



Figure 9 Cork planks after the water-boiling operation.



Figure 10 Boring of stoppers from a cork strip in the industry.

The processing of cork depends on the type of cork: virgin and second cork are directed for trituration to produce cork granules that will be used for cork agglomerates; the reproduction cork planks (from the third extraction on) are used to produce stoppers.

The cork planks undergo postharvest preparation for further industrial processing consisting of immersion in water at approximately boiling point for 1 h. The objective of this operation is to flatten the stem-curved raw planks and to soften the cork tissue for easier subsequent cutting (**Figure 9**). In boiling water the cork expands and the most important practical consequence is that the raw cork planks increase in thickness, on average by 12%. There is a high variation in thickness increase with water boiling between different cork planks, with values ranging from almost nil increase to more than one-third of the initial dimension.

Cork planks that have a thickness over 27 mm are directed for production of stoppers. For this they are cut into strips and the stoppers are bored with a hollow cutting cylinder with an inner diameter equal to the desired stopper diameter (**Figure 10**). The stoppers are dimensionally rectified, washed, bleached, dried, and classified into commercial quality classes according to the extent of the porosity shown on their surface, as given by the lenticular channels. In the stoppers the lenticular channels run parallel to the top and bottom faces.

The cork planks that have a thickness below 27 mm are directed for the production of disks. The planks are cut into bands, and laminated tangentially in the cork into 2–5-mm-thick cork sheets from which the disks will be punched out. The disks will be used glued on bodies of agglomerated cork, i.e., for champagne and sparkling wine.

The residues from the boring of stoppers and of disks (amounting to more than 75% of the initial cork plank) are trituated and agglomerated. Cork agglomerates are used to produce agglomerated stoppers and for cork boards and sheets used in various surfacing situations, i.e., flooring, paneling, joints. In a mixture with rubber, a composite material is produced for industrial and construction vibrational absorption.

A special insulation material called expanded cork agglomerate is made by high-temperature (*c.* 300°C) expansion and self-agglomeration of cork granules in autoclaves with superheated steam. The agglomerate has a dark brown color and is used for heat and sound insulation.

See also: **Temperate Ecosystems:** Fagaceae.

Resins, Latex and Palm Oil

P P Bhojvaid and D C Chaudhari, Forest Research Institute, Dehradun, Uttaranchal, India

© 2004, Elsevier Ltd. All Rights Reserved.

Introduction

Besides timber and fuelwood, many commercial products of biological origin are sourced from forests all over the world. These comprise medicinal herbs, edible plants and plant parts, aromatic oils, gums, resins, latex, fibers, flosses, and a variety of other products commonly referred to as non-wood forest products. Resins, latex, and palm oil are one such category of product which have found place in industrial, commercial, and subsistence use with

humans. While resins and latex are exudations which are secreted in response to natural and induced injuries to plants, palm oils are extracted from the fruits and seeds of certain tree species. The purpose of this article is to provide basic information on important resins, latex, and palm oil-producing forest plants with special reference to plant sources and description, uses, collection, primary processing, and value-added processing.

Resins

Definition and History

The term oleoresin is used to distinguish the fresh liquid exudation from trees having a high content of volatile oil. These are amorphous (noncrystalline) substances with a complex mixture of organic compounds called terpenes, which are insoluble in water but soluble in certain organic solvents. These yield on distillation two important commercial products, turpentine oil and nonvolatile solid rosin, which is also known as calophony.

Use of pine resins dates back to the period when wood was used for shipbuilding. The pitch obtained from pine trees for caulking the seams of wooden ships and preserving their ropes and rigging was the initial phase of the resin production industry. Consequently, the term naval stores industry denotes the industrial production of oleoresin or resin, used for waterproofing wood ships.

Resin Canals

Resin is produced in two types of resin canals, which are distributed in the tree stem. The large longitudinal ducts have an irregular distribution in the middle and outer portion of tree stem and the smaller horizontal canals are restricted to the outer part of the stem bark. These canals are formed by secondary division of growth cells (cambium), and are lined with a thin-layered wall of secretory epithelium enclosing a central hollow portion. The canals are interconnected to form a continuous network of resiniferous canals in the tree stem. Consequently, when one of these canals is cut at the stem surface, the resin flows to the openings from the inner portions of the stem.

