Euphorbiaceae family comprises approximately 8000 species, belonging to 321 genera. According to Leon (1987), Mabberley (1987) and Rehm and Espig (1991), crops of economic importance in this large family are:

- roots — cassava (*Manihot esculenta*)
- rubber — Hevea (*Hevea brasiliensis*)
- fruits — emblic, Otaheite gooseberry (*Phyllanthus* spp.), tjoopa, rambai, mafai (*Baccaurea* spp.), Chinese laurel (*Antidesma bunius), Ricinodendron* spp.
- nuts — tacay (*Caryodendron orinocense*)
- vegetables — katuk (*Sauropus androgynus*), chaya (*Cnidoscolus chayamansa*)
- oil — castor (*Ricinus communis*), tung trees (*Aleurites* spp.), Chinese tallow tree (*Sapium sebiferum*), physic nut (*Jatropha curcas*)
- hydrocarbon — *Euphorbia* spp.
- medicinal — *Croton* spp., *Jatropha* spp.

The genus *Jatropha* belongs to tribe Joannesieae of Crotonoideae in the Euphorbiaceae family and contains approximately 170 known species. Dehgan and Webster (1979) revised the subdivision made by Pax (1910) and now distinguish two subgenera (*Curcas* and *Jatropha*) of the genus *Jatropha*, with 10 sections and 10 subsections to accommodate the Old and New World species. They postulated the physic nut (*Jatropha curcas* L. [sect. *Curcas* (Adans.) Griseb., subg. *Curcas* (Adans.) Pax]) to be the most primitive form of the *Jatropha* genus. Species in other sections evolved from the physic nut or another ancestral form, with changes in growth habit and flower structures. Hierarchical cluster analysis of 77 New World *Jatropha* species showed for the most part concordance with Dehgan and Webster's (1979) infrageneric classification (Dehgan and Schutzman 1994). Figure 1 shows the phenogramme of Neotropical *Jatropha* species. Further cladistic analysis supported Dehgan and Webster's (1979) evolutionary model of the genus *Jatropha*.

The following are other species that belong to the section *Curcas*: *J. pseudo-curcas* Muell. Arg., *J. afrocurcas* Pax, *J. macrophylla* Pax & Hoffm., *J. villosa* Wight (syn.: *J. wightiana* Muell. Arg.), *J. hintonii* Wilbur, *J. bartlettii* Wilbur, *J. mcvaughii* Dehgan & Webster and *J. yucatanensis* Briq. McVaugh (1945) considered *J. yucatanensis* to be a synonym of *J. curcas*. One species, *J. villosa*, is of Indian origin. Two, *J. afrocurcas* and *J. macrophylla*, are of East African origin, whereas all the other species in this section are native to the Americas.

Although most of the *Jatropha* species are native to the New World, approximately 66 species are native to the Old World. Dehgan and Webster (1979) offered a key to the infrageneric taxa but this should not be considered as final since information is still lacking on many species. No complete revision of the Old World *Jatropha* exists. Hemming and Radcliffe-Smith (1987) revised 25 Somalian species, all of the subgenus *Jatropha*, and placed them in six sections and five subsections. *Jatropha multifida* L. and *J. podagrica* Hook. of section *Peltatae*, *J. integerrima* of section *Polymorphae*, and *J. gossypiifolia* of section *Jatropha* are well known and cultivated throughout the tropics as ornamental plants.

Linnaeus (1753) was the first to name the physic nut *Jatropha curcas* L. according to

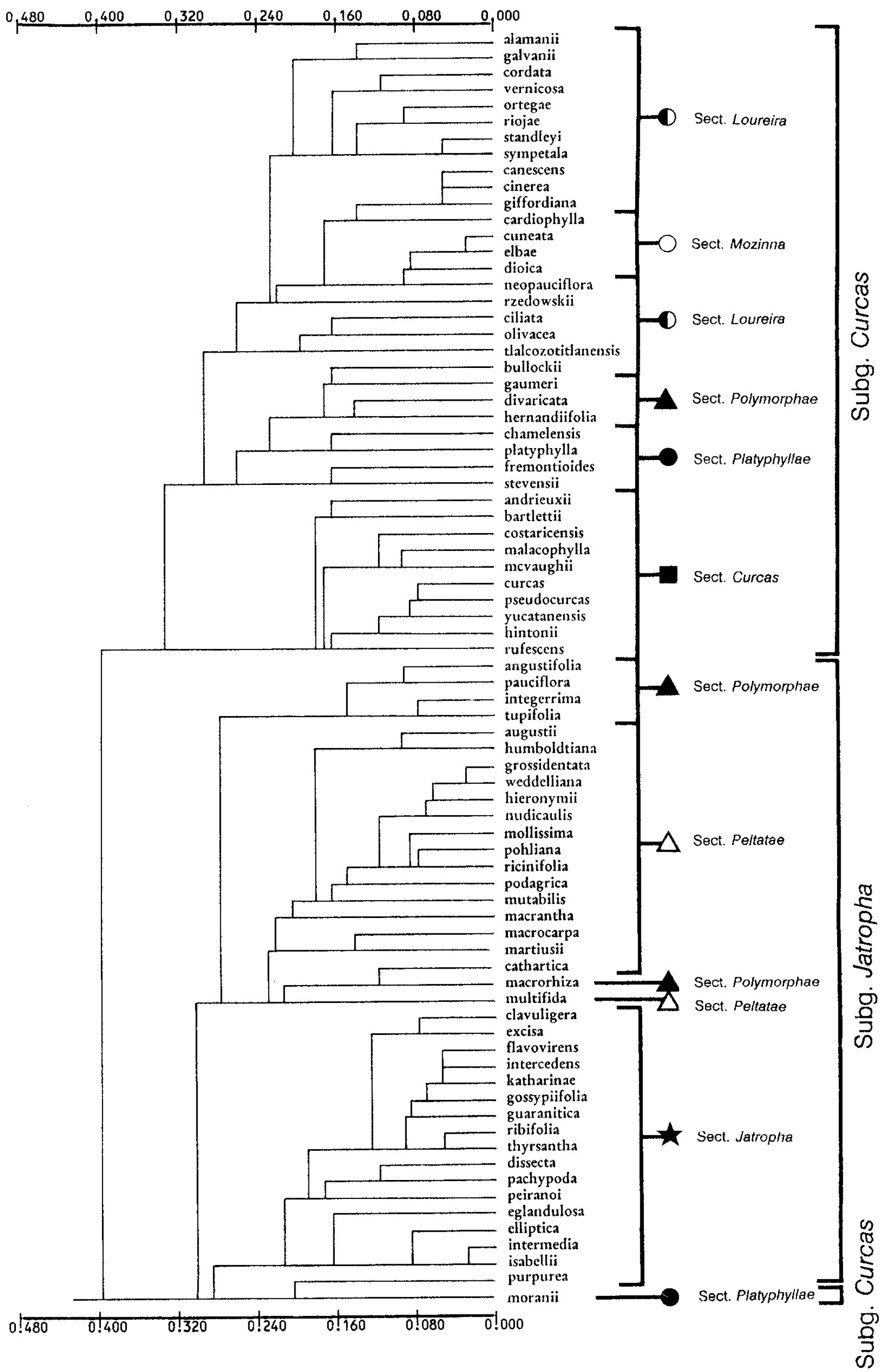

Fig. 1. Phenogramme of 77 Neotropical *Jatropha* species from 32 characters, using F.J. Rohlf's NTSYS-pc programme. Infrageneric designations are from Dehgan and Webster (1979) (reprinted with permission from Dehgan and Schutzmann 1994).

the binomial nomenclature of "Species Plantarum" and this is still valid today. According to Dehgan and Webster (1979) and Schultze-Motel (1986), synonymous names of the physic nut are:

Curcas purgans Medik., Ind. Pl. Hort. Manhem. 1: 90. 1771; Baill. Étud. Gen. Euphorb. 314, 1858.

Ricinus americanus Miller, Gard. Dict. ed. 8. 1768.

Castiglionia lobata Ruiz & Pavon, Fl. Peruv. Prodr. 139, t. 37. 1794.

Jatropha edulis Cerv. Gaz. Lit. Mex. 3: supl. 4. 1794.

J. acerifolia Salisb., Prodr. Chapel Allerton 389. 1796.

Ricinus jarak Thunb., Fl. Javan. 23. 1825.

Curcas adansoni Endl., ex Heynh. Nomencl. 176. 1840.

Curcas indica A. Rich. in Sagra, Hist. Fis. Pol. Nat. Cuba 3: 208. 1853.

?*Jatropha yucatanensis* Briq. Ann. Cons. Jard. Genève 4: 230. 1900; Standley, Contr. U.S. Nat. Herb. 23: 640. 1923; McVaugh, Bull. Torrey Bot. Club 72: 35. 1945.

Curcas curcas (L.) Britton & Millsp., Bahama Fl. 225. 1920.

The genus name *Jatropha* derives from the Greek *iatrós* (doctor) and *trophé* (food) which implies medicinal uses. According to Correll and Correll (1982), *curcas* is the common name for physic nut in Malabar, India.

Numerous vernacular names exist for the physic nut: physic nut, purging nut (English); pourghère, pignon d'Inde (French); purgeernoot (Dutch); Purgiernuß, Brechnuß (German); purgueira (Portuguese); fagiola d'India (Italian); dand barrî, habel meluk (Arab); kanananaeranda, parvataranda (Sanskrit); bagbherenda, jangliarandi, safed arand (Hindi); kadam (Nepal); yu-lu-tzu (Chinese); sabudam (Thailand); túbang-bákod (the Philippines); jarak budeg (Indonesia); bagani (Côte d'Ivoire); kpoti (Togo); tabanani (Senegal); mupuluka (Angola); butuje (Nigeria); makaen (Tanzania); piñoncillo (Mexico); coquillo, tempate (Costa Rica); tártago (Puerto Rico); mundubi-assu (Brazil); piñol (Peru) and pinón (Guatemala) (Münch 1986; Schultze-Motel 1986).

3 Botanical description

The physic nut is a drought-resistant species which is widely cultivated in the tropics as a living fence. Many parts of the plants are used in traditional medicine. The seeds, however, are toxic to humans and many animals. Considerable amounts of physic nut seeds were produced on Cape Verde during the first half of this century, and this constituted an important contribution to the country's economy. Seeds were exported to Lisbon and Marseille for oil extraction and soap production. Today's global production is, however, negligible.

The physic nut, by definition, is a small tree or large shrub which can reach a height of up to 5 m. The plant shows articulated growth, with a morphological discontinuity at each increment. Dormancy is induced by fluctuations in rainfall and temperature / light. The branches contain latex. Normally, five roots are formed from seedlings, one central and four peripheral. A tap root is not usually formed by vegetatively propagated plants (Kobilke 1989). The physic nut has 5 to 7 shallow lobed leaves with a length and width of 6 to 15 cm, which are arranged alternately. Inflorescences are formed terminally on branches and are complex, possessing main and co-florescences with paracladia. Botanically, it can be described as a cyme. The plant is monoecious and flowers are unisexual; occasionally hermaphrodite flowers occur (Dehgan and Webster 1979). Ten stamens are arranged in two distinct whorls of five each in a single column in the androecium, and in close proximity to each other. In the gynoecium, the three slender styles are connate to about two-thirds of their length, dilating to massive bifurcate stigmata (Dehgan and Webster 1979).

Pollination of the physic nut is by insects. Dehgan and Webster (1979) believe that it is pollinated by moths because of "its sweet, heavy perfume at night, greenish white flowers, versatile anthers and protruding sexual organs, copious nectar, and absence of visible nectar guides". When insects are excluded from the greenhouse, seed set does not occur without hand-pollination. The rare hermaphrodite flowers can be self-pollinating. During field trials, Heller (1992) observed a number of different insects that visited flowers and could pollinate. In Senegal, he observed that staminate flowers open later than pistillate flowers in the same inflorescence. To a certain extent, this mechanism promotes cross-pollination. Münch (1986) did not observe this chronological order in Cape Verde. It seems that the mechanism is influenced by the environment. After pollination, a trilocular ellipsoidal fruit is formed. The exocarp remains fleshy until the seeds are mature. The seeds are black, 2 cm long and 1 cm thick. The caruncle is rather small. Wiehr (1930) and Droit (1932) described the microscopical anatomy of the seeds in detail, while Singh (1970) described that of fruits. Gupta (1985) investigated the anatomy of other plant parts. The physic nut is a diploid species with $2n = 22$ chromosomes. Relevant parts of the plant are shown in Figures 2 and 3.

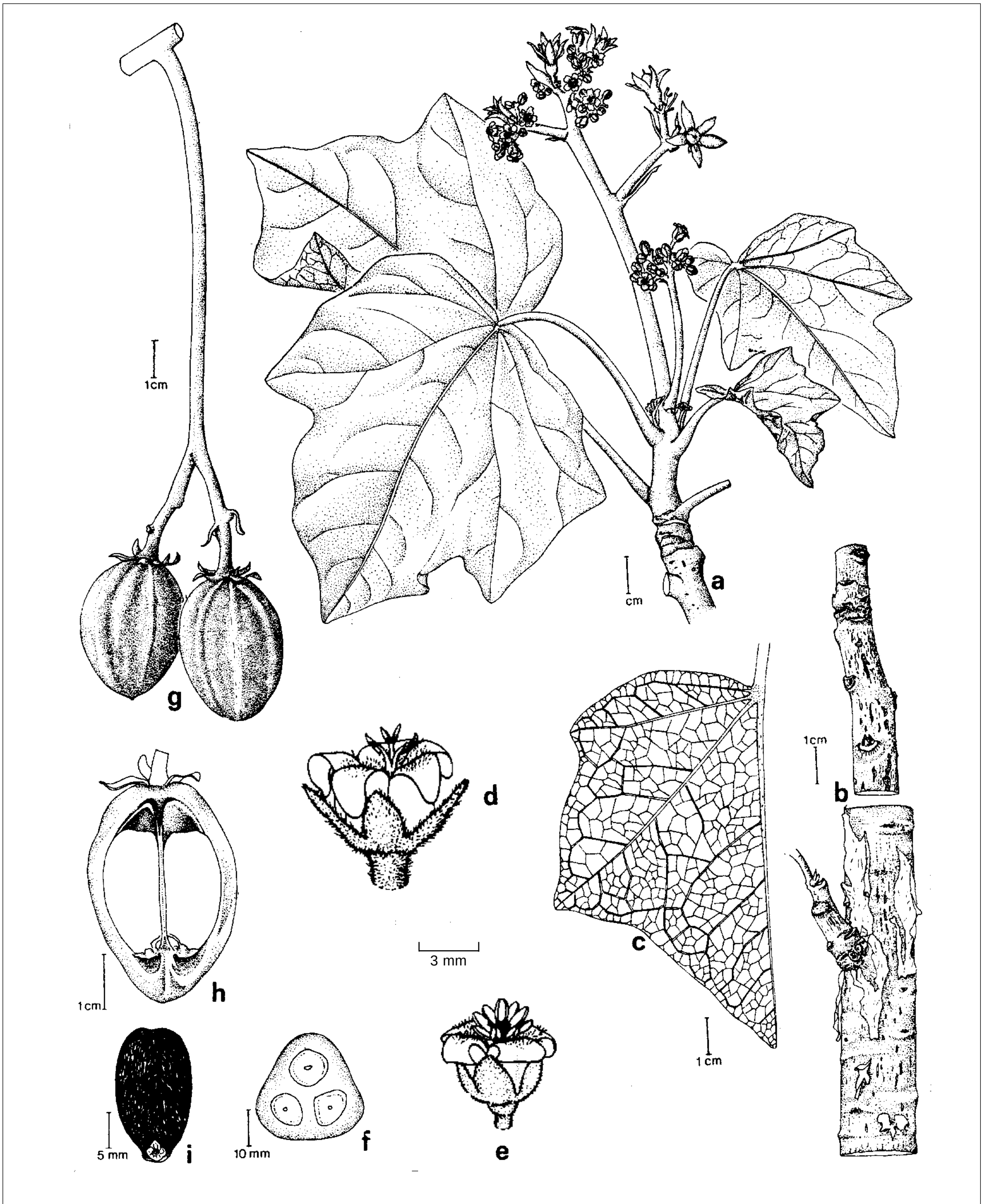

Fig. 2. Important parts of the physic nut: a - flowering branch, b - bark, c - leaf veinature, d - pistillate flower, e - staminate flower, f - cross-cut of immature fruit, g - fruits, h - longitudinal cut of fruits; a - c and f - h from Aponte 1978; d and e from Dehgan 1984 (reprinted with permission).

