came as a serious blow to the US and her allies and this, in a large measure, led to the exploitation of many other sources of natural rubber, including the Russian dandelion (*Taraxacum kok-saghyz* Rodin-Asteraceae), the Mexican guayule (*Parthenium argentatum* Gray-Asteraceae) and *Cryptostegia* spp. (Asclepiadaceae). The War also provided a stimulus to the synthetic rubber industry. Among the most important synthetics are the butadiene styrene copolymers, the various butadiene copolymers, the chloroprene polymers (neoprene), the polysulfide polymers (thiokol) and plasticised vinyl chloride and a few others. Synthetic rubber equalled natural rubber in world output in the early 1960s and moved ahead thereafter. Despite the competition from synthetic rubber, natural rubber continues to occupy an important place where elasticity, resilience and tackiness are required.

Para Rubber Tree

Hevea brasiliensis **(Willd. ex Adr. de Juss.) Müell.-Arg. (n = 18)**
Family: Euphorbiaceae

Hevea brasiliensis, a native of the tropical rain forests of the Amazon Valley, is a tall tree attaining a height of about 20 m. The trunk is 2-3 m in girth and bears a spreading or conical leaf canopy at the top. The leaves are a trifoliate compound with long petioles and the leaflets are shortly stalked and elliptic to obovate with an acuminate apex. The flowers are small, green and sweetly scented, borne in pubescent panicles with female flowers at the top and males lower down (Figure 14.2). The fruit is a tripartate capsule, containing one seed in each compartment. At maturity, it dehisces explosively and noisily, the seeds being scattered to a distance of about 10-12 m. The seeds are variously speckled and rich in oil that is quite similar to the linseed oil (Figure 14.3).

The latex vessels do not run precisely vertically but in anti-clockwise spirals to the right at an angle of 30° from the perpendicular. They are arranged in concentric rings in the bark alternating with the rings of secondary phloem. The vessels are laterally interconnected with each ring, but the connections are disrupted as the trunk increases in circumference. Latex vessels are more numerous in the inner bark than in the outer (Figure 14.4). To obtain maximum yield during tapping, the bark must be cut as close to the wood as possible without damaging the delicate growth layer–the vascular cambium.

PRODUCTION

In 2012, Asia dominated the world supply of natural rubber, accounting for more than 90 per cent of the world production of 11 445 176 metric tonnes. The five largest natural rubber producing countries, in the order of importance, were Thailand (3 500 000 metric tonnes), Indonesia (3 040 000 t), Malaysia (970 000 t), Vietnam (863 773 t), and India (805 000 t) – the first two contributing around 60 per cent of the world's production. The other natural rubber producers were China, Côte d Ivoire, Brazil, the Philippines, Myanmar, Sri Lanka, Nigeria, Guatemala and Liberia. The major exporting countries were Thailand, Indonesia, Malaysia, Vietnam, Singapore, Sri Lanka and Cambodia. China continues to be the largest consumer of natural rubber in the world, accounting for nearly 37 per cent of the world consumption of natural rubber. The other rubber consuming countries are India, Malaysia, the US, Western Europe and Japan.

The production in India is concentrated mainly in the states of Kerala (Kottyam and Quilon districts), Tamil Nadu and Karnataka.

The trees are ready for tapping when they are about six or seven years old. At the first tapping, only a small amount of viscous latex exudes but the yield increases progressively and reaches full productivity at the age of 12. The trees are abandoned after 25-30 years when they are no longer economically profitable.

TAPPING AND PROCESSING

Rubber collectors of the Amazon Valley, known as 'seringueiros', originally gathered latex by cutting down the wild trees of *Hevea*, but later tapped them by making random wounds with the help of crude heavy hand axes or hatchets (the machadino method). Although care was taken not to injure the growth layer, damage was not uncommon. Such ruthless tapping not only disfigured the trees but also made them vulnerable to insect attack and wood rot. At the height of the rubber boom between 1870 and 1911, small tapping knives with a U-shaped head had been introduced and a series of separate parallel cuts were made into the trunk (Amazonas method). In contrast to the modern day tapping techniques, early systems were, thus, extremely wasteful and inefficient.

In the early days, coagulation of latex was accomplished by pouring the fresh latex over the already air-dried coagulum sticking to a long pole and rotating it over the smoke arising from a cone over a smouldering fire. The process was repeated until a gigantic ball of rubber weighing 70 to 90 kg was obtained. The fruits of the palm, *Attalea excelsa* Mart., were especially prized for rubber smoking as they yielded a dense smoke containing acetic acid, creosote and tar. In some areas, paddles (flattened sticks with a long handle) were dipped into a bowl of rubber-milk and each layer was then smoked.