Tapping Process

Resin is a secondary product which is produced by normal metabolic processes in trees; however, it exudes only in response to natural or induced injury to tree stems. Consequently secretion of resin is a defense mechanism in response to wounds and injuries and acts as a disinfectant against microbes and prevents the ingress of borer insects.

In normal resin tapping, a small superficial incision results in resin flow from horizontal canals, which in turn stimulate flow from longitudinal canals located deep in the stem. Trees above 30 cm diameter at breast height (1.37 m above ground level) are suitable for economical tapping. The best time for tapping is March to October; however, maximum resin yield is obtained in the months of May to July and September to October. In light-intensity tapping, superficial blazes result in minor injuries, which are healed in one to two growing seasons. However, unscientific blazing can cause irreversible damage and make trees prone to fire due to the inflammable nature of resin and pine-wood. Consequently, the classical method of tapping with the use of random blazes, which are frequently repeated, leading to large scars on tree stems, has been replaced by the environmentally friendly and ecologically sound rill method. In this method, only tree bark is chipped and small surface incisions are made in a definite geometric pattern using a sharp knife. The resin flow is enhanced with the use of dilute acid, 2-4-D, or other chemical stimulants, thereby increasing resin yield (Figure 1).

Processing of Resin

Processing of resin is essentially a technique to separate its main constituents, rosin and turpentine oil. Two different methods in vogue are direct heating and steam heating. The former involves heating resin in vats covered by light lids with the intermittent addition of water in small quantities. The resultant steam from the vat runs through a spiral pipe passing through cold water. This condensation process results in separation of turpentine, which is collected in a vessel at the end of a pipe. The rosin left in the vats is filtered before filling in packing vessels. This method, however, does not yield superior-quality rosin.

In steam heating, vats with a V-shaped bottom are provided with steam jackets for heating resin. Some quantity of inferior turpentine oil is added to the crude resin and the vat is covered with an airtight lid. The mixture is then heated by steam jackets and stirred by a helical belt mixer provided in the vessel. Subsequent cooling facilitates heavy impurities settling at bottom, while the lighter fraction accumulates at the surface and is removed by a ladle. The resin is then allowed to flow into a tank, leaving the sludge in the welter. Subsequently, resin is pumped for distillation in a still heated by a steam jacket. The lighter oil comes first, followed by heavier fractions during distillation. The steam injection is stopped and rosin is allowed to cool



Figure 1 Recurrent incisions on stem surface in the lip and cup method of resin tapping result in injuries (a) leading to fires and subsequent tree mortality (b). In the rill method of tapping (c), the application of chemical stimulants facilitates higher yields and the small superficial incisions are quickly healed by the natural process of bark growth (d).

for complete dehydration and evaporation of remaining traces of turpentine oil. The pine rosin obtained in this process is of much higher value than that obtained by direct heating.

Classification of Resins

The classification of resin is very complex. The resins occur in a pure to nearly pure state or as a mixture

with essential oils and gums. Furthermore, resins are produced from several plant species. Consequently satisfactory classification and grouping of resins or of the resin-yielding plants become difficult. However, a simplistic classification can be into three broad categories: (1) hard resins; (2) oleoresin; and (3) gum resins, as shown in Table 1.

Hard resins These are usually solid, more or less transparent, colorless, odorless, brittle substances with a little amount of essential oils and are the best source of raw material for varnishes. The most important commercial resins in this category are copals, dammars, mastic, and dragon's blood.

Copal Copal is characterized by its hardness and high melting point. Copal is soluble in alcohol and oils; the oil-soluble forms were also used in the manufacture of linoleum. Commercial copal is obtained from *Agathis*, a tree species of Southeast Asia, found in Malay, Indonesian archipelagos, and the Philippines.

Damar (dammar) Damars are solid resins, less hard but more durable than copal, and white to yellow in color. Damars are soluble in hydrocarbon solvents and drying oils. Damar for international commerce is obtained from dipterocarp trees in Southeast Asia. The sal (*Shorea robusta*) tree is tapped in India to obtain damar. Its main use is in the manufacture of paper, wood varnishes and lacquers, and paints. Minor uses include manufacture of inks, polishes, and water-resistant coatings. In India, sal dammar is widely used as incense and in the indigenous system of medicine.