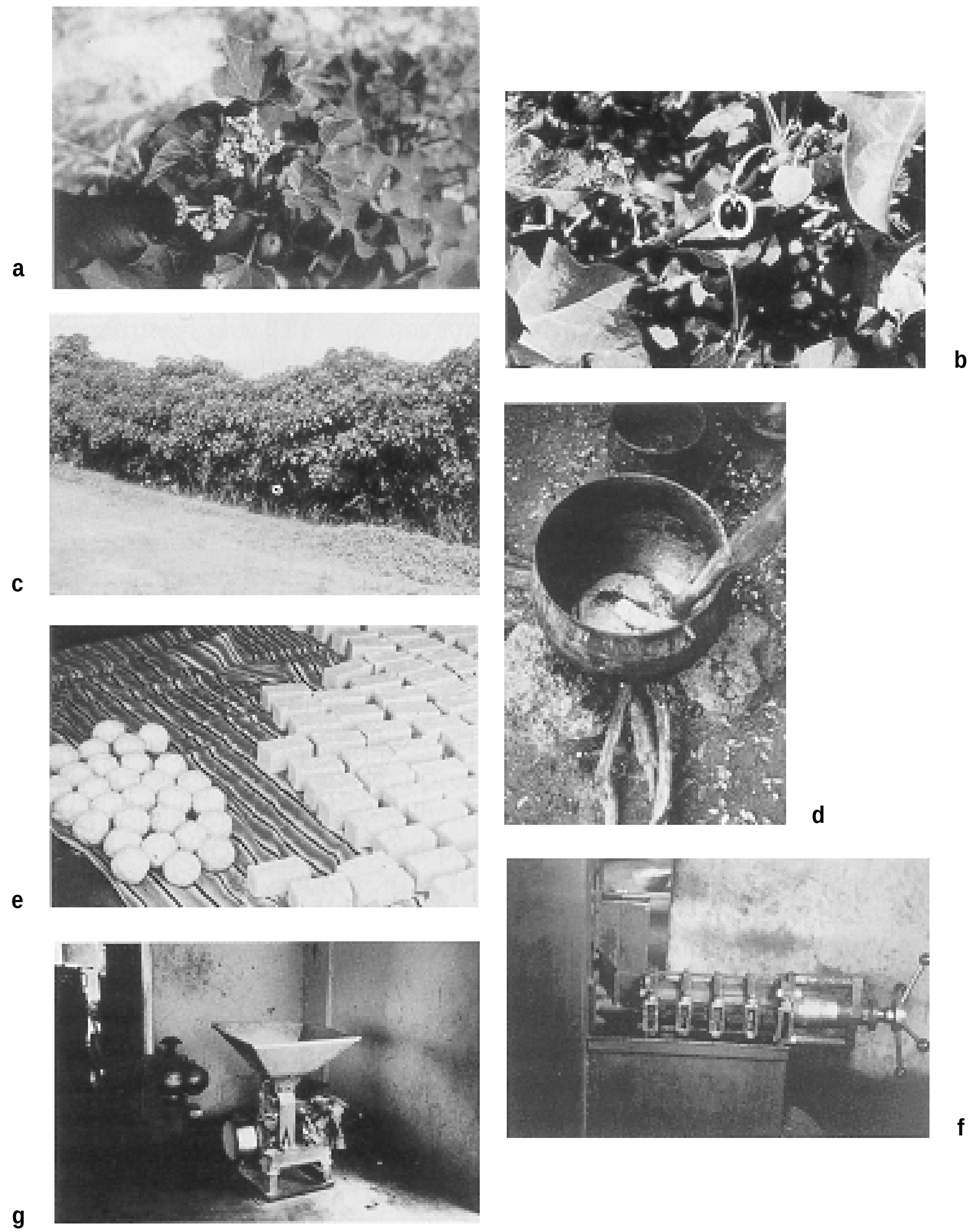

Fig. 3. (a) Inflorescence; (b) branch with fruits; (c) hedge in Mali; (d) cooking of oil with soda solution; (e) soap production in Ouélessebougou, Mali; (f) Sundhara oil press; (g) grain mill with Hatz engine (sources b-g: Henning)

4 Origin and centre of diversity

A number of scientists have attempted to define the origin of physic nut, but the source remains controversial. Martin and Mayeux (1984) identified the Ceara state in Brazil as a centre of origin but without giving any arguments. Dehgan and Webster (1979) cite Wilbur (1954) as follows: "it was without doubt part of the flora of Mexico and probably of northern Central America before the arrival of Cortez, and it most likely originated there ... the subsection, hence, appears to be one which originally was nearly or completely restricted to Mexico." According to other sources, the physic nut seems to be native to Central America as well as to Mexico where it occurs naturally in the forests of coastal regions (Aponte 1978). However, Dehgan (pers. comm.) did not find true wild physic nut plants when collecting *Jatrophas* in Mexico. Those he found had always "escaped" from cultivated hedges. During a visit to Professor Dehgan's Horticultural Systematics Laboratory, the author checked hundreds of herbarium specimens from the following herbaria for the distribution of the physic nut in Mexico, Central America and the Caribbean: DAV, F, FLAS, GH, MICH, MO, NY, RSA, TEX, UC and US. The material collected originated mostly from Mexico and all Central American countries: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama, with the majority coming from Mexico. Many records also exist for the Caribbean: Bahamas, Cuba, Dominica, Dominican Republic, Haiti, Puerto Rico, Saint Lucia, Santo Domingo, St. Croix, Trinidad and other West Indian countries. In the following South American countries, the physic nut occurs to a lesser extent, according to their representation in the herbaria listed above: Argentina, Bolivia, Brazil, Colombia, Ecuador and the Galapagos Islands, Paraguay, Peru and Venezuela. It has been introduced into Florida.

Herbarium specimens of the Americas were usually collected from hedges along roads and paths, live fence posts or disturbed sites ("disturbed forest"). Standley and Steyermark (1949) confirm this and state for Guatemala that "the shrub may not be native in Guatemala, since it is found principally in hedges, but if not, doubtless it has been in cultivation for a long time". However, the information provided by many collectors seems to support the argument that the species was collected from "natural" vegetation in the Americas, as the following vegetation forms were given on the herbarium labels mentioned above: bosque humido, forest, bosque seco tropical, cactus and thorn scrub, shrubby slope, thicket near river bank, tropical dry forest, bosque seco y espinoso, dry steep hillside, woodland, hillside with dense shrubs and woods, or coastal thickets. It is highly probable that the centre of origin of the physic nut is in Mexico (and Central America) since it is not found in these forms of vegetation in Africa and Asia but only in cultivated form. The "true" centre of origin, however, still has to be found. To elucidate this, the original collecting sites in Mexico and Central America would have to be revisited and the existing diversity assessed, preferably by molecular techniques.

From the Caribbean, this species was probably distributed by Portuguese seafarers via the Cape Verde Islands and former Portuguese Guinea (now Guinea Bissau) to other countries in Africa and Asia. No facts are available in the literature before 1800 as to when the physic nut was introduced into Cape Verde (Serra 1950). Freitas (1906), citing Pusich, says that the physic nut was already known several years prior to 1810, as he mentioned it in his book “Memoria ou descripção physico-politica das ilhas de Cabo Verde”. Chelmicki and Varnhagen (1841) mention that exports of physic nuts had already begun in 1836. Many decrees were published in the “Boletim Oficial de Cabo Verde” from 1843 onwards to promote the planting of physic nut (Freitas 1906; Serra 1950).

Burkill (1966) assumes that the Portuguese brought the physic nut to Asia: “Perhaps it did not reach Malacca until a date when the Dutch were in possession, for the

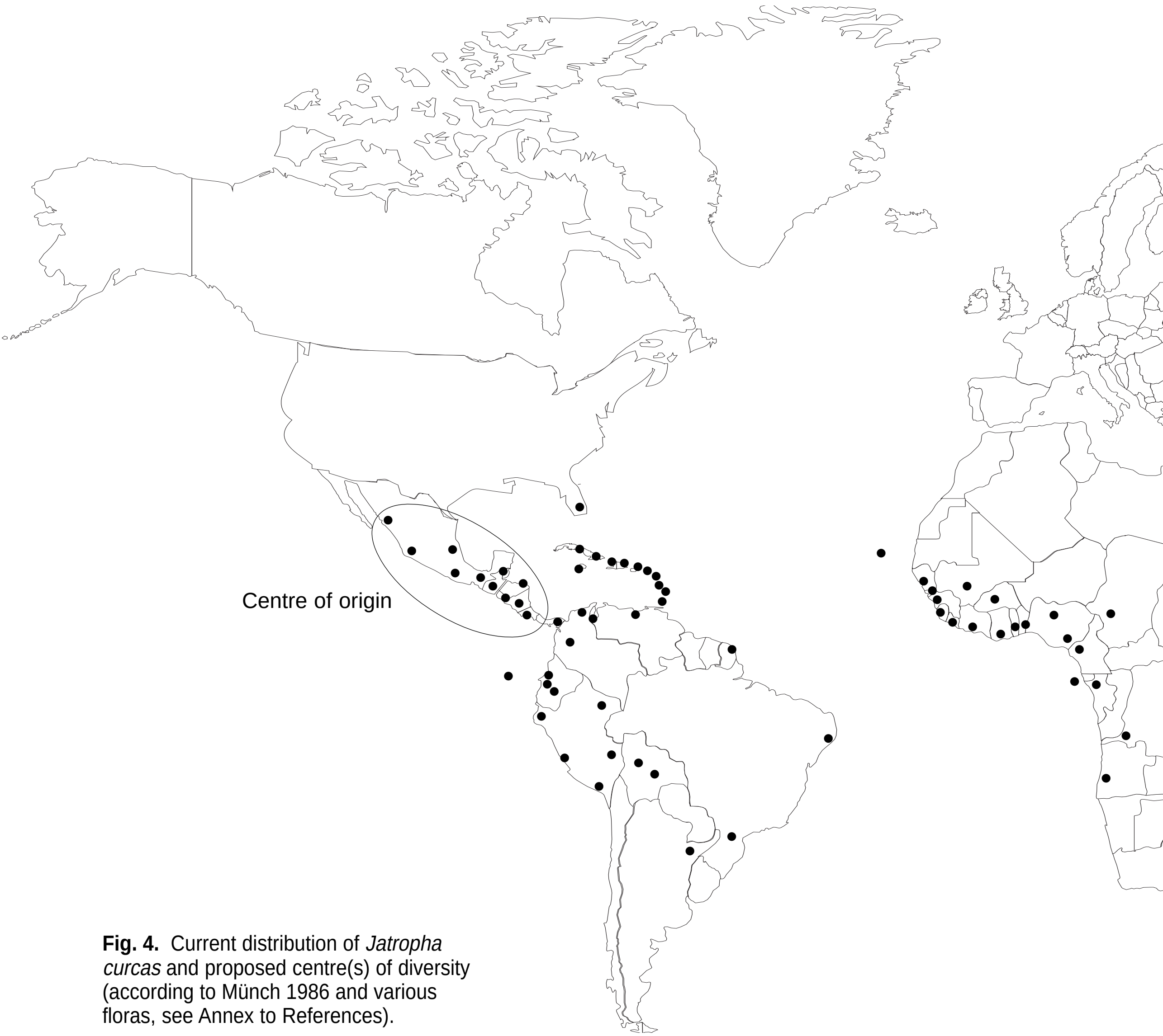

Fig. 4. Current distribution of *Jatropha curcas* and proposed centre(s) of diversity (according to Münch 1986 and various floras, see Annex to References).

Malays call it by a name meaning Dutch castor oil. Nevertheless, the Portuguese transported it to the Old World. The Javanese, among other names, call it Chinese castor oil. It is regarded in most countries, in Africa as well as in the East, as the 'castor oil plant', which shows that it was brought in and planted for the oil; further, it is widely known as the 'hedge castor oil plant', showing where it was planted, namely in hedges. Merrill (Bur. Gov. Lab. Philipp. 6, 1903 p. 27) shows that it was in the Philippines before 1750." Today it is cultivated in many countries. Figure 4 shows its distribution according to various sources (see Bibliography).

5 Properties

Numerous investigations have been carried out to determine the content of physic nut seeds. Results of the older analyses are not reported here, because the methods are not comparable with modern methods. Prof. J.E. Mendes Ferrao, University of Lisbon, was especially instrumental in determining physic nut content. Table 1 shows the results of determinations of moisture, ash, crude protein, crude fat, crude fibre (based on the seed kernel) and of the crude fat content (based on the seed) of different samples from Cape Verde (Santiago and Fogo) and Sao Tome and Principe. Part of the analyses was performed only on the seed kernel, not on the whole seeds and cannot, therefore, be compared with other analyses.

Numerous sources are available on the fatty acid composition of physic nut oil originating from different countries. The values given in Figure 5 refer only to the four most important fatty acids: palmitic (C16:0), stearic (C18:0), oleic (C18:1) and linoleic acid (C18:2). Fatty acids were determined by gas chromatography of the fatty acids after methylesterification. The average saturated fatty acid content of the seed samples is low: 15.38% for palmitic (C16:0) and 6.24% for stearic acid (C18:0). The average content of the unsaturated fatty acids, oleic (C18:1) and linoleic acid (C18:2) is considerably higher at 40.23 and 36.32%. Depending on the origin, either oleic or linoleic acid content is higher. The seed oil belongs to the oleic or linoleic acid group, to which the majority of vegetable oils belong (Rehm and Espig 1991).