In highly systematised plantations in the Far East, on the other hand, the tapping and processing are scientifically managed. In our present day tapping systems, a thin shaving or paring of bark, 1.25-1.50 mm in thickness (excision method), is removed at regular intervals rather than making a series of vertical incisions in the bark as practised by the native people in Brazil.

Depending on the type and extent of the cuts, three different methods of tapping are recognised, V-cut system, herring bone system and spiral panel system, also known as Jebong system. The first two systems are the forerunners of the modern left spiral cut and were extensively used in the early days of the rubber plantation industry. In the V-cut system, two slanting incisions are made as the two arms of V and at the bottom of their junction, metallic spouts made of either zinc or iron are inserted to conduct the latex into the receiving cup.

In the herring bone system, a number of oblique cuts, all converging to a vertical line, are made into the bark. These tapping cuts may be on both sides of the line, or only on one side. The latex runs down the cuts into the central one that conducts it to the cup placed at the bottom.

In the spiral panel system, a typical cut at an angle of 30-35 ° is made from the upper left to the lower right, half way around the tree (half spiral panel) or completely around the circumference of the trunk (full spiral panel). A specially designed Jebong's knife of high-quality steel is used. The knife has a V-shaped head, which can be adjusted to cut the proper thickness of bark (about 1 mm). The latex vessels are thus, severed transversely. Nowadays most rubber in the Far East is tapped on a single half spiral cut (Figure 14.5). Tapping is invariably started in the early hours of the morning when the flow of the latex is copious owing to high turgor pressure. It slackens as the time passes by and finally stops at midday. Latex runs down the channel of the cut to a spout and into a small receptacle to which a few drops of an anticoagulant such as ammonia, formaldehyde, or sodium hydroxide is added. The yield of latex can be increased, sometimes as much as 30 per cent, by the application of growth hormones such as 2, 4-D and 2, 4, 5-T just below the tapping cut. During each tapping, coagulated latex on the cut is removed by hand and kept separately as 'scrap', which on processing yields rubber of inferior grade.

The trees are tapped every other day but often are given rest after heavy tapping, during foliage drop or rain. Each subsequent cut is made immediately below the previous one. After the tapping has reached the ground level on one side, the opposite side is worked. If the early tappings are carefully done, new bark regenerates in the region of the tapped panel because of the meristematic activity of the underlying cambium and is ready for tapping again.

Lower panels give more yield than the higher panels. Tapping is generally started at 2 m or more above the ground and about 15 cm of the trunk bark is tapped during a year. In this way, it normally takes 10-12 years to work one side, and thereafter the other side is tapped.

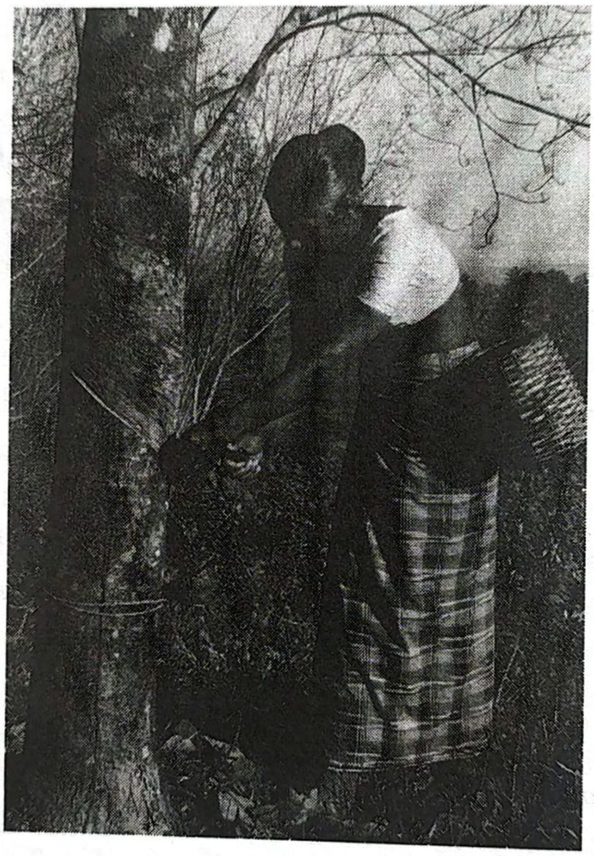

Figure 14.5 Half spiral panel system of tapping *Hevea* latex. With the help of a special Jebong's knife, the bark is pared off (excision method) deep enough to cause the latex to flow without damaging the tree.