Mastic Mastic is obtained from *Pistacia lentiscus*, a small tree of the Mediterranean region. Bombay

mastic is obtained from *P. cabulica*, occurring in Afghanistan, Baluchistan, and Gilgit (Kashmir). Mastic is produced in the form of small tears, pale yellow in color, clear and glassy in nature, and is liable to fracture. Its age-long use in Arab countries has been for chewing as a mouth freshener and to help preserve the teeth and gums. Its aromatic properties also make it suitable as a flavoring agent for alcoholic beverages. In the past, it was also used in the manufacture of high-grade varnishes for paintings, and for medicinal purposes.

Dragon's blood The plant sources of dragon's blood are *Daemonorops* spp. (Southeast Asian rattan), *Dracaena* spp., and *Croton* spp. *Daemonorops didymophylla* bears bunches of scaly fruits, which are covered with red resin. The major production of this resin comes from the islands of Sumatra and Borneo and some parts of peninsular Malaysia. The resin of commerce is in the form of powder, granules, sticks, or friable lumps with a deep dull red color and its use is largely confined to very specialized markets, such as violin varnish.

Oleoresins Oleoresins contain a considerable amount of essential oil in addition to resinous materials and have a distinct aroma and flavor. Among the oleoresins used in commerce, turpentine, balsam, copaiba, and elemis are prominent. The distinction between these groups is very slight and often confusing.

Turpentine Turpentine is oleoresins obtained almost exclusively from coniferous trees. For commercial purposes, crude turpentine is obtained by tapping trees of *Pinus* spp. On distillation, oleoresins

Table 1 Resin types, resin-producing species, and main resin-producing regions

Resin type	Main genera	Plant family	Main producing region
Hard resins			
Copal	<i>Agathis</i>	Araucariaceae	Southeast Asia
Dammar	<i>Shorea, Hopea, Vatica, Vateria</i>	Dipterocarpaceae	Southeast Asia
Mastic	<i>Pistacia</i>	Anacardiaceae	Mediterranean
Dragon's blood	<i>Daemonorops</i>	Palmaceae	Southeast Asia
Oleoresins			
Turpentine	<i>Pinus</i>	Pinaceae	Southeast Asia, Europe, USA
Benzoin	<i>Styrax</i>	Styracaceae	Southeast Asia
Styrax	<i>Liquidambar</i>	Hamamelidaceae	Asia Minor, Central America
Peru/tolu balsams	<i>Myroxylon</i>	Leguminosae	Central and South America
Copaiba	<i>Copaifera</i>	Leguminosae	South America
Elemi	<i>Canarium</i>	Burseraceae	Southeast Asia
Gum resins			
Asafoetida/galbanum	<i>Ferula</i>	Umbelliferaceae	Asia Minor
Gambose	<i>Garcinia</i>	Sapotaceae	Siam, Indochina, India, Ethiopia
Myrrh	<i>Commiphora</i>	Burseraceae	Somalia, Arabia
Frankincense	<i>Boswellia</i>	Burseraceae	Southern coast of Arabia, Northeast Africa

yield the essential oil or spirits of turpentine and the solid residue is called rosin. Turpentine and rosin are one of the major forest-based industries in the world. Rosin has a variety of uses in industry, in the paper industry (paper sizing), printing-ink industry, paint and varnish industry, leather industry, soap industry, and in the production of batteries, synthetic rubbers, perfumes, joysticks, fireworks, and adhesives. Turpentine oil is one of the basic raw materials for chemicals for a wide range of industries such as paints and varnishes, polishes, aromatic chemicals and pharmaceuticals, soap, and perfumery. Its products are also used in the manufacture of synthetic rubber, waxes, insecticides, and germicides.

Principal sources of oleoresin Out of 100 species of pines, only a few dozen are being tapped commercially as a source of crude oleoresin for rosin and turpentine production. In others, the poor yield or quality of resin makes tapping uneconomic. More than three-quarters of pine oleoresin is obtained from *P. palustris*, *P. elliotii* (USA), *P. sylvestris* (Russia and Northern Europe), and *P. pinaster* (France, Italy, Portugal, and Spain). The principal sources for commercial production of oleoresin are listed in Table 2.