Table 1. Composition of physic nut seeds from Cape Verde (Fogo und Santiago) and Sao Tomé und Principe (from Ferrao and Ferrao 1981, 1984; Ferrao *et al*. 1982).

			Contents (%)					
	Seed composition (%)		Kernel					Seed
Location	Shell	Kernel	Moist.	Ash	Crude prot.	Crude fat	Crude fibre	Crude fat
Fogo	35.46	64.54	4.68	4.48	20.25	52.83	0.94	34.09
Santiago	44.92	55.08	3.78	3.83	23.48	59.78	1.90	32.90
Sao Tomé	47.74	49.98	7.79	6.37	28.44	46.72	4.23	23.67
Mean	42.71	56.53	5.42	4.89	24.06	53.11	2.36	30.22

Toxicology

The toxicity of the seeds is mainly due to the following seed components: a toxic protein (curcin) and diterpene esters. Poisoning is reported in Chapter 6 (Uses). Curcin is similar to ricin, the toxic protein of the castorbean (*Ricinus communis*). The pure substances are the most potent toxins in the plant kingdom and will kill when administered in quantities of micrograms. Georgi Markov, a Bulgarian journalist who lived in London, was killed in 1978, probably with ricin poison that was contained in an umbrella spike (Griffiths *et al.* 1987). Felke (1913) was the first to isolate curcin. Curcin hinders protein synthesis *in vitro*

(Stirpe *et al.* 1976). Diterpenes have been isolated from seeds (Adolf *et al.* 1984) and roots (Naengchomnong *et al.* 1986; Chen *et al.* 1988). These substances promoted skin tumours in a mouse cocarcinogenesis experiment. Horiuchi *et al.* (1987) suggested that an epidemiological study be carried out on human cancer in Thailand, since the skin of Thai people comes into direct contact with the seed oil. The GTZ financed a study on the possibility of detoxifying the seed cake and the mutation potential of the diterpenoids in the oil. Prof. Wink of the University of Heidelberg carried out the study (Wink 1993).

The major findings were:

- seed cake still contains approximately 11% oil content, in which the thermostable toxic diterpenes are bound
- heating of up to 100°C for 30 minutes did not de-activate the lectins in whole seeds and dry seed cake
- cooking of ground seeds or seed cake for 5 minutes deactivates the lectins
- the oil has no mutagenic properties; when handled with care, there is no danger for workers.

Feeding trials were carried out with many different animal species (dog – Siegel 1893; rabbit – Felke 1913; guinea pigs and hares – Droit 1932). In more recent trials, the toxicity of ground seeds has been demonstrated on mice, rats, goats, calves and chicks (Adam and Magzoub 1975; Ahmed and Adam 1979; Liberalino *et al.* 1988; El-Badwi *et al.* 1995). In contrast to this, Panigrahi *et al.* (1984) did not find such drastic poisoning of mice and rats with seeds of Mexican origin.

The results of these feeding trials cannot be accurately compared because of the different origin of the seeds, the preparation of diet, dosage and other factors. The toxic effects seem to be different on different animal species. Use in animal nutrition is not, therefore, possible without detoxification. Wink (1993) gave indications for detoxification in laboratory experiments. However, feasibility and profitability have to be proven on a large scale.

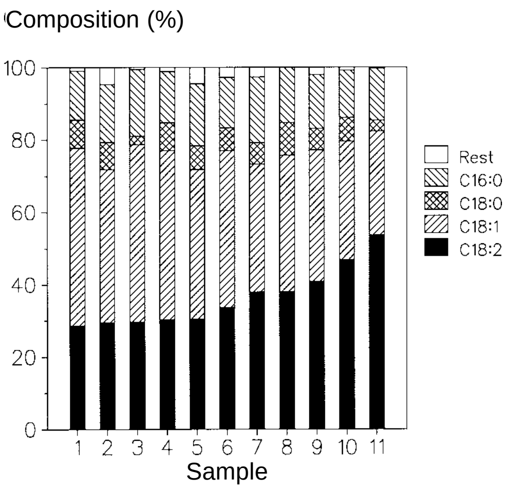

Fig. 5. Fatty acid composition of the seed oil of different seed samples (1 - Sao Tomé and Principe (Ferrao and Ferrao 1984); 2 - Paraguay (Matsuno *et al.* 1985); 3 - India (Banerji *et al.* 1985); 4 - Pakistan (Nasir *et al.* 1988); 5 - Cape Verde, Santiago (Ferrao and Ferrao 1981); 6 - Senegal (Heller 1992); 7 - Cape Verde, Fogo (Ferrao *et al.* 1982); 8 - Mexico (Aponte 1978); 9 Cape Verde, Santiago (Heller 1992); 10 - Brazil, Araçatuba, SP (Teixeira 1987); 11 - Brazil, Tatui, SP (Teixeira 1987).

6 Uses

Whole plant and food/fodder

The plant is widely cultivated in the tropics as a living fence in fields and settlements. This is mainly because it can easily be propagated by cuttings, densely planted for this purpose, and because the species is not browsed by cattle. According to Budowski (1987), physic nut is one of the hedge plants frequently found in certain regions of El Salvador. It is also one of the main trees planted in Upper Guinea as a hedge (Diallo 1994). In Mali, there are several thousand kilometres of *Jatropha* hedges and the Cotton Marketing Authority of Mali is planning to establish new hedges (Fig. 3c; Lutz 1992; Henning and von Mitzlaff 1995). Physic nut is also quite common in Burkina Faso (Zan 1985). In Cape Verde, physic nut was recently planted in arid areas for soil erosion control. Of a total area of 1386 ha planted with trees (such as *Acacia*, *Parkinsonia* and *Prosopis*) in 1989, 5.4% were physic nut. It also formed 14.6% of the total area of 4462 ha reforested in 1990 (Van den Bergh 1985; Spaak 1990). In Madagascar, it is used as a support plant for vanilla. The wood was used as a (poor quality) burning material in Cape Verde. In a green manure trial with rice in Nepal, the application of 10 t of fresh physic nut biomass resulted in a yield increase of 11%, compared with 23% with *Adhatoda vasica*, 17% with *Albizzia lebbek* and 14% with *Hdarrhwa antidysenteria*. Unfertilized rice had a yield of 4.11 t/ha (paddy) (Sherchan *et al.* 1989).

Duke (1985), citing Ochse (1931), says that the young leaves may be safely eaten when steamed or stewed. In the literature, it is reported that the physic nut seed is eaten in certain regions of Mexico once it has been boiled and roasted (Aponte 1978; Panigrahi *et al.* 1984; Delgado and Parado 1989; Martinez 1994, pers. comm.). According to analyses carried out by Wink, the Mexican seeds do not contain phorbol esters. Levingston and Zamora (1983) report that the seeds are edible, once the embryo has been removed. It seems that seeds of Mexican origin have less toxic content so that, with proper processing, the seeds can be eaten. Consumption of processed seeds of other origin should on principle be avoided. Many cases of poisoning with physic nut are reported in the literature (Siegel 1893). Lippmann (1913) described in detail the medical findings of two workers who ate 30 to 40 physic nut seeds. Abdu-Aguye *et al.* (1986) described the poisoning of two children who accidentally ingested seeds and Joubert *et al.* (1984) reported a similar case in South Africa.

Physic nut plants are planted around houses to guard against misfortunes in the southeast of Piaui (Brazil) (Emperaire and Pinton 1986). *Jatropha curcas* (and *Erythrophleum guineense*) was used in supernaturally guided ordeals by the Shambaa in Usambara to determine the guilt or innocence of the accused. Accused persons had to consume the poison; the innocent vomited whereas the guilty died (Fleuret 1980).

Medicine

Preparations of all parts of the plant, including seeds, leaves and bark, fresh or as a decoction, are used in traditional medicine and for veterinary purposes. The oil has a strong purgative action and is also widely used for skin diseases and to soothe pain such as that caused by rheumatism. A decoction of leaves is used against cough and as an antiseptic after birth. Branches are used as a chewing stick in Nigeria (Isawumi 1978). The sap flowing from the stem is used to arrest bleeding of wounds. Nath and Dutta (1992) demonstrated the wound-healing properties of curcain, a proteolytic enzyme isolated from latex. Latex has antimicrobial properties against *Staphylococcus aureus*, *Escherichia coli*, *Klebsiella pneumoniae*, *Streptococcus pyogenes* and *Candida albicans* (Thomas 1989). Kone-Bamba *et al.* (1987) demonstrated the coagulating effects on blood plasma. Other uses in traditional medicine are described in the following sources: Irvine (1961), Persinos *et al.* (1964), Kerharo and Adam (1974), Quisumbing (1978), Levingston and Zamora (1983), Co and Taguba (1984), Duke (1985), Gupta (1985), Oliver-Bever (1986), Elisabetsky and Gely (1987), Lentz (1993) and Manandhar (1995). Further scientific research confirmed the effects described above in trials. Extracts from physic nut fruits showed pregnancy-terminating effects in rats (Goonasekera *et al.* 1995). The authors suggested further studies to elucidate whether the embryotoxic effect is due to a specific action or a result of general toxicity. Muanza *et al.* (1995) found that a methanol extract of physic nut leaves afforded moderate protection for cultured human lymphoblastoid cells against the cytopathic effects of human immunodeficiency virus. Extract of the leaves showed potent cardiovascular action in guinea pigs and might be a possible source of beta-blocker agent (Fojas *et al.* 1986).

Plant protectant and molluscicide

According to a survey by Grainge and Ahmed (1988) on plants with insecticidal properties, extracts from all parts of the physic nut show such properties. The seed oil, extracts of physic nut seeds and phorbol esters from the oil were used to control various pests with, in many cases, successful result. Table 2 shows a list of insects which were given different preparations. As these trials are still in the experimental stage, the oil or extracts cannot yet be used by farmers as plant protectants.

Aqueous extracts of physic nut leaves were effective in controlling *Sclerotium* sp., an *Azolla* fungal pathogen (Garcia and Lawas 1990). In laboratory experiments, ground physic nut showed molluscicidal activity against the host of liver fluke (*Lymnaea auricularia rubiginosa*), a disease which is widely distributed in the Philippines (Agaceta *et al.* 1981), and also against the hosts of *Fasciola gigantea* and *Schistosomia* in Senegal (Vassiliades 1984). Extracts from crushed whole seeds showed molluscicidal activity against several schistosome vector snails (Liu *et al.* in press; Rug *et al.* 1996). Phorbol esters were probably the active agents in the different extracts used.

However, it should be pointed out that the physic nut is a host for cassava viruses that can be transmitted. Münch (1986) states that cassava superelongation disease (*Sphaceloma manihoticola* / *Elsinoe brasiliensis*) can be transmitted from the physic nut. Another *Jatropha* species, *J. multifida*, is an alternate host plant for African Cassava Mosaic Virus (ACMV), which is transmitted by whiteflies (*Bemisia tabaci*) in India and East and West Africa (Okoth 1991). It can be assumed that this also applies to physic nut. Since this plays an important role in disease epidemiology, physic nut should not be used to fence in cassava fields. Physic nut is considered a potential weed in the Northern Territory of Australia because of its distribution throughout the world, the toxicity of its

Table 2. Pesticidal properties of various seed extracts.

Insect	Pest of	Preparation	Reference
Helicoverpa armigera	cotton	acetone extract of seeds;	Solsoloy *et al.* (1987)
		aqueous extract from oil;	Solsoloy (1993)
		seed oil	Solsoloy (1995)
Aphis gossypii	cotton	aqueous extract from oil;	Solsoloy (1993)
		seed oil	Solsoloy (1995)
Pectinophora gossypiella	cotton	aqueous extract from seed oil	Solsoloy (1993)
Empoasca biguttula (syn. *Amrasca biguttula)*	cotton	seed oil	Solsoloy (1995)
Phthorimaea opercullela	potato	seed oil	Shelke *et al.* (1985)
Callosobruchus maculatus	pulse	seed oil	Jadhav and Jadhav (1984)
Callosobruchus chinensis	mungbean	seed oil	Solsoloy (1995)
Sitophilus zeamays	corn	seed oil	Solsoloy (1995)
Manduca sexta	?	phorbol esters	Sauerwein *et al.* (1993)
Sesamia calamistis	sorghum	oil and phorbol esters	Henning 1994

seeds, related plants and its control (Crothers 1994). It is spread by seeds on rocky slopes in Cape Verde, thus creating dense stands. In uncultivated lands, it is a potential weed.

Technical uses

In former times, the seed oil was used mainly for soap production. Because of growing interest in extracting seed oil in Cape Verde, several studies were carried out to assess the feasibility of setting up oil-extraction plants (Esteves 1960; Andrade 1978; Cossel *et al.* 1982). The Cossel *et al.* (1982) study was carried out for GTZ which, at that time, was running a project on integrated development measures on the islands of Fogo and Brava, and the oil-extraction plant would have been an integral part of a soap-production facility. Since the soap factory was not considered to be competitive, this part of the project was not further pursued. In spite of the positive economic conclusions of Portuguese studies (Esteves 1960; Andrade 1978), none of the plans were put into practice. Soap is produced in an indigenous way today in Mali, where oil is boiled with a soda solution (Fig. 3d and e; Henning 1994). The laborious process, which uses a basis of ground seeds, is described by Freitas (1906). Research carried out by the Tata Oil Mills Co. Ltd., Bombay has shown that with a mixture of 75% hydrogenated physic nut oil, 15% refined and bleached physic nut oil and 10% coconut oil, a soap can be produced with lathering values equivalent to their regular production line toilet soap. Hardened physic nut oil could be a satisfactory substitute for tallow or hardened rice bran oil (Holla *et al.* 1993).

Seed oil can be extracted either hydraulically using a press or chemically using solvents. Chemical extraction cannot be achieved on a small-scale basis. Several types of mechanical equipment are available: screw presses (hand- or engine-powered), spindle presses and hydraulic presses, which are distributed widely throughout developing countries for the extraction of seed oils for nutrition purposes. Hydraulic presses are widely used for shea nut processing in West Africa. A consulting group of the Protestant Church of Germany (FAKT), in collaboration with organizations in India and Nepal, improved the oil expeller commonly used in South Asia (based on “the model no. 1” by Anderson, dated 1906). The main aims of this project were:

- to reduce the weight of the machines (important for transportation in remote areas of Nepal)
- to modernize the techniques used; to enhance oil recovery
- to make use of other oil seeds for extraction.

Seven machines are now being tested in Nepal under field conditions and a manufacturing facility has been installed. The so-called Sundhara oil expeller was also tested for processing physic nut (Fig. 3f). The extraction rate was 47.2, 82.0 and 88.9% for the first, second and third pass respectively, without shelling of seeds. The oil content of the seeds was 34.5% (FAKT 1992, no date). With solvent extraction, 95 to 99% of the total available oil can be obtained.