A recent improvement in the tapping system is to make incisions upwards on the panel rather than downwards. Studies have shown that the cuts opened every fourth day on the upward-cut system give yields as good as those obtained by opening cuts every third day on the downward-cut system.

To maintain a high-quality of rubber products, scrupulous cleanliness is observed from the tapping stage until the latex reaches the processing unit. Collecting vessels, spouts and buckets are kept free from dust, bark particles, scrap rubber and other foreign matter.

The rubber is shipped either as a concentrated liquid latex or in a solid form. For concentration purposes, the latex after having been sieved is either centrifuged or treated chemically with alginates that cause the rubber particles to swell and rise to the top like the cream in a bottle of milk (creaming process). Water and other non-rubber constituents are drained off the processing tank. An anticoagulant is added to the concentrated mass of latex, which is then exported in drums.

To prepare solid rubber, the strained and diluted latex is transferred to large aluminium tanks to which acetic or formic acid is added (2 kg of acetic acid or 1 kg of formic acid to 400 kg of rubber latex). As a result of this treatment, the tiny rubber particles, dispersed throughout the latex, clump together on the top as a soft, white spongy mass. Certain chemicals may be added to prevent fungal growth and lighten the colour of the finished product. This soft coagulum or slab, after washing, is passed through a succession of rollers to squeeze out the excess water and also to flatten it to a desirable thickness (about 3.0 mm). It is also air-dried, thus producing sheets of 'crepe rubber'. Quite often, the sheets are smoked by exposing them to the pyroligneous acid vapours from the burning wood. The smoked product is known as 'sheet rubber'. Smoked sheets are translucent, amber or brown coloured, elastic and durable. Most of the rubber is exported in this form. The dried rubber must be broken down in a rubber mill (milled) before chemicals can be mixed.

A recent innovative approach is to ship raw rubber in a compressed granular form ('heveacrumb') rather than as a smoked sheet. Many methods have been devised to produce it, but the Pulvatex (Stam) and Mealorub processes are most commonly used. In the former method, the latex containing an appropriate volume of di-ammonium phosphate (a protective colloid), is sprayed using a centrifugal device into a heated air stream. The tiny spray droplets dry-up rapidly, forming 'crumb' or powdered rubber. In the Mealorub method, the fresh latex is mixed with stabilisers and other chemicals, such as sulphur, zinc oxide and other vulcanising substances, to prolong its storage life. Alternatively, it is heated at 80 °C for two and a half hours, until the whole mass disperses uniformly. This latex, on coagulation, yields a crumbly mass, which is then dewatered, mechanically disintegrated and air dried. A higher premium is offered for this product in the international market.

In a third method, the 'Heveatex' method, casein is first added to the latex, which is then flocculated by zinc chloride. In the 'Nitrite Crumb' method, sodium nitrite is used in the place of casein and an acid does the coagulation. The crumbly mass obtained by these methods is dewatered, disintegrated and dried as usual.

UTILISATION

Rubber is an indispensable item in the modern industrialised society. Nearly 50 000 different products are made directly or indirectly from rubber. Approximately 70 per cent of rubber production is consumed in the manufacture of tyres, tubes and other articles associated with the automobile industry; about six per cent is utilised for footwear and nearly four per cent for wire and cable insulation. Other miscellaneous manufactured articles include rubberised fabric, raincoats, household and hospital supplies (such as sheets, hot water bags, surgeon's gloves, etc.), shock absorbers, washers, gaskets, belts, hoses, sports goods, toys, erasers, adhesives, rubber bands and a host of other auxiliary products.

Hard rubber, vulcanite or ebonite (highly sulphurised rubber) is used in the electrical and radio engineering industries, for protective lining in chemical plants and also in the fabrication of battery boxes, fountain pens, barrels, tobacco pipes, telephones, combs, etc.

Concentrated latex is used for most dipped goods, such as gloves, balloons and contraceptive appliances. Sponge rubber from foamed latex is used in upholstery, for example, seating, cushions, mattresses, pillows; in life belts and in carpeting. Rubber powder, along with bitumen, is used for road surfacing.

Rubber also finds its use in all sorts of military clothing, pressurised suits for aircraft personnel operating at high elevations, frogmen's suits for divers spending considerable time underwater and insulated suits to keep men in arctic zones warm.