Benzoin Benzoin is obtained from trees of the *Styrax* species native to Southeast Asia. There are two types of benzoin of commerce: Siam benzoin is obtained from *Styrax tonkinensis* and Sumatra benzoin from *S. benzoin* and *S. paralleloneurus*. Fresh Siam benzoin is semisolid but soon hardens to form brittle drops, often translucent, and yellowish-red to brown in color. Sumatra benzoin also hardens to form solid drops. Both are traded as solid blocks and are used in aromatic chemical industries such as expensive delicate perfumes. Sumatra benzoin is widely used in pharmaceutical preparations, as inhalations for the treatment of catarrh and as antiseptics. In China, it is also used in traditional Chinese medicine.

Table 2 The principal sources for commercial production of oleoresin

Species	Resin-producing countries
<i>Pinus elliotii</i>	Brazil, Argentina, South Africa, USA, Kenya
<i>P. massoniana</i>	People's Republic of China
<i>P. kesiya</i>	People's Republic of China
<i>P. pinaster</i>	Portugal
<i>P. merkusii</i>	Indonesia, Vietnam
<i>P. roxburghii</i>	India, Pakistan
<i>P. oocarpa</i>	Honduras, Mexico
<i>P. caribaea</i>	Kenya, South Africa, Venezuela
<i>P. sylvestris</i>	Russia
<i>P. halepensis</i>	Greece
<i>P. radiata</i>	Kenya

Styrax *Styrax* or storax is a balsamic oleoresin extracted from the genus *Liquidambar*. Asian styrax is obtained from *L. orientalis* of Asia Minor and American styrax from *L. styraciflua* of Mexico and Central America. Asian styrax is a semisolid, sticky brown substance. American styrax is usually darker but cleaner than Asian styrax. Both contain cinnamic acid or derivatives of cinnamic acid, whereas American styrax has a typical balsamic odor masked by a styrene-like odor. On distillation, both types of styrax yield an essential oil which is widely used in perfumery. Styrax is also used in pharmaceutical preparations, particularly in bronchial medicine.

Peru and tolu balsams Peru and tolu balsams are oleoresins, obtained as exudates from the *Myroxylon* tree, which is native to Central America and northern parts of South America. Balsam of Peru is obtained from *Myroxylon balsamum* var. *pereiraie* (syn. *M. pereirae*), a tree of Central America. Balsams contain benzoic or cinnamic acid and are highly aromatic. True balsam contains much less oil than turpentine. Balsam yields essential oils on distillation, which is used in perfumes as a fixative and in medicine as a mild antiseptic for treating cutaneous disorders and in the preparation of expectorants.

Copaiba Copaiba is obtained from certain Amazonian species of *Copaifera*. This resin yields copaiba oil on distillation. Crude copaiba balsam is a clear, pale yellow in liquid form. It darkens and becomes less fluid on prolonged storage or exposure to air. It is employed in pharmaceutical preparations, mainly as an antiseptic and anti-inflammatory agent. Copaiba oil is one of the ingredients used in shampoos, soaps, and cosmetics. While *C. guianensis*, *C. multijuga*, and *C. reticulata* are the principal sources of copaiba in Brazil, the major production in Colombia, Venezuela, and Guyana is from *C. officinalis*.

Elemi Elemi is a resinous product obtained from *Canarium* species in the Philippines and Manila. Manila elemi is soft and fragrant and is obtained from the trunk of *C. luzonicum*. Fresh elemi is oily and pale yellow or greenish in color, but becomes hard on exposure to air. It has a balsamic odor and a spicy, rather bitter taste. Distilled oil from elemi is used in the perfume industry. It is also one of the ingredients in the preparation of lacquers and varnishes.

Gum resins These are mixtures of gums and resins and exhibit the characteristics of both. Gum resins also contain a small amount of essential oils and are usually produced by plants of dry arid regions. The important gum resins are gamboge, asafoetida, myrrh, and frankincense.