Diesel fuel

As early as 1911, Rudolf Diesel, who invented the diesel engine, made the following statement in a letter: “It is generally forgotten, that vegetable and animal oils can be used directly in diesel engines. A small diesel engine ran ... with peanut oil during the world exhibition of Paris in 1900, and which worked so exceptionally well, that the change of fuel was realized by only a few visitors” (Kiefer 1986). In experiments carried out until 1950, vegetable oils were used without problem in common engines with prechamber injection. Henning and Kone (no date) reported activities involving the use of physic nut oil in engines in Segou, Mali during World War II.

Since the oil crisis of the 1970s and recognition of the limitations of world oil resources, this technology has received special attention. Most of the research was carried out in temperate regions with the aim of making available to farmers possibilities for diversifying in view of the increasing subsidy-driven surpluses in traditional commodities. Another argument for the cultivation of oil crops for energy purposes is the increasing global warming / greenhouse effect. When these fuels are burned, the atmosphere is not polluted by carbon dioxide, since this has already been assimilated during the growth of these crops. The CO_2 balance, therefore, remains equable.

Special interest has been shown in the cultivation of physic nut for this purpose, especially since it is drought resistant and can potentially be used to produce oil from marginal semi-arid lands, without competing with food production. In addition, these fuels can be used partly to substitute costly oil imports for landlocked countries. The use of physic nut seed oil in car engines is reported in the literature (Mensier and Loury 1950; Cabral 1964; Takeda 1982; Ishii and Takeuchi 1987) and in unpublished research reports. A GTZ experiment in the Cape Verde Islands to power engines with physic nut seed oil failed. This was due to mismanagement by workers who incorrectly used the oil as a lubricant in an engine, which was destroyed. However, the direct injection Elsbett engine performed well during long-term experiments. Recently, GTZ launched another project to show the feasibility of (physic nut oil) production and use in several stationary engines under field conditions in Mali (Fig. 3g). In a former GTZ project carried out in Mali, it has been demonstrated that physic nut oil is competitive with imported diesel, especially in remote areas, where fuel is often not available (Lutz 1992; Appropriate Technology International, concept paper "Mali vegetable motor fuel production").

A wide array of technical options is available for using vegetable oil in diesel engines. The filtered oil can be used directly in many suitable engines (Deutz, Hatz, IFA, Elsbett, DMS, Farymann and Lister-type (India)). These include, apart from prechamber injection, direct-injection engines which can be used in a stationary way to drive mills and generators or in vehicles. All the engines were tested in long-term experiments with different vegetable oils, including physic nut oil (Lutz 1992; Pak and Allexi 1994).

Transesterified oil can be used in any diesel engine. This process is normally carried out in centralized plants since the small-scale economy of transesterification has not been determined. During the process, methanol, a highly flammable and toxic chemical, has to be used. This requires explosion-proof mixing equipment which might not always be available in certain developing countries. An Austrian-funded project in Nicaragua is constructing a plant that aims to produce 1600 t of methyl esters annually at a cost of US$0.74 per gallon. G.F. van Grieken (unpublished) assessed the energy efficiency of the methyl ester production process of physic nut and found that the efficiency of the EMAT (Ester Metilico de Ester et de Tempate) process is high, with an energy input:output ratio of 1:5.2. Ouedraogo *et al.* (1991) compared the performance of transesterified rapeseed and physic nut oil in diesel engines. Their results showed that neither of these fuels can be claimed to be superior.

A recent development is the "Schur Diesel" where vegetable oil (80%), petrol (14%), alcohol (6%) and a certain amount of an unknown component are mixed. This fuel can be used in all Diesel engines (Lutz 1992; Anon. 1993). However, owing to the unavailability of petrol and alcohol in rural areas of developing countries, this process might not yet be applicable for such areas.

In general, it would appear that the technological basis presents no problems and has been resolved. Economic analyses have demonstrated that physic nut fuel can compete with Diesel fuel in villages in Mali (Demant and Gajo 1992; Henning and von Mitzlaff 1995).

Other uses

The press cake cannot be used in animal feed because of its toxic properties, but it is valuable as organic manure since it has a nitrogen content similar to that of the seed cake of castorbean and chicken manure. The nitrogen content ranges from 3.2 to 3.8%, depending on the source (Juillet *et al.* 1955; Moreira 1970; Vöhringer 1987). Freitas (1906) reported on trials with physic nut seed cake used on wheat at the Estacao Agronomica de Lisboa from 1871 to 1872. Moreira (1970) applied physic nut seed cake at different rates to different crops in pots and in field trials. Applications showed phytotoxicity, expressed as reduced germination, when high rates of up to 5 t/ha were applied. Phytotoxicity to tomatoes seeded in the field was reduced by increasing the time difference between application and seeding.

The GTZ project in Mali carried out a fertilizer trial with pearl millet where the effect of manure (5 t/ha), physic nut press cake (5 t/ha) and mineral fertilizer (100 kg ammonium phosphate and 50 kg urea/ha) on pearl millet was investigated. Pearl millet yields per ha were 630 kg for the control, 815 kg for manure, 1366 kg for press cake and 1135 kg for mineral fertilizer. As the costs for mineral fertilizer were higher than those for the press cake, the rentability was 30 000 FCFA (US$60) higher for the latter (Henning *et al.* 1995).

Fruit hulls and seed shells can be used as a burning material.

Figure 6 summarizes the multiple utilization possibilities of the physic nut.

The case of the GTZ project in Mali will be used to demonstrate the economic benefits of physic nut cultivation. The *Jatropha* system is based on existing hedges that were used to fence in fields and to control erosion. The project promotes this system by creating a market for physic nut products. Small, simple hand- or engine-driven oil presses were installed to produce oil that can be used to drive stationary engines. These engines drive grain mills, water pumps or the oil press itself. The oil is also a raw material for soap production that generates income to local women producers. The press cake is appreciated by farmers and can be sold for 10 FCFA per kg (US$0.02/kg). Economic analysis has shown that physic nut can be produced at a price of 215 FCFA (US$0.63) (including all costs), which is 78% of the official diesel price. Henning (1996) gives a description of an economic calculation for three different processing and use systems: (1) a hand-operated “Bielenberg” press with a capacity of approximately 10 t of seed per year, (2) a Sundhara press driven by an Indian-built Lister-type engine, and (3) a Sundhara press driven with a Hatz engine. Internal rates of return were calculated as 75, 49 and 26%, respectively. The primary aim of this project is not to use physic nut oil as a fuel, but rather to use this important element to promote the cycle system, which combines ecologic, economic and income-generating effects (Henning and von Mitzlaff 1995). The macro-economic analysis, which took into consideration both the substitution value of the oil as a domestic fuel, and the indirect effects (erosion control, press cake as fertilizer, etc.), showed an economic rate of return of 135% (Henning 1996). People started planting new hedges. A survey carried out by the project has shown that the length of hedges in the zone of Falan increased by 20% and by 40% in the zone of Kita repectively, from 1994 to 1995 (Henning, pers. comm.).

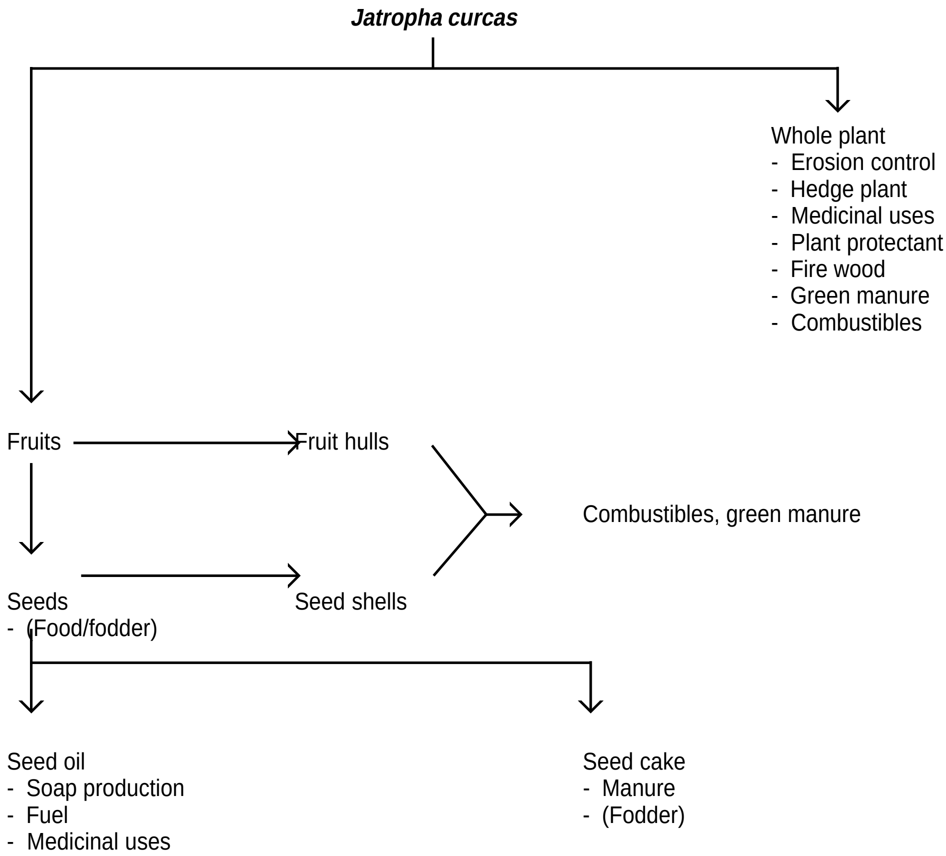

Fig. 6. Different forms of physic nut utilization (modified from Kiefer 1986).

7 Genetic resources

Existing genetic variation

So far, only four records of systematic provenance trials exist where an attempt was made to examine the genetic variation of the physic nut.

Sukarin *et al.* (1987) did not observe any morphological differences between 42 clones originating from different locations in Thailand and planted in a provenance trial at the Khon Kaen Field Crops Research Center. Differences in vegetative development and first seed yields were not reported.

Adaptive trials on *J. curcas* and *J. gossypiifolia* were undertaken at Hisar, Bangalore and Sardar Krushinagar in India (Bhag Mal, pers. comm.). The evaluation of five cultivars revealed a good degree of variation for plant height, branches per plant and seed yield per plot at Hisar. Quite high seed yields (1733 kg / ha) were observed in one cultivar when two physic nut cultivars and *J. gossypiiflora* were compared. At Bangalore, the two species were compared only for plant height. In all these trials, only local Indian types were used.

In Northern Nicaragua, an Austrian-funded project enabled planting of 1200 ha with Nicaraguan and Cape Verde provenances. These two types looked different in the field: the Nicaraguan type has a less branched habit, larger paler leaves and bigger seeds, whereas the Cape Verde provenance produced higher seed yields. In the Nicaraguan material, a male sterile plant was observed which produces more fruits than the hermaphrodite types. Male sterile plants will facilitate breeding efforts for higher seed production (Foidl, pers. comm.). The yield differences between the Cape Verde and Nicaragua types are being analyzed (Thierolf, pers. comm.).

Table 3. Origin of seed provenances (provenance number used in Figures 6 and 7 in parentheses) and climatic data of collecting sites (Heller 1992).

Origin of provenances	Altitude (m)	Average temp. (°C)	Average annual rainfall (mm)
Cape Verde, Fogo (1)	150-1600	19-25	200-1000
Senegal, Santhie Ram (2)	15	28	700
Ghana, Nyankpala (3)	183	27.8	1080
Benin, Cotonou (4)	7	25.3	1330
Burkina Faso, Kongoussi (5)	300	?	520
Kenya, Kitui (6)	1020	28?	790
Tanzania, Mombo (7)	430	>20	670
Burma, Sink Gaing, Mandalay (8)	80	27	825
India, Kangra (9)	580	?	?
India, Kangra(10)	434	11-38	?
India, Poona (11)	556	24.6	672
Costa Rica, Rio Grande (12)	10	27.5	2000
Mexico, Veracruz (13)	16	24.8	1623

In 1987 and 1988, Heller (1992) tested a collection of 13 provenances in multilocation field trials in two countries of the Sahel region: Senegal and Cape Verde. The two locations in Senegal, Samba Gueye and Toubacouta, lie north of the border with The Gambia, in the Department of Fatick. On Cape Verde, the trials were conducted on the island of Santiago at Sao Jorge and Tarrafal (Chao Bom). The sites have a semi-arid climate, with a short rainy season (approximately 4 months) and a longer dry season of approximately 8 months with a wide variation in rainfall (200-800 mm). Table 3 shows the origin of the seed provenances used and the climatic data for the locations. Provenances originated from different countries in North and Central America, West and East Africa, and Asia. As seeds from Mexico and Costa Rica were not available in 1987, these were compared with the Senegal provenance in a separate trial in 1988.

Vegetative development was evaluated at each location and was seen to vary greatly (Table 4). Significant differences in the vegetative development were detected among the various provenances at all locations. Plants of various provenances appeared very uniform as to morphological characters (such as leaf shape) (Heller 1992).

The paired calculation of both provenance trials in Senegal (at Toubacouta and Samba Gueye) showed that genotype-environment-interaction (GxE) was significant for all parameters, that is to say, the environments exerted a specific influence on certain provenances. Plant heights at 3.6 months after planting (MAP) are given as an example. Figure 7 indicates how provenances reacted differently to the environments. The two locations are situated at a distance of only 19 km from each other. The rainfall conditions can, there-

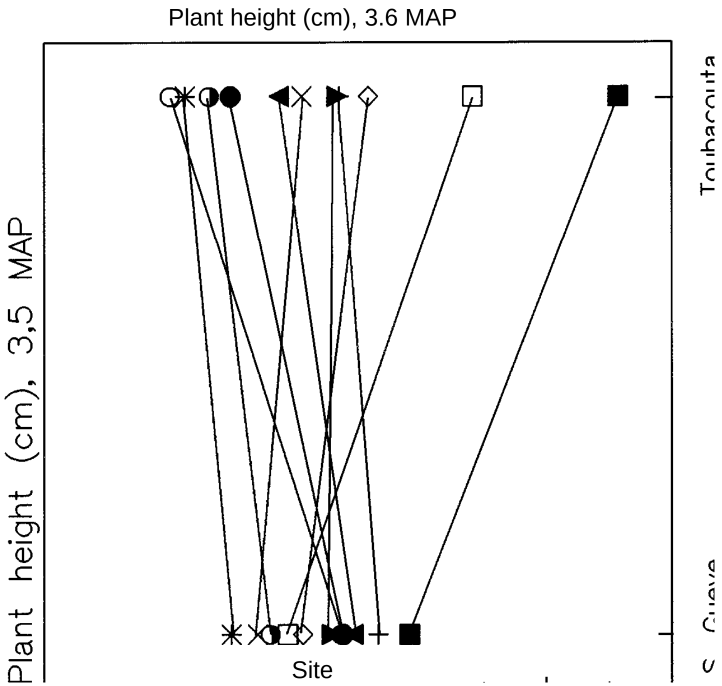

Fig. 7. Genotype-environment-interaction: Plant height (cm) of provenances at Samba Gueye and Toubacouta, 3.6 MAP (for provenances see Table 2).

fore, be considered nearly identical. The Toubacouta location showed better soil properties than the Samba Gueye location, to which some provenances reacted specifically. On Cape Verde, GxE was not significant, with the differences between the two sites probably greater than in Senegal.

Table 4. Descriptive statistical values of phenological traits and yield and yield components for 11 provenances evaluated in Samba Gueye, Senegal (Heller 1992).

Character	Min.	Max.	Mean	SE[1]	CV[2]
Vegetative development					
Plant height (cm), 3.7 MAP[3]	93.4	105.1	98.2	1.8	1.8
Plant height (cm), 10.9 MAP	121.0	135.1	129.9	2.9	2.3
Plant height (cm), 15.3 MAP	135.9	155.3	149.8	3.3	2.2
Plant height (cm), 25.3 MAP	152.1	185.2	173.6	4.1	2.3
Stem diameter (mm), 3.7 MAP	43.4	48.4	45.2	0.6	1.2
Stem diameter (mm), 15.3 MAP	69.3	81.7	74.7	1.8	2.4
No. of branches/plant, 3.7 MAP	3.3	4.5	4.2	0.3	6.8
No. of branches/plant, 15.3 MAP	4.9	6.3	5.5	0.2	3.8
Average length of branches/ plant (mm)	257.9	503.5	416.5	26.7	22.3
Generative development (7.9 MAP)					
No. of capsules/shrub	4.86	9.30	6.72	1.14	17.01
Wt. of capsules/shrub (g)	3.58	15.00	11.00	1.99	17.81
Wt./capsule (g)	1.52	1.92	1.66	0.09	5.56
No. of seeds/shrub	3.84	19.58	13.71	2.38	17.34
Wt. of seeds/shrub (g)	2.40	9.60	6.72	1.30	19.37
1000-seed weight (g)	417	575	494.4	22.60	4.60
No. seeds/capsule	1.90	2.15	2.05	0.09	4.36
Prop. seeds capsule (%)	57.70	65.40	60.90	1.90	3.10
Shrubs with yield, (%) of survived	48.0	93.3	81.80	5.60	6.90
Generative development (25.3 MAP)					
No. of capsules/shrub	0.20	9.00	3.91	1.61	41.11
Wt. of capsules/shrub (g)	0.52	15.72	6.09	2.90	47.54
Wt./capsule (g)	1.38	1.75	1.52	0.09	6.14
No. of seeds/shrub	0.60	17.80	6.98	3.29	47.11
Wt. of seeds/shrub (g)	0.32	9.22	3.48	1.69	48.55
1000-seed weight (g)	476	525	490.6	23.90	4.90
No. of seeds/capsule	1.55	1.96	1.75	0.10	5.67
Prop. seeds capsule (%)	53.50	59.60	56.60	1.70	3.10
Shrubs with yield, (%) of survived	20.40	94.50	71.40	6.80	9.50

1 **SE = standard error.**
2 **CV = coefficient of variation.**
3 **MAP = months after planting.**

No interaction could be tested between provenances at all four locations, due to the great differences in precultivation between Senegal and Cape Verde. The absolute growth height cannot, therefore, be used as a parameter to characterize specific adaptation of provenances to test sites. The provenances were ranked with regard to plant height (Fig. 8). The various locations can be graded according to their positive action on growth. Certain provenances indicated good or bad adaptation to certain sites (Fig. 8).

Yield and yield components were analyzed at Samba Gueye, 7.9 and 25.3 MAP. Parameters showed a wide variation (Table 4). No significant differences were determined for the parameters of weight per capsule (7.9 and 25.3 MAP), number of seeds per capsule and proportion of seeds in the capsule (7.9 and 25.3 MAP) and no differences were found in the 1000-seed weight at the second harvest (25.3 MAP). In the rest of their yield parameters (number and weight of capsules per shrub, number and weight of seeds per shrub (at 7.9 and 25.3 MAP) and 1000-seed weight at 25.3 MAP), provenances differed significantly. Plants on Cape Verde did not reach the generative stage. This was due to both the lower rainfall and the insufficient precultivation period.

With both harvests, the seed yield per shrub was very low, with a maximum of 9.6 g for the provenance Benin at 7.9 MAP and 9.2 g for the provenance Burkina Faso at 25.3 MAP. The provenance Burma showed lowest seed yields, combined with best vegetative development. The low yields at 25.3 MAP may have been due to high precipitation

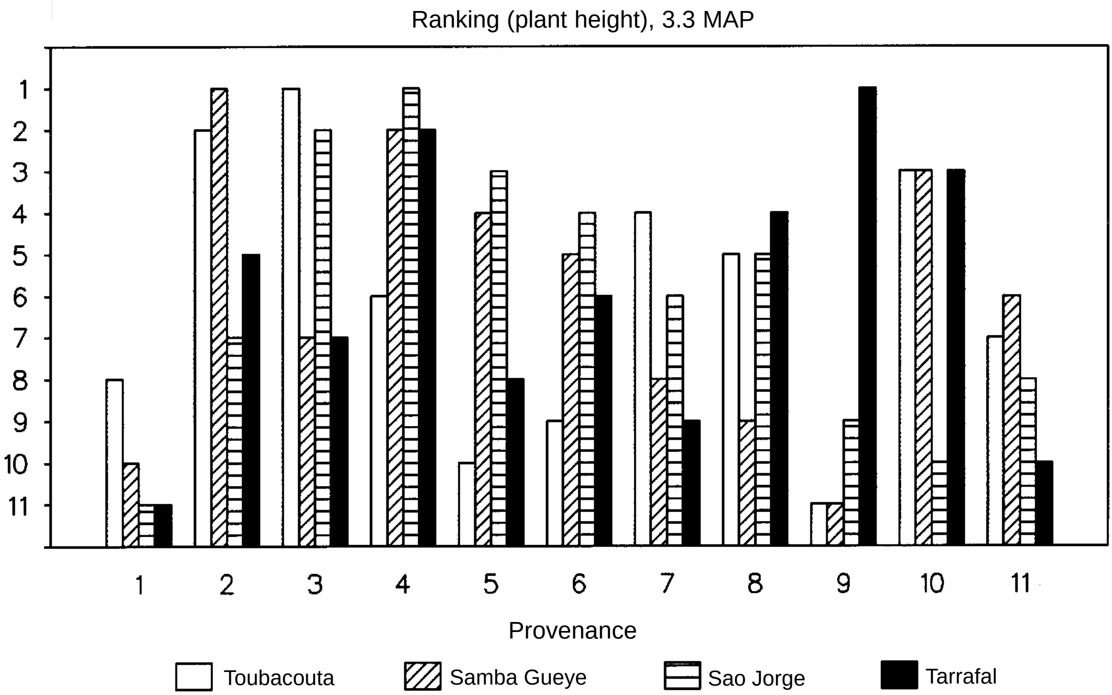

Fig. 8. The ranking of provenances by plant height at trial locations after the first rainy season, 3.3 MAP (for provenances see Table 2).

in the previous rainy season, which may have caused strong vegetative development at the expense of seed yields. Yields, on a hectare basis, were very low. None of the provenances tested in Heller's trials reached the values reported for Thailand by Sukarin *et al.* (1987) and Stienswat *et al.* (1986).

The contents of the original seed and harvest at Toubacouta were determined. The crude fat content is an important component of the oil yield per hectare; crude fibre and protein content are of importance for eventual use as seed cake in animal nutrition, as are crude protein and mineral content (P, Ca, Mg, Na and K) for utilization as fertilizer. With all parameters determined, analytic results showed a wide range between the different provenances. Crude fat content of the original seed ranged from 28.4 to 42.3%, with that of the harvest at Toubacouta varying between 23.2 and 38.3% (Table 5). On average, these values are in accordance with those determined by Ferrao and Ferrao (1981, 1984) and Ferrao *et al.* (1982) for samples from Cape Verde (Fogo and Santiago) and Sao Tomé and Principe.

Table 5. Composition (%) of seeds (dry matter) of the original seed and one harvest at Toubacouta of 13 provenances (Heller 1992).

Character	Min.	Max.	Mean	SE[1]	CV[2]
Original seed					
Crude fat	28.4	42.3	35.6	-	-
Crude fibre	24.4	30.8	28.2	-	-
Crude protein	13.7	22.4	19.0	-	-
Ash	3.6	5.2	4.6	-	-
P	0.45	0.76	0.61	-	-
Ca	0.27	0.80	0.47	-	-
Mg	0.36	0.46	0.42	-	-
Na	0.021	0.057	0.040	-	-
K	0.74	1.39	1.03	-	-
Harvest at Toubacouta					
Crude fat	23.2	38.3	31.9	-	-
Crude fibre	25.1	35.8	31.4	-	-
Crude protein	12.4	20.0	15.9	-	-
Ash	4.2	5.7	4.9	-	-
P	0.54	0.68	0.65	-	-
Ca	0.43	0.66	0.55	-	-
Mg	0.39	0.45	0.44	-	-
Na	0.054	0.22	0.118	-	-
K	0.70	1.22	0.97	-	-

[1] **SE = standard error.**
[2] **CV = coefficient of variation.**

The calculation of correlations of the different parameters for the harvest at Toubacouta showed significant correlations between nearly all parameters. A highly significant positive relationship exists between the 1000-seed weight, crude fat and crude fibre content, while the 1000-seed weight correlates negatively with crude fibre and ash content. Ferrao and Ferrao (1984) found highly significant correlations between seed samples from Sao Tomé and Principe for the 1000-seed weight and percent of crude fat content.

These provenance trials show, even in this limited survey, phenotypic variation. The selection, however, was probably too small as provenances from the centre of origin were not well represented. In addition, the time frame was too short for an assessment of the yield potential of the physic nut. The seeds utilized in the trials could not be collected by Heller himself at the locations. Collectors were requested to collect from a minimum of four healthy plants, representative of the population. However, this could not be verified. According to Burley and Wood (1976), samples should be collected from a larger number of trees. Thus, the samples received for the trials should not be considered representative of the population.

Nevertheless, some interesting aspects were evident. By recording vegetative development, Heller (1992) discovered the existence of genotypes specifically adapted to marginal conditions or which show strong vegetative growth during youth. This could be of importance for establishing pioneer vegetation on very marginal sites, as well as plantations to control erosion and supply mulching material, without considering seed-production aspects. The first seed yields were very low, but showed a great range. Long-term determinations are necessary, however, to estimate the yield potential. Differences in the 1000-seed weight of provenances cultivated at the same location were slight, whereas crude fat contents varied greatly. Significant positive correlations between the 1000-seed weight and percentage of crude fat content indicate interesting possibilities for selection, if genotypes exist where these are combined with high yields. The variability of the toxic contents of the provenances was not examined in these trials. Recent research by Becker (pers. comm.) confirmed the variability in toxic contents.

Conservation of physic nut

Physic nut is conserved in only three institutions. Three provenances from Costa Rica are maintained as field collections at the CATIE, Costa Rica. The Centre National de Semences Forestières (CNSF) in Burkina Faso has 12 provenances from Burkina Faso under medium-term storage conditions (see Appendix I). These were collected mainly from two areas in Burkina Faso. The INIDA, Cape Verde still maintains the field collection established as a provenance trial by Heller (1991) in 1987 (Jose G. Levy 1996, pers. comm.). The existing genetic variation of physic nut is not represented in the collections, as the centre of origin is represented with only five provenances from two countries.

Physic nut is conserved on-farm in the centre of origin and other regions, because it is used as a hedge. As this cultivation system does not seem to change, it can be assumed that genetic erosion is not important at present. It is questionable whether there is any need to conserve more provenances *ex situ*. However, there is no survey on the extent to which existing diversity is maintained in hedges. As the centre of origin still has to be ascertained and the diversity in these areas to be assessed, strategies for *in situ* conservation cannot yet be developed.

Germplasm used in afforestation programmes in different countries (India, Mali) uses only locally available material. By doing so, good opportunities might have been missed for using material with higher yield potential or with more desirable characteristics.

Seed storage behaviour of Euphorbiaceae is generally orthodox according to Ellis *et al.* (1985) (one exception being *Hevea*). Orthodox seed storage behaviour means "Mature whole seeds not only survive considerable desiccation (to at least 5% moisture content) but their longevity in air-dry storage is increased in a predictable way by reduction in seed storage moisture content and temperature (e.g. to those values employed in long-term seed stores)" (Hong *et al.* 1996). Physic nut also has orthodox seeds. Two- or six-month-old seeds received for the provenance trials described above, were stored in unsealed plastic bags at ambient temperatures (approximately 20°C) for 5 months and germinated on average by 62% (ranging from 19 to 79%) after having been seeded in soil. When stored for 7 years in plastic bags (not sealed) at a temperature of approximately 16°C, the seeds still showed an average germinating capacity of 47% (ranging from 0 to 82%) when tested with the "between paper" method (Heller, pers. comm.). When the seeds were analyzed for their chemical composition after 3 years of storage, they had a moisture content of 6.2% (average of all provenances).

Kobilke (1989) investigated the viability of seeds of different ages (1 to 24 months) that were collected directly from the sites or stored for a certain time. Seeds older than 15 months showed viabilities below 50%. One explanation for this rapid decrease is that these seeds remained at the site, having been exposed for long periods to extreme changes in levels of humidity and temperature.

High levels of viability and low levels of germination shortly after harvest indicate innate (=primary) dormancy. This behaviour has also been reported for other Euphorbiaceae (Ellis *et al.* 1985). Kobilke (1989) also tried to break induced dormancy. Intervals of presoaking and drying or partial removal of the testa proved more successful than presoaking alone.

8 Breeding

Breeding objectives

Breeding objectives will depend on use. Oil yield will, in most cases, be the most important part of physic nut cultivation. Components that contribute to physic nut oil yield per hectare are: number of pistillate flowers per inflorescence and subsequent number of capsules per shrub, number of seeds per capsule, 1000-seed weight, oil content of seeds (%) and plants per hectare. As the maximum number of seeds per capsule is limited and the agronomic factor of planting density does not offer much flexibility for increasing yields, selection should focus on the other yield components.

Ferrao and Ferrao (1984), and later Heller (1992), found highly significant correlations in different seed samples between the 1000-seed weight and percent of crude fat content. This might be interesting from the breeders' point of view, as simple selection for high 1000-seed weight could imply increased crude fat contents. From this, it cannot be concluded that shrubs which produce seeds of a high 1000-seed weight, and consequently a higher crude fat content, will yield more oil per hectare. A high 1000-seed weight can also be the consequence of a low seed yield per shrub. Further research on this is required.

Other important objectives are reduced plant height to facilitate harvesting of capsules and development of non toxic cultivars, where the seed cake could be used as fodder.

Breeding method

As the physic nut is a cross-pollinated crop, any genetic improvement has to be based on populations. Mass selection would be the simplest breeding method, where superior selected plants are composited. Populations can be stepwise improved if they remain large, so that additive genetic variation can be used. The method of recurrent selection is widely used in forest tree breeding. This involves concurrent cycles of selection with or without progeny tests. There are possibilities for the breeder to modify the method. In addition, hybrid cultivars could be bred to use the heterosis effect. The existence of male sterile cultivars as reported by Foidl (pers. comm.) would facilitate crossings.