Asafoetida This plant exudate is obtained from *Ferula asafoetida* species, which occur in Afghanistan, Iran and Turkey. The product is obtained by cutting the stem of the shrubby plant close to the ground (prior to the flowering stage) to expose the taproot. A small quantity of latex exudes and this is collected every few days. Sometimes the root is sliced every few days to produce more exudate. Asafoetida has a strong odor and a bitter acrid taste due to the sulfur compounds present in the essential oil. It is used throughout Asia in spice blends and as a flavoring agent for meat sauces, pickles, curry and other food products, and as a medicine. Since it is so strong in taste and odor, asafoetida is often blended with diluents such as starch and flour and is sold in compounded form.

Galbanum Galbanum is obtained from *Ferula galbaniflua*. The natural distribution of this species is in Iran and northwest India. The oleoresin is obtained by making an incision or cuts on the stem and the resultant exudate is an orange-yellow gummy fluid, which hardens on exposure to air. Like asafoetida, it is also often mixed with extraneous matter. It has a tenacious and powerful aromatic odor. The essential oil contains a number of sulfur compounds. It is used in medicine as well as to a limited extent as a perfume fixative.

Gamboge This is a hard, brittle, yellow gum resin produced by several species of *Garcinia*, specially *G. hanburyi* of Siam and Indochina and *G. morella* of India. It is used to color golden lacquers, as a watercolor pigment, and in medicine.

Myrrh This is the myrrh of antiquity, used in incense, perfume, and in embalming. One of the oldest and the most valuable gum resins, it occurs in two forms. The first type is derived from *Commiphora myrrha*, a large shrub or a small tree of Ethiopia, Somalia, and Arabia. The second type is sourced from *C. erythraea*, an Arabian species of similar appearance.

Frankincense or olibanum A fragrant gum resin obtained from the stems of *Boswellia* species, specially *B. carterii*, native to northeastern Africa and the southern coast of Arabia, its principal use is as incense in Roman Catholic and Greek churches.

Latex

Natural latex is a hydrocarbon polymer obtained from the sap of a number of plants. It is usually white, but rarely buff-yellow to grayish in color.

Latex contains 30–40% rubber and the rest are nonrubber constituents such as proteins, amino acids, starches, sugars, organic acids, resins, gums, tannins, pectin, and minerals. Nonrubber constituents stabilize the rubber particles, which are otherwise in a state of continuous motion known as Brownian movement. Further details on the history and production of latex are given elsewhere (see **Paper-making: Paper Raw Materials and Technology**).

Palm Oil

History

The history of palm oil can be traced back to the days of the Egyptian pharaohs 5000 years BC. It has been used for a very long time for food, medicine, and industrial purposes. The palm oil of commerce is obtained from fruits of the tree *Elaeis guineensis*. This species is a native of West Africa and was introduced to Malaysia in the beginning of the twentieth century. Most of the introduced plants in Malaysia were obtained in 1884 from four palm trees growing at the botanical gardens in Bogor. Commercial production started in 1917 in Malaysia. Indonesia and the Philippines have also started massive palm oil plantation programs.

Next to soybean, palm oil is the most important vegetable oil in world vegetable oil trade. Tree species such as *Cocos nucifera* (coconut) and *Elaeis guineensis* (African palm oil) are major species, which are commercially cultivated throughout tropical regions for palm oil production. Two types of oil are obtained from the palm fruit: mesocarp oil and endocarp (kernel) oil. African palm oil is a source of both types of oils, the mesocarp and the kernel each containing about 50% oil. Palm oil is also obtained from the following tree species:

- *Jessenia bataua* occurs in North and South America, including Panama and Trinidad. Its fruit is a source of oil. The composition of its oil is similar to that of olive oil.
- *Bactris gasipaes* (Pejibaye palm) has great potential as a crop in humid neotropics for starch, protein, oil, and carotene. Its mesocarp yields 40–60% oil on a dry-weight basis.
- *Attalea colenda* is a native of the coastal plains of western Ecuador. The oil content of the seed is 56.9% on a dry-weight basis. This palm oil has a high concentration of lauric acid. Its kernel is similar to coconut oil and kernel oil of African palm oil.
- *Phytelephas aequatorialis* (Tagua palm) the interior mesocarp has 22% fat, and is rich in linoleic acid (21%).