Dehgan (1984) found that emasculation was not necessary for hybridization in the insect-free greenhouse. The reason for this was the absence of insect vectors and the time lag of anthesis of staminate flowers. The standard routine of bagging should be sufficient in the field. However, to avoid self-pollination if staminate and pistillate flowers were to open simultaneously – physic nut is self-compatible – emasculation could be required. This can be achieved very easily as staminate and pistillate flowers look very distinct. Dehgan's (1984) extensive trials on interspecific hybridization were aimed at investigating phylogenetic affinities in *Jatropha*. The findings on the crossability of 20 species in the two subgenera are very interesting if such crossings were desired for breeding. All F_1 hybrids, except *J. curcas* x *multifida*, were more vigorous than the parental species. In most of the successful crossings, the physic nut was involved as the maternal parent and barriers to interspecific compatibility with other *Jatropha* sections are demonstrated.

Selection based on provenance trials

The aim of a provenance trial is to estimate the differences between populations or environments relative to their productivity. This is often pursued to produce a base population for breeding. Burley and Wood (1976) describe exact methods for forest trees in their "Manual on species and provenance research with particular reference to the tropics". These methods are no doubt also applicable to shrubs such as physic nut, although the test phases are shorter. Species and provenance trials contribute fundamental information for large-scale afforestation in the tropics. At present, there is no alternative to such trials on representative sites (Burley and Wood 1976). Afforestation on the basis of provenance trials alone can, with certain species, improve productivity by 50% (Zobel *et al.* 1988). Systematic provenance trials at different locations have not yet been carried out with the physic nut to the necessary extent, and material from the centre of origin has not been sufficiently screened. The genetic background of the physic nut grown in Africa and Asia is unclear. It is not known from which genetic basis it derives or how wide the genetic basis of plants is in those areas.

Provenance trials are usually carried out at several sites. Certain provenances may differ relatively from others if cultivated at different sites, which is due to GxE interaction. Ranking of families, provenances or species can change completely, or a change of productivity without inversion of ranking can take place with a change in location (Namkoong *et al.* 1988; Zobel *et al.* 1988). Zobel *et al.* (1988) described many examples of tropical forest trees, with interaction being significant in some cases. A GxE interaction also occurred in trials with physic nut (Heller 1992). Additional well-planned provenance trials would make it possible to select provenances better adapted to local conditions.

9 Production areas

The cultivation of physic nut was of economic importance in Cape Verde. Silveira (1934) estimated that 8000 ha were planted with physic nut, which represented 12% of the islands' total surface or 16% of their cultivated area. The whole seed production was exported to Lisbon for oil extraction and soap production. Maximum exports from Cape Verde were 5622 t in 1910 and 4457 t in 1955. Exports of seed contributed in certain years for up to 60% of the total monetary value of the island's agricultural exports (Fig. 9). Seeds have not been exported since 1970, in spite of the fact that old plantations still exist and there has been a new reforestation effort with physic nut. Apart from Cape Verde, physic nut was cultivated only in some countries of West Africa and Madagascar for seed exports to Marseille. Plantations established recently in different countries had varying objectives:

- reforestation for erosion control in Cape Verde
- erosion control with hedges and combined oil production (diesel fuel) in Mali
- oil production on 10 000 ha in marginal areas of India (Patil and Singh 1991).
- establishment of 1200 ha of physic nut energy plantation for production of methyl esters in Nicaragua (Foidl, pers. comm.).

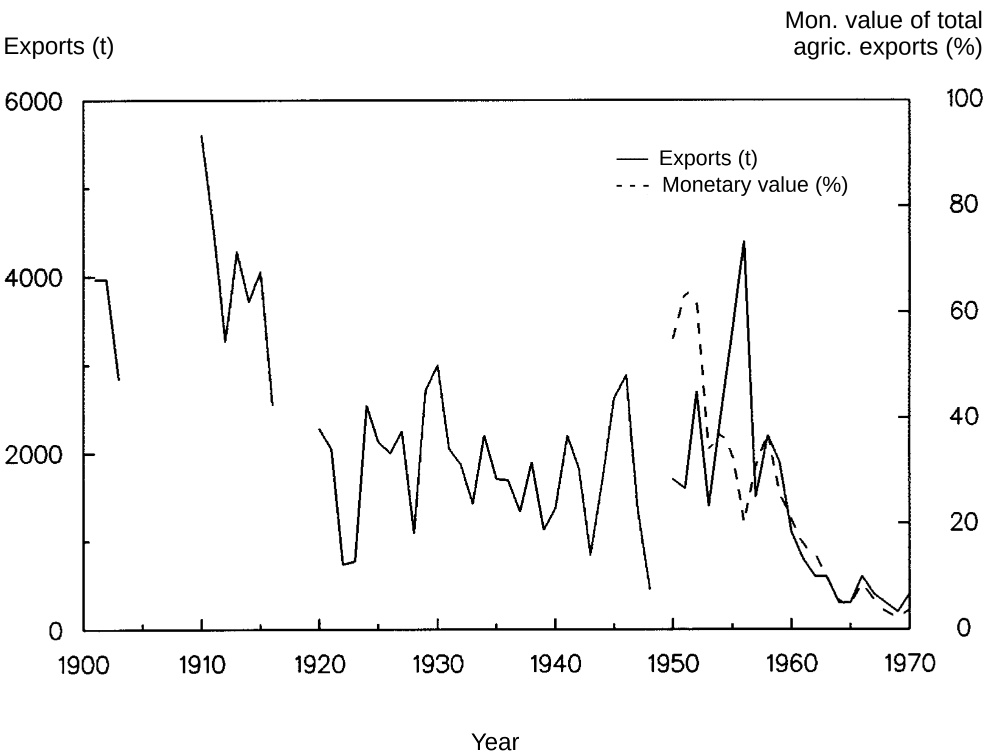

Fig. 9. Export of physic nut seeds from Cape Verde during the period 1900-1970 (Silveira 1934; Grillo 1951).

10 Ecology

Like many other *Jatropha* species, physic nut is a succulent that sheds its leaves during the dry season. It is, therefore, best adapted to arid and semi-arid conditions. Most *Jatropha* spp. occur in the following seasonally dry areas: grassland-savanna (cerrado), thorn forest scrub and caatingas vegetation, but are completely lacking from the moist Amazon region (Dehgan and Schutzman 1994). The current distribution of physic nut shows that introduction has been most successful in drier regions of the tropics with an average annual rainfall of between 300 and 1000 mm. Good examples are Cape Verde and Mali. Münch (1986) reports that physic nut even withstood years without rainfall in Cape Verde. However, it also grows successfully with higher precipitations.

As physic nut occurs mainly at lower altitudes (0-500 m), it can be concluded that it is adapted to higher temperatures. The areas where it has been collected in the centre of origin and from where the material was taken for provenance trials show average annual temperatures well above 20°C and up to 28°C. Physic nut withstood slight frost in the Chã das Caldeiras, Fogo (approximately 1700 m altitude) (Kiefer 1986). It is not sensitive to daylength.

It grows on well-drained soils with good aeration and is well adapted to marginal soils with low nutrient content. On Cape Verde, the physic nut is found especially in the stony "ribeiras" i.e. dry stream courses (Fig. 10a), and on rocky slopes where it is spread by seeds. In heavy soils, root formation is reduced. Physic nut is a highly adaptable species, but its strength as a crop comes from its ability to grow on poor, dry sites.


b


a

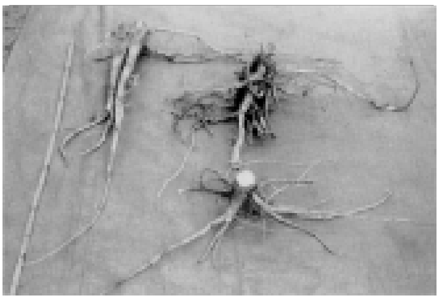
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Fig. 10. (a) Physic nut in "ribeira", Fogo, Cape Verde; (b) germination; (c) rooting pattern of plants originating from direct seeding (left), transplanting of precultivated seedlings (top right) and direct planted cuttings (bottom right), approximately 2 years old.

11 Agronomy

Growth and development

With good moisture conditions, germination needs 10 days (Fig. 10b). The seed shell splits, the radicula emerges and four little peripheral roots are formed. Soon after the development of the first leaves, the cotyledons wither up and fall off. Further growth is sympodial. With seeding in the month of May, a stem length of 1 m was reached in Thailand after 5 months of growth (Sukarin *et al.* 1987). A terminal flower was formed. The authors observed two flowering peaks, one in November and the other in May. In permanently humid equatorial regions, flowering occurs throughout the year. Fruit development needs 90 days from flowering until seeds mature. Further development corresponds to rainy seasons: vegetative growth during the rainy season and little increment during the dry season. Old plants can reach a height of up to 5 m. With good rainfall conditions, nursery plants bear fruit after the first rainy season, with directly seeded plants bearing for the first time after the second rainy season. With vegetative propagation, the first seed yield is higher.

Table 6. Seed yield of the physic nut (per shrub and hectare).

Reference	Location	Age (years)	Yield Shrub (g)	Yield Hectare (kg)
Avila (1949)	Cape Verde	?	700-900	n.d.[1]
Bhag Mal (pers. comm.)	India	3	n.d.	1733
Foidl (pers. comm.)	Nicaragua	?	n.d.	5000
Henning (pers. comm)[2]	Mali	?	n.d.	2640
Ishii and Takeuchi (1987)	Thailand	?	n.d.	2146
Larochas (1948)	Mali	?	n.d.	8000
Martin and Mayeux (1984)	Madagascar	?	3000-3500	n.d.
Matsuno *et al.* (1985)	Paraguay	3	n.d.	100
Matsuno *et al.* (1985)	Paraguay	4	n.d.	700
Matsuno *et al.* (1985)	Paraguay	5	n.d.	1000
Matsuno *et al.* (1985)	Paraguay	6	n.d.	2000
Matsuno *et al.* (1985)	Paraguay	7	n.d.	3000
Matsuno *et al.* (1985)	Paraguay	8	n.d.	4000
Matsuno *et al.* (1985)	Paraguay	9	n.d.	4000
Naigeon (1987)	Cape Verde	?	n.d.	1750
Silveira (1934)	Cape Verde	?	n.d.	200-800
Stienswat *et al.* (1986)	Thailand	1	318	794
Sukarin *et al.* (1987)	Thailand	1	63.8	n.d.
Zan (1985)	Burkina Faso	diff.	955	n.d.

[1] n.d. = not determined.
[2] Survey on hedges: 0.8 kg seeds per m hedge. Hectare yield assumes a distance of 3 m between the hedges.

Reports in the literature on physic nut yields are contradictor. Table 6 lists the seed yields per shrub and hectare in different countries. In most cases, information on the age and propagation method of the plants, variation between years are missing. At least 2-3 t of seeds/ha can be achieved in semi-arid areas. The fruit is harvested by hand and fruit hulls and seeds are separated manually. The best pickers in Nicaragua harvest up to 30 kg of fruits hour, which would mean approximately 18 kg of seeds.

Freitas (1906) reported two harvest times, corresponding to the flowering times. Observations of other authors showed that the main harvest occurs several months after the end of the rainy season, since flowering is connected to vegetative development. The physic nut can reach an age of about 50 years (Larochas 1948; Takeda 1982).

Propagation methods

Avila (1949) and Freitas (1906) have described several traditional propagation methods on Cape Verde: direct seeding, precultivation of seedlings, transplanting of spontaneous wild plants and direct planting of cuttings. All possibilities for crop establishment are listed below (Münch 1986; Kobilke 1989).

Generative propagation (seeds)

- Direct seeding
- Transplanting of precult. plants
  - seed bed (bare roots)
  - container

Vegetative propagation (cuttings)

- Direct planting
- Transplanting of precultivated plants
  - seed bed (bare roots)
  - container

Factors influencing crop establishment of plants propagated by different methods are:

Generative propagation (seeds)

- direct seeding – seeding depth, date and quality of the seed
- transplanting – type and length of precultivation, planting date

Vegetative propagation (cuttings)

- direct planting – character of cuttings (length, diameter, age), cutting time, storage, fungicide treatment, planting time and depth
- transplanting – as with direct planting of cuttings and precultivation of seeds.

Not all factors are of equal importance. Successful precultivation is characterized by high germination rates of seeds, high sprouting rates of cuttings and survival. Basing the propagation method on rainfall conditions plays a decisive role in the survival and properties of the plant in the field.

Comparative research on the influence of different propagation methods on survival and vegetative development was conducted by Kobilke (1989) in Cape Verde and by Heller (1992) in Senegal in nearly identical trials. The following methods were tested: direct and vegetative development was conducted by Kobilke (1989) in Cape Verde and by Heller (1992) in Senegal in nearly identical trials. The following methods were tested: direct seeding; transplanting of bare root plants (precultivated in seed bed or in the wild); transplanting of plants with root ball (precultivated in polyethylene bags); transplanting of precultivated cuttings and direct planting of cuttings.

The survival rate at Sao Jorge, Cape Verde, was significantly higher than that obtained using corresponding methods in Senegal. The ranking of various treatments with respect to survival rate did not change for the different locations. Both vegetative cultivation methods and methods of generative precultivation were more successful than direct seeding (Fig. 11). Since interaction was not significant, the different environments had no specific influence on the plants propagated by different methods.

Differences in seed yields between different propagation methods could not be determined in this trial because the observation period was too short. However, in another experiment designed by Heller (1992) in Senegal in 1987, to compare direct seeding, transplanting of seedlings and direct planting of cuttings of different diameters, differences in seed yields were detected. The first seed yield of cuttings of >30 mm diameter was significantly higher than that of precultivated plants (Fig. 12). No significant differences were found between precultivated plants and the other two treatments or among the cutting treatments. In the second harvest no significant differences could be determined.

In another series of trials, Kobilke (1989) and Heller (1992) investigated the influence of planting time, cutting length, storage and fungicide application on the survival and dry matter accumulation of cuttings planted directly. Thitithanavanich (1985) investi-

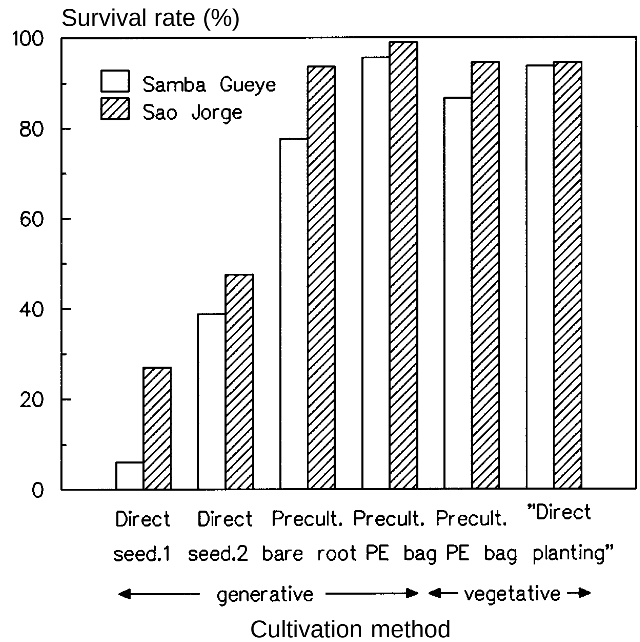

Fig. 11. Comparison of survival rates (%) of plants propagated by different methods at Samba Gueye and Sao Jorge, 1988 (Kobilke 1989; Heller 1992).

gated the root formation of physic nut cuttings of different diameters (1, 2 and 3 cm) and lengths (15 and 30 cm) in the nursery bed. Thicker cuttings formed more roots than the thinner ones. Cuttings of 30-cm length developed more roots and their survival rate was higher than cuttings of 15-cm length. Narin-Sombunsan and Stienswat (1983) showed that treating cuttings with IBA (indole-butyric acid) hormone did not promote root formation. The rooting of stem cuttings is influenced more by rooting media; good aeration and drainage proved profitable. According to Hartmann and Kester (1983), the following two factors are generally responsible for sprouting: the age of the plant from which cuttings are taken and the position of the cutting within the plant.

Factors responsible for the survival of direct seeding (seeding time, seeding depth) were studied by Heller (1992). Based on yearly averages, the low survival rates for direct seeding (19.8%) are striking, whereas the same provenance seeded in polyethylene bags for provenance trials showed a germination of 68%. The survival rate depended not only on sowing time and depth of sowing, but also on the trial year. No statements can be made on the occurrence of water stress shortly after seeding, since soil moisture was not determined. The trials confirmed that seeding should be done when rainfall is certain, after the beginning of the rainy season. Thus, seeding depends very much on timing. These research results are explained in more detail in Heller (1991, 1992).

When establishing a physic nut crop, the survival rate can be influenced by the choice of cultivation method. In addition to costs and a fixed agricultural working calendar, the intended utilization of a plantation must be taken into consideration when selecting the cultivation method. For the quick establishment of hedges and plantations for erosion control, directly planted cuttings are best suited; for long-

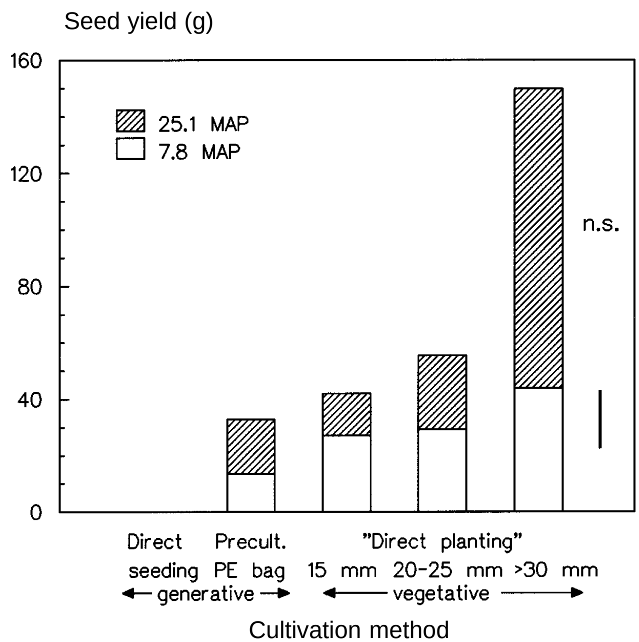

Fig. 12. Seed yield (g per shrub) of plants propagated by different methods at Samba Gueye, 7.8 and 25.1 MAP (*P* = 0.05, Tukey).

lived plantations for vegetable oil production, plants propagated by seeds are better. However, if early seed yields are desired in such plantations, directly planted stakes could also be used. With better rainfall conditions, the plantation could also be established by direct seeding, if higher maintenance work (weeding) can be guaranteed. For the quick propagation of selected mother plants, the vegetative method of precultivating cuttings in Rigi pots is more suitable.

As an alley crop in the conventional sense, where the effect of nutrient pump is of interest, the non-leguminous physic nut is not appropriate. But under certain circumstances, physic nut alleys could function as windbreaks for annual cultures during their establishment phase, as Banzhaf (1988) demonstrated with windbreak strips of fallow vegetation. At the same time, an energy component could be integrated into the cropping system. The planting of physic nut hedges reduces the cultivation area, and thus the yield per hectare of the annual crop. Felske (1991) investigated possibilities for integrating physic nut into annual crop production systems. Pruning of hedges to reduce shading of neighbouring crops and to facilitate harvesting is common in Mali.

In association with annual crops, the root system of the physic nut is of special importance . The tap root of directly seeded plants probably competes less with the roots of the annual crop than the root system of precultivated plants, propagated by seeds, or cuttings planted directly. The different development of root systems is shown in Figure 10c. Differences observed in first seed yields of differently propagated plants probably will disappear some years after planting. The type of root system probably influences the longevity of plants under stress conditions.

The above statements show the influence of various factors on survival. According to Avila (1949), satisfactory planting widths are 2 x 2, 2.5 x 2.5 and 3 m x 3 m. This is equivalent to crop densities of 2500, 1600 and 1111 plants/ha. Plants propagated by cuttings show a lower longevity and possess a lower drought and disease resistance than plants propagated by seeds. Stienswat *et al.* (1986) investigated the influence of different crop densities (2 x 2, 2 x 1.5, 2 x 1 and 2 m x 0.5 m) on the vegetative development and first seed yield of 13 to 14-month-old shrubs in Thailand. The plants set widest apart had the best vegetative development and the highest seed yields (794 kg/ha and 318 g/shrub, respectively). On sloped semi-arid sites, reforestation with shrubs or trees is normally done in catchments, to improve the water supply for the plants and for better erosion control. Avila (1949) also recommended reforestation in catchments. Goor and Barney (1968) and Lamprecht (1986) gave detailed recommendations for afforestation on arid sites. Large-scale plantations are only appropriate for marginal lands on which annual food crops cannot be produced. If high pressure for arable land exists, the physic nut would normally be planted as a hedge to fence in fields.

Pests and diseases

Several pests and diseases have been reported for physic nut (Table 7).

Some pests and diseases were observed by the author in Senegal. Physic nut suffers

The ecological conditions in Zimbabwe are probably not favourable and plants are stressed (Harris, pers. comm.). In other countries, pests and diseases do not cause severe problems although millipedes can cause total loss of young seedlings. These seedlings are also susceptible to competition from weeds during their early development. Therefore weed control, either mechanical or with herbicides, is required during the establishment phase. The project in Nicaragua investigated the pest, diseases and weed control in physic nut (Foidl, pers. comm.).

Table 7. Pests and diseases observed on physic nut plants by different authors.

Name	Damage and symptoms	Source
Phytophthora spp., *Pythium* spp., *Fusarium* spp., etc.	damping off, root rot	Heller (1992)
Helminthosporium tetramera	leaf spots	Singh (1983)
Pestalotiopsis paraguarensis	leaf spots	Singh (1983)
Pestalotiopsis versicolor	leaf spots	Phillips (1975)
Cercospora jatrophae-curces	leaf spots	Kar and Das (1987)
Julus sp. (millipede)	total loss of seedlings	Heller (1992)
Oedaleus senegalensis (locust)	leaves, seedlings	Heller (1992)
Lepidopterae larvae	galleries in leaves	Heller (1992)
Pinnaspis strachani (cushion scale)	die-back of branches	van Harten, pers. comm.
Ferrisia virgata (wooly aphid)	die-back of branches	van Harten, pers. comm.
Calidea dregei (blue bug)	sucking on fruits	van Harten, pers. comm.
Nezara viridula (green stink bug)	sucking on fruits	van Harten, pers. comm.
Spodoptera litura	larval feeding on leaves	Meshram and Joshi (1994)

12 Limitations of the crop

The only real limitation of this crop is that the seeds are toxic and the press cake cannot be used as a fodder (see chapter 5). The press cake can only be used, therefore, as organic manure. The low yields revealed in several projects may have been caused by the fact that unadapted provenances had been used. If investigation of its genetic diversity and its yield potential had been covered by adequate scientific research, this problem could have been overcome.

13 Prospects

Physic nut is well adapted to marginal areas with poor soils and low rainfall, where it grows without competing with annual food crops, thus filling an ecological niche. It is widely distributed in the tropics and is already used to a certain extent. Any further promotion of its use would, therefore, be facilitated by this. The species has numerous uses and in their combination lies the potential of this crop. The most important is the combination of erosion control and oil production. The use of the oil as a substitute for diesel fuel and for soap production in rural areas would improve the living conditions of the people and would offer additional income.

As physic nut is not browsed by cattle, it can grow without protection and can be used as a hedge to protect fields. The use of different propagation methods means that appropriate methods can be selected according to labour, costs and desired type of plantation. Living fences can be established very quickly by planting cuttings directly in the field. The harvest of physic nut seeds fits perfectly into the agricultural calendar in Mali: the main seed harvest is in August/September; millet is harvested in October. All parts of the plant are used in traditional medicine and active components are being investigated in scientific trials. Several ingredients appear to have promising applications both in medicine and as a plant protectant.

14 Research needs

An analysis of the research undertaken with the physic nut to date reveals the following research priorities:

- Systematic collecting of physic nut germplasm in the centre of origin
- Identification of provenances with desirable characteristics according to use through characterization and evaluation: drought resistance, desired growth habit, seed yield, oil content, non-toxicity (fodder) or high toxic content (pesticide)
- Investigation of the genetic distinctness of physic nut in the centre of origin and other regions where it has been introduced by electrophoretic and molecular methods
- Investigation of the taxonomic status of existing plantations
- Investigation of the agronomic potential of other *Jatropha* spp., e.g. *Jatropha canescens*
- Initiation of a selection / breeding programme with multilocation testing of promising provenances
- Research on medical and insecticidal properties of seed components for development of products
- Influence of pruning on seed yields
- Economic analysis of seed oil production in rural areas for diesel fuel and soap production
- Economic analysis of the fertilizer value of the seed cake
- Development of methods for detoxification of the seed cake
- Socioeconomic studies on how physic nut can aid development in local communities.

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Appendix I. Research contacts, centres of crop research, breeding and plant genetic resources of physic nut

Austria

Sucher and Holzer Alberstr. 4 8010 Graz Fax: +43-316-383703	Development project in Nicaragua (see Nicaragua)

Brazil

Prof. José Roberto Moreira
Biomass Users Network
Rua Francisco Dias Velho, 814
Brooklin Novo
04581-001 Sao Paulo SP

Burkina Faso

Centre National de Semences Forestières (CNSF) 01 BP 2682 Ougadougou 01 Fax: +226-301232	Germplasm collection for distribution (12 prov. from Burkina Faso)
Makido Ouedraogo Institut des Sciences de la Nature et Institut de Developpement Rural Université de Ouagadougou Ouagadougou	Engine tests with transesterified physic nut oil

Cape Verde

Instituto Nacional de Investigacao e Desenvolvimento Agrario (INIDA) CP 84 Praia Fax: +238-711133	Germplasm collection in field genebank (13 provenances, see Table 3)

Costa Rica

Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) PO Box 7170 Turrialba Fax: +506-556-1533	Germplasm collection in field genebank (3 provenances from Costa Rica)

France

Mr. R. Schilling
Mr. M. Vaitilingom
Centre de coopération internationale
en recherche agronomique
pour le développement (CIRAD)
2477, avenue du Val de Montferrand
BP 5035
34032 Montpellier Cedex 1
Fax: +33-67615570

Former IRHO part of CIRAD

Germany

Mr. Stefan Peterlowitz
Deutsche Gesellschaft für Technische
Zusammenarbeit (GTZ) GmbH
OE 4201
PO Box 5180
65726 Eschborn
Fax: +49-6196-79-7165
Email: GTZ-TTI@geod.geonet.de

Biofuels, engine tests, presses, reforestation, project in Mali

Prof. Dr. Klaus Becker
Institute for Animal Production in the
Tropics and Subtropics
University Hohenheim
PO Box 70562
70593 Stuttgart
Fax: +49-711-4593702
Email: kbecker@uni-hohenheim.de

Fodder, toxicology, detoxification

Prof. Dr. Michael Wink
Institut für Pharmazeutische Biologie
Ruprecht-Karls-Universität Heidelberg
Im Neuenheimer Feld 364
69120 Heidelberg
Fax: +49-6221-544884

Toxicology, pesticidal properties

FAKT Büro Furtwangen
R. Metzler
Stephan Blattmann Str. 11
78120 Furtwangen
Fax: +49-7723-5373

Development of oil presses

Jürgen Gliese
TBW
naturger. Technologien, Bau- und
Wirtschaftsberatung
Baumweg 16
60316 Frankfurt / M.
Fax: +49-69-440049
Email: tbw@pop-frankfurt.com

Consultant on *Jatropha* system, socioeconomy

India

Dr. Sudhir Kochhar
Project Coordinator All India
Coordinated Research Project on
Underutilized Crops
National Bureau of Plant Genetic
Resources (NBPGR)
Pusa Campus
New Delhi - 110 012

Genetic resources

Mr. Vinayak Patil
Agro Forestry Federation Prosper Park
Shringada Talao
Nashik 422 001
Fax: 0253 8097

World Bank project in Maharashtra

Prof. Dr. G.D. Sharma
Dept. Plant Breeding
CCS Haryana Agricultural University
Hisar - 125 00

Adaptive trials

Dr. A.H. Sonone
Plant Breeder
Dept. Botany
Mahatma Phule Agricultural University
Rahuri - 413 722 (Dist. Ahmednagar)

Agronomic trials

Dr. N.H. Patel
Associate Research Scientist
(Plant Breeding)
Regional Research Station
Gujarat Agricultural University
Sardar Krushinagar - 385 506
(Dist. Banaskantha (Via) Ahmedabad
(Gujarat)

Adaptive trials

Dr. K.N. Ganeshiah
Plant Breeder
Dept. Plant Breeding and Genetics
University of Agricultural Sciences
GKVK Campus
Bangalore - 560 065

Adaptive trials

Italy

Dr. Joachim Heller
IPGRI
Via delle Sette Chiese 142
00145 Rome
Fax: +39-6-5750309
Email: J.HELLER@CGNET.COM

Genetic resources, agronomy

Mali

Mr. Reinhard Henning
Projet Pourghère
DNHE - GTZ
BP 134 Bamako
Fax: +223-227184
Email: henning@pourgher.malinet.ml

Biofuel, engine tests, soap production, presses, erosion control

Nicaragua

Mr. Nikolaus Foidl
Proyecto Biomasa
DINOT/UNI
Apartado Postal 432
Managua
Fax: +505-2-490937
Email: biomasa@nicarao.apc.org.ni

Biofuel, methylesterification, detoxification of press cake and oil, pesticidal properties, chemical composition, agronomic trials, pests, presses, development of new extraction (see Appendix II for project publications)

Philippines

Aida D. Solsoloy
Cotton Research and Development Institute
Batac
Ilocos Norte

Pesticidal properties

Portugal

Prof. J.E. Mendes Ferrao
S. Aut. Agronomia Tropical e Subtropical
Instituto Superior de Agronomia
Universidade Técnica de Lisboa
Tapada da Ajuda
1399 Lisboa CODEX
Fax: +351-1-3635031

Chemical composition

UK

Dr. Phil Harris
The Henry Doubleday Research Association
Ryton Organic Gardens
Ryton-on-Dunsmore
Coventry CV8 31G
Fax: +44-1203-639229

Evaluation of physic nut projects

USA	
Prof. Dr. Bijan Dehgan Horticultural Systematics Laboratory Department of Environmental Horticulture University of Florida 1545 W.M. Fifield Hall PO Box 110670 Gainesville, Florida 32611 Fax: +1-904-392-3870 Email: BD@gnv.ifas.ufl.edu	Taxonomy of *Jatropha*, botanical collection of *Jatropha* spp.
Dr. Norman Jones Senior Forestry Specialist - AGRAF The World Bank Group Washington, DC 20433 Fax: +1-202-522-1142 NJONES@worldbank.org	Genetic resources
Huntington Botanical Gardens 1151 Oxford Road San Marino CA 91108	Botanical collection of *Jatropha* spp.
Carl Bielenberg RFD 1 Marshfield Vermont 05658 Tel/Fax: +1-802-456-8993	Small-scale presses, oil use in adapted motors
Zimbabwe	
Mr. Geoff Oliver Plant Oil Producers' Association PO Box UA 518 Union Avenue Harare	Adaptive trials

Appendix II. Publications of Proyecto Biomasa, DINOT/UNI, Nicaragua.