Uses

Palm oil is used in food, chemical, cosmetics, and pharmaceutical industries. It is considered best for manufacturing solid-fat products. Palm oil olein and stearin are used worldwide in making margarine, shortening, and confectionery, and in frying snack foods. It is a cost-effective option as it does not require an expensive hydrogenation process for solidification. Palm oil has a high content of natural antioxidants and its stability at high temperatures makes it excellent as a deep-frying medium. It also gives fried products a longer shelf-life, while its bland taste brings out the natural flavors of food.

Palm oil is also used in the manufacture of soaps, detergents, and other surfactants. It is a good raw material for producing oleochemicals, fatty acids, fatty alcohols, glycerols, and derivatives for the manufacture of cosmetics, pharmaceuticals, household, and industrial products. Oleochemicals manufactured from palm oil and palm kernel oil are now popular for the manufacture of environmentally friendly detergents as they are readily biodegradable.

Nutritional Value

Nutritional scientists have established that palm oil is cholesterol-free and does not require hydrogenation. Red and golden palm oil are the richest natural sources of carotenoids, including β -carotene, a potent antioxidant and precursor of vitamin A. Palm oils are natural sources of the antioxidant vitamin E constituents such as tocopherols and tocotrienols, which play a protective role in cellular aging, arteriosclerosis, and cancer. Further, palm oil contains linoleic acid, an essential fatty acid, which facilitates absorption and availability for use in the body.

Palm oil production

Each tree is capable of bearing about 10–12 bunches of fruit per year. The number of fruits per bunch varies from 1000 to 3000 in mature trees. The average weight of each bunch varies from 20 to 30 kg. The fruit-producing life of the palm is around 20–30 years. The average yield of palm oil is more than $3700 \text{ kg ha}^{-1} \text{ year}^{-1}$ compared to $857 \text{ kg ha}^{-1} \text{ year}^{-1}$ for peanut and $389 \text{ kg ha}^{-1} \text{ year}^{-1}$ for soybean oil. World production of palm oil is 25.66 million tonnes. Malaysia and Indonesia palm oil production accounts for 20% of all world vegetable oil production. Some basic data on production, consumption, and world trade of palm oils are given in Table 3.

Table 3 World trends in plantation area, production, export, and import of coconut and palm oils

<i>Parameter</i>	<i>Palm oil</i>	<i>Coconut oil</i>
Area planted (million ha)	6.5	11.9
Production (million tonnes)	25.66	10.0
Export (million tonnes)	14.2 ^a	1.16 ^c
Import (million tonnes)	8.89 ^b	1.3 ^d

^aIndonesia and Malaysia.
^bEurope, Middle East, China, India, and Pakistan.
^cPhilippines.
^dEurope and USA.

Future Directions

There has been a general decline in the use of latex and resins in the world in the last century. This is due to the preference of industry for raw materials which are of consistent, predictable quality and are not subjected to the vagaries of weather, insect pest, disease, and political stability in producing countries, and which are available at an attractive price. In many cases the synthetic alternatives meet these needs and are also technically superior to the natural products they replace. However, certain gums, resins, and latex are still being used, either due to their functional properties, which synthetics cannot meet, or due to their lower price compared to synthetics. These observations are, however, limited to the larger consumer markets at a global level and essentially the natural products described in this article do contribute enormously to local, regional, and national economies. Consequently, this group of non-wood forest products has great potential in alleviating poverty and in the sustainable management of natural forests in developing countries. Therefore, there is a need to maintain quality and improve it in order to retain and increase the markets of these natural products. This will require focused efforts to improve, standardize, and catalog the collection, harvesting, and postharvesting techniques. This will facilitate increased yields and minimum damage to forests, thereby adding incentives to collectors in terms of green and sustainable marketing. In conclusion, there are good grounds for optimism that, despite recent changes in global markets, there will continue to be a demand for these natural products. There are opportunities in the producing countries, provided due attention is given to aspects such as quality control of the product, equitable utilization, and sustainable management of the resource.

See also: Medicinal, Food and Aromatic Plants: Forest Biodiversity Prospecting. **Papermaking:** Paper Raw Materials and Technology. **Silviculture:** Managing for Tropical Non-timber Forest Products. **Sustainable**

Forest Management: Definitions, Good Practices and Certification.

Further Reading

- Anonymous (1950) The Wealth of India- Industrial Series, Publication and Information Directorate, pp. 242–271. New Delhi, India: CSIR.
- Anonymous (1972) *Indian Forest Utilization*. Dehradun, India: Forest Research Institutes and Colleges.
- Anonymous (1973) *Processing of Natural Rubber*. FAO Agricultural Services Bulletin, no. 20 Rome: Food and Agriculture Organization.
- Balick MJ (ed.) (1988) The palm-tree of life: biology, utilization and conservation. *Advances in Economic Botany* 6: 1–282.
- Balick MJ and Beck HT (eds) (1990) *Useful Palms of the World: A Synoptic Bibliography*. New York: Columbia University Press.
- Basu SK and Chakraverty RK (1994) *A Manual of Cultivated Palms in India*. Calcutta, India: Botanical Survey of India.
- Chaudhari DC (1995) *Manual of Rill Method of Resin Tapping from Pines*. Dehradun, India: Indian Council of Forestry Research and Education.
- Coppen JJW (1995) *Gums, Resins and Latexes of Plant Origin*. Rome: Food and Agriculture Organization.
- Corner EJH (1966) *The Natural History of Palms*. Berkeley, CA: University of California Press.
- Data on Agriculture/Agricultural Production-Primary Crops/Natural Rubber*. FAOSTAT- FAO statistical databases. Available online at: <http://apps.fao.org>.
- Hillis WE (1987) *Heartwood and Tree Exudates*. Berlin: Springer-Verlag.
- Howes FN (1949) *Vegetable Gums and Resins*. Waltham, MA: Chronica Botanica.
- Johnson DV (1998) *Tropical Palms*. Rome: Food and Agriculture Organization.
- Jones DL (1995) *Palms Throughout the World*. Washington, DC: Smithsonian Institution Press.
- Mantell CL (1950) The natural hard resins: their botany, sources and utilization. *Economic Botany* 4: 203–242.

socioeconomic development of the producing countries. Until the start of World War II natural rubber was the sole supply of an elastic material. Since the 1950s it has had to compete with a variety of oil-derived synthetic rubbers; nevertheless natural rubber has managed to establish good markets in products that require natural rubber's specific properties. The obvious environmental advantages which natural rubber possesses over the synthetic rubbers have never translated into financial advantage: both kinds have for decades suffered, like most industrial raw materials and agricultural commodities, from poor prices. Despite this, producing natural rubber remains the main and often the sole source of family income for millions of small farmers around the world.

History

Natural rubber is found in the form of latex in at least 2000 species of plants: these include *Hevea* spp., *Manihot*, and *Castilloa* from tropical America; *Landolphia* and *Funtumia* from Africa; and *Guayule* from Russia. There is only one rubber-bearing species of commercial significance – *Hevea brasiliensis* – a native of the Amazonian (mainly Brazilian) rainforest.

Hevea is widely distributed in the rainforest, a few trees per hectare, and rubber had been extracted by forest-dwellers from these trees for centuries for the manufacture of playballs and religious artefacts. During the eighteenth century several European explorers noted the existence of the tree and its product. In England, the eminent chemist Joseph Priestley observed the ability of the product to erase pencil marks and gave it the name 'rubber.' It is odd that this name has persisted in the English language for it relates to a property of the material that is of little use. The name in most other languages (e.g., caoutchouc, Kautschuk) is more apt, stemming from the Tropical American Indian *cachuchu*: 'weeping wood.' The older English name 'india rubber' represents a misunderstanding of rubber geography.

With the development in the mid-nineteenth century, mainly in Britain and the USA, of technologies (shaping, vulcanization) for converting the raw material into useful products, the demand for natural rubber started to grow so fast that the supply from Brazil was proving inadequate, despite savageries inflicted on forest rubber-gatherers, and the price was rising excessively. During the 1860s Sir Clement Markham of the India Office (UK), who had been responsible for transferring the quinine-bearing plant *Cinchona* from tropical America to organized plantings (plantations) in India, had the inspiration of

Rubber Trees

P W Allen, Harpenden, UK

© 2004, Elsevier Ltd. All Rights Reserved.

Introduction

The forest tree *Hevea brasiliensis*, native to the Amazonian rainforest, has been grown in Asia and Africa for over a century to produce natural rubber, a raw material used for the manufacture of a range of products, especially tires. Production and export of natural rubber has played a major role in the