Researcher, Institute[1], Date	Publication title
Dr. Charles Aker UNAN León Enero 1993 - Diciembre 1994	Ensayos regionales de Variedades y métodos de siembra
Lic. José Munguía UNAN - León Mayo - 93 / Noviembre - 94	El Tempate *Jatropha curcas* L. y sus insectos asociados en áreas experimentales
Lic. Enilda Cano UNAN - León Enero - 93 / Diciembre - 94	Rastreo de parasitoides en el cultivo del Tempate *Jatropha curcas* L.
Lic. Ricardo García Dr. Charles Aker UNAN - León Noviembre - 92 / Diciembre - 94	Polinización y Sistema de apareami ento de *Jatropha curcas* L.
MSc. Verónica Díaz, Lic. Rebeca Pastora UNAN - León Enero - 93 / Diciembre - 94	Caracterización de ADN, genómico de *Jatropha curcas* L.
Carmén M. Guerrero Rocha, Carol M. Sánchez Tellez, Rosa A. Sáenz Artola UCA Mayo - 92 / Julio - 93	Estudio de sensibilización del Cultivo de Tempate (*Jatropha curcas* L.)
Martha Hilda Blandón, Margarita Aguirre G., Karla V. Amador UCA Febrero - 92 / Junio - 93	Estudio de factibilidad del Sistema Agro-Industrial del Tempate (*Jatropha curcas* L.) como sustituto del Diesel
Sonja Grillenberger, Estudiante Austríaca Agosto - 1993 / Enero 1994	Extracción de Látex de algunas Euphorbiaceaeas
Myriam Torres Gaitán UNI. Tesis Junio - 1993 / Noviembre - 1993	Diseño General de una maquina descas carilladora de la semilla de Tempate

Marling Buitrago Santamaría UNI. Tesis Septiembre - 1991 / Mayo 1992	Diseño general de la maquinaria para el proceso de extracción del aceite de Tempate desde la selección hasta precalentamiento
Juan Carlos Gutierrez UNI. Tesis Junio - 1992 / Agosto 1993	Diseño general de una maquina de secado de la semilla de Tempate
Martha Lidya Torres T., Violeta Carolina Amador Mora UNI. Tesis Noviembre - 1992 / Junio 1995	Industrialización de la transesterificación del aceite de Tempate
George Dreischulte, Estudiante Alemán 1989 - 1990	Diseño de un Ensayo de Fertilización
Francisco López C. UNI. Tesis Agosto - 1992 / Julio 1995	Diseño de un molino para la cáscara del fruto de Tempate
Manuel Gonzáles Murillo UNI. Tesis Agosto - 1993 / Julio - 1995	Diseño general de una maquina perfoabonadora de subsuelos para el cultivo del Tempate
MSc Martha Salamanca UNAN - León Enero - 1993 / Diciembre - 1993	Identificación taxonómica de los Acaros que se encuentran en el Tempate (*Jatropha curcas* L.) 1992
Martin Spanzel, Estudiante Austríaco Eva Gutierrez. UNAN - León Agosto - 1993 / Enero - 1994	Sistema de Riego en Tempate enTelica, León
Juana Emigdia Ferrufino UNAN - León Junio - 1993 / Febrero - 1994	Estudio de los depredadores que se encuentran en el cultivo Tempate (*Jatropha curcas* L.)
Ing. Marlene Vargas UNAN - León Abril - 1993 / Febrero - 1994	Manejo de maleza en cultivo de Tempate
Lester Guerrero, Mauricio Alvarez UNAN - León Abril - 1993 / Febrero - 1994	Estudios preliminares para el establecimiento de un sistema de manejo integrado de plagas subclase Acari en Tempate
Danilo Padilla UNAN - León Abril - 1993 / Febrero - 1994	Diagnóstico de las enfermedades del Tempate (*Jatropha curcas* L.) en diferentes localidades de Nicaragua

Ana Julia Vargas UNAN - León Abril - 1993 / Febrero - 1994	Establecimiento de un banco de germoplasma
Milena Garmendia UNAN - León Junio - 1993 / Febrero - 1994	Patogenecidad de *Beauveria bassiana*, sobre *Pachicoris torridus*
Indiana Coronado, Martha Dá vila UNAN - León 1994 - 1995	Fertilización Cultivo de Tempate
Enilda Cano, Mirna Ortiz, Clarisa Cárdenas UNAN - León 1995	Estudio de cría masiva de *Crysoperla externa* y liberaciones en el campo para el control de *Pachicorris torridus* en el Tempate
Dpto. Técnico, UCA - Telica León. 1994 - 1995	Relación del sembrado directo de semilla de Tempate en bancales en vivero y plantaciones directas a lugares estables
UCA - Telica León. 1994 - 1995	Formación del árbol de Tempate (*Jatropha curcas* L.)
María de la Cruz Siles H., Arnulfo Montoya L. BIOMASA 1994 - 1995	Poda del Tempate, Cooperativa "Juan de Dios Muñoz", Nicaragua
Dpto. BIOMASA, Estación Experimental Valle de Sebaco 1994 - 1995	Efecto de bioinsecticida Tempate contra mosca blanca
Dpto. Técnico, UCA - Telica León. 1994 - 1995	Podas del árbol de Tempate (*Jatropha curcas* L.)
Dpto. Técnico, UCA - Telica León. 1994 - 1995	Productividad de árboles de Tempate, pro ducidos por estacas tiernas y no tiernas
Marlyng Buitrago S. BIOMASA 1993	Cálculos de las humedades de las semillas en el secador solar
Marlyng Buitrago S. BIOMASA 1993	Cálculo de pesos específicos reales del fruto de Tempate Variedad Cabo Verde y Nicaragua
Marlyng Buitrago S. BIOMASA 1994	Curvas de secado de las semillas de Tempate

Marlyng Buitrago S. BIOMASA 1993	Dimensiones de la semilla de Tempate. Variedad Cabo Verde y Nicaragua
Johannes Landbeck, Estudiante Austríaco 1989 - 1990	Trabajo evaluativo sobre datos básicos de la semilla de Tempate
Danilo Padilla UNAN - León Mayo - 1991 / Septiem. - 1992	Comportamiento de dos variedades de Tempate *Jatropha curcas* L., en el pacífico de Nicaragua
Lilliam Lezama, Xochilt Aguilar UNAN - León Mayo - 1992 / Septiem. - 1993	Comportamiento de dos variedades de Tempate *Jatropha curcas* L., en el pacífico de Nicaragua
Asdruval Pastora, María José Rosales UNAN - León Agosto - 1991 / Enero 1993	Efectos de la hormona Benzil Aminopurina sobre la floración del Tempate
Lester Guerrero, Mauricio Alvarez UNAN - León Mayo - 1992 / Diciembre 1992	Estudios preliminares para el establecimiento de un sistema de Manejo Integra do de Plagas subclase Acari en Tempate
Amando Picado V. E.A.G. Estelí 1994	Establecimiento de ensayos de micropropagación con sustratos nutritivos de Muashige Skoog (1961) con semisólido
Amando Picado V. E.A.G. Estelí 1994	Banco de germoplasma, Región Norte Central de Nicaragua
Amando Picado V. E.A.G. Estelí. 1994	Micropropagación *In Vitro*, del Tempate
César Dolmus, Adelina Centeno Fulvio Centeno UNAN - León Feb. - 1993 / Feb.- 1994	Efecto hormonal de benzilamina purina (BAP), en la floración y fructificación de *Jatropha curcas* L., en diferentes condiciones
Martina Halussler, Alemana Dalia Ortiz UNAN - León 1993 - 1994	Propagación de *Jatropha curcas* L. Tempate por injerto
Empresa Consultora AGROCONSULT y BIOMASA 1994	Análisis financiero y económico del Proyecto Agroindustrial del cultivo de Tempate

María de la Cruz Siles H., Arnulfo Montoya BIOMASA 1994 - 1995	Obtención de plantas de Tempate, a raíz desnuda
Francisco Montealegre UNAN - León 1994 - 1995	Síntomas de deficiencia nutricional y elementos limitantes en el cultivo de Tempate (*Jatropha curcas* L.)
Fernando Altamirano, Lester Guerrero UNAN - León 1993 - 1994	Dinámica poblacional de ácaros, fitófagos y depredadores
Cristoph Grimm, María de la Cruz Siles, Arnulfo Montoya BIOMASA 1994	Prueba de 2 productos químicos en el con trol de chinches (Hemiptera), en plantaciones de *Jatropha curcas* L., en Mateare, Nicaragua
Indiana Coronado, Martha Dávila UNAN - León 1994 - 1995	Influencia del Nitrógeno, Fósforo y Potasio, sobre los rendimientos del cultivo de Tempate
Eva Gutierrez UNI 1994 - 1995	Evaluación técnica y agronómica del riego por goteo para el Tempate, en la Cooperativa "Juan de Dios Muñoz". Telica - León
Maritza Sánchez M., María Cruz Siles H. Arnulfo Montoya BIOMASA 1995	Inhibición apical del cultivo de Tempate a través del Ester Metílico de aceite de Tempate (EMAT)
Martha Vásques, José Munguía, Cora Ma. Jímenez UNAN - León, CENAPROVE	Patogenecidad de *Beauveria bassiana* sobre *Pantomorus femoratus*
Ricardo Rueda, Charles Aker, Claudia Silva, UNAN - León 1995	Ecología genética y conservación de poblaciones naturales de *Jatropha* sp. en Nicaragua
Modesto Gómez, René Gon záles, Charles Aker UNAN León 1995	Efectos de diferentes herbicidas sobre el control de malezas en el cultivo del Tempate, *Jatropha curcas* L.
Rolando Dolmuz B., Ricardo Rueda UNAN - León 1994 - 1995	Efectos de tres malezas leguminosas en la productividad de plantaciones comerciales de *Jatropha curcas* L. Tempate

María Cruz Siles, Arnulfo Montoya BIOMASA 1994 - 1995	Prueba del Compost de Cáscara de Tempate
Rebeca Pastora, María Inés Dávila UNAN - León 1995	Efectos de la aplicación de productos que comerciales que contengan BAP y ANA, sobre la productividad del Tempate
Concepción Narvaéz, Patricia Castrillo, Carmén Marina Rizo UNAN - León 1995	Umbral de daño económico para plántulas de *Jatropha curcas* L., atacadas por *Pantomorus femoratus*
Maritza Sánchez M., María de la Cruz Siles H., Arnulfo Montoya BIOMASA 1994	Establecimiento y manejo de viveros del cultivo del Tempate
Maritza Sánchez M., María Cruz Siles H., Arnulfo Montoya BIOMASA 1994	Establecimiento y manejo de plantaciones de Tempate
Charles Aker, Enilda Cano UNAN - León 1995	Dinámica poblacional, nivel de daño económico y control biológico de *Pachicorris torridus* (Hemiptera: Scutelleridae)
Empresa Nicaraguense de Petróleo Gobierno de Austria UNI. Enero 1995	Proyecto Tempate. Producción de Ester Metílico de Tempate como Sustituo del Combustible Diesel
Maritza Sánchez M. BIOMASA 1994 - 1995	Estudio de *Lagocheirus undatus* en la Región II
Maritza Sánchez M., Danilo Padilla UNAN - León BIOMASA 1994 - 1995	Métodos de control y manejo de las enfermeda des del Tempate
Francisco Montealegre, María de la Cruz Siles H., Dalia Ortiz, Maritza Sánchez M. UNAN - León. BIOMASA	Propagación vegetativa del Tempate por injerto
Arnulfo Montoya, Maritza Sánchez, María Cruz Siles BIOMASA 1995	Efecto de poda en el cultivo de Tempate, en las localidades Mateare, UNI Central

Eduarzo Zamora S., María de la Cruz Siles BIOMASA 1994	Efecto del extracto acuoso de hojas de Marango sobre el crecimiento y desarrollo del Tempate (*Jatropha curcas* L.)
Anabell Reyes, José René González, Modesto Gómez, Charles Aker UNAN - León 1993 - 1995	Ensayos regionales de variedad y métodos de siembra
José Munguía UNAN - León 1993	Taxonomía de insectos asociados al Tempate
Anabell Reyes, René Gómez UNAN - León 1993	Dinámica poblacional de insecto en los ensayos regionales
Indiana Coronado, Martha Dávila UNAN - León 1994 - 1995	Fertilización Cultivo de Tempate
Marlyng Buitrago S. BIOMASA 1991 - 1992	Datos de consolidación de las semillas de Tempate. Variedad Cabo Verde y Nicaragua
Marlyng Buitrago S. BIOMASA 1990 - 1991	Datos de consolidación de las semillas de Tempate. Variedad Cabo Verde y Nicaragua
Marlyng Buitrago S. BIOMASA 1994	Porcentajes de semillas seleccionadas para la siembra la producción de aceite de Tempate
Luis Sonzini Meroi, Marlyng Buitrago S. BIOMASA 1995	Informes sobre resultados de ensayos de extracción de aceite
Sixto Rómulo Vega Urroz, Sara María Flores López UNI 1995	Optimización del proceso de extracción de aceite y análisis de la posibilidad de realización simultánea con el proceso de transesterificacion, para la semilla de Tempate

[1] Institute codes: UNAN = Universidad Nacional Autónoma de Nicaragua; UCA = Universidad Centroamericana; BIOMASA= Projecto Biomasa; E.A.G. Estelí= Escuela de Agricultura y Ganaderia de Estelí; CENAPROVE= Centro Nacional de Proteccion Vegetal.