HEVEA RUBBER – PAST AND FUTURE

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INTRODUCTION

A tree gum used by natives to make bouncing balls caught the attention of the first European visitors to the New World. They took samples of this gum back to Europe, where the English, upon discovering that it could be used to rub out marks made on paper, called it rubber. It still bears this name in all English-speaking countries. From this humble beginning as a New World curiosity, natural rubber has developed into an important crop for the lowland tropics. About 3.4 million metric tons of it are produced annually and its uses are legion. I shall mention some of the events that have made it possible for rubber to reach its present importance in agriculture, industry and world trade.

The discovery of vulcanization in 1839 by the American chemist Charles Goodyear was the first big step toward improving the properties of crude rubber. Goodyear, whose memory is honored in the name of one of the major rubber companies, heated rubber with sulfur and produced a product that was vastly superior to the raw material. His vulcanized rubber was less sticky than raw rubber, had greater strength and more resistance to heat and cold, and was altogether more suitable for a multiplicity of purposes. Goodyear's landmark discovery was soon followed by innovations in the fields of solvents, additives, compounding, processing, molding and curing.

When the auto began to roll on pneumatic tires, it was clear that none of the wild tree sources would be able to meet the foreseeable demands for rubber. Rubber tree culture had somehow to be developed, and this brings us to the story of *Hevea brasiliensis* (Willd. ex A. Juss.) Muell. Arg., commonly known as the Brazilian rubber tree. It is native to the Amazon River basin and belongs in the Euphorbiaceae. The superior qualities of the natural elastomers produced by this tree have never been surpassed by any of the synthetic products.

Before proceeding with the story of *Hevea*, however, I wish to mention some of the other rubber-producing plants that have played a part in the story of rubber. The rubber balls which Columbus saw the Indians using in Central America and the Caribbean almost certainly were made from the latex of trees of one of the species in the genus *Castilla*, which belongs in the Moraceae, or mulberry family. The rubber balls seen by Cortez in Mexico may have been made either from *Castilla* or from the desert shrub known as guayule. Several of the *Castilla* species produce much more latex at a single tapping than any *Hevea* tree will yield. However, they will not produce such yields if tapped more frequently than once or twice per year. *Castilla* rubber is of good quality and wild trees of this genus contributed substantially to the rubber supplies of the United States during World War II, when every available wild tree was sought out and tapped. *Castilla* could almost surely be greatly improved as a rubber producer through research. Wild trees of this genus still supply rubber for the local rubber needs in the tropics (Fig. 1).

Guayule, *Manihot, Funtumia, Cryptostegia,* Russian dandelion and many other plants have been exploited for rubber to some extent in the past, especially in times of high prices, but in the long run none could compete with *Hevea*. Interest in guayule rubber has waxed and waned over the years and there has been a continuing production right up to the present

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Fig. 1. Tree of *Castilla elastica* in Nicaragua showing marks of recent excessive and destructive tapping. Even the exposed roots have been tapped. (Photograph by the author.)

day. Guayule culture is once again attracting attention because its competitive position has improved with the rise in cost of raw materials needed for making synthetic rubber, and it can grow and produce rubber under lower rainfall conditions than many other crops. Several of the rubber-producing plants mentioned above have an interesting history, but this paper will deal only with some highlights in the story of *Hevea*.

HEVEA MOVES TO ASIA

It is fitting that there should be a paper on *Hevea* in this symposium in 1976. It was in 1876, exactly 100 years ago, that Henry A. Wickham collected several basketfuls of seeds of *Hevea brasiliensis* in Brazil at a site along the Tapajoz River. Wickham succeeded in transporting these delicate, short-lived seeds across dense forest to Santarem and down the Amazon River 640 km to Belem. From there they were shipped across the Atlantic to the Kew Botanical Gardens in England. Some seeds were still viable upon arrival at Kew, and the records state that approximately 2700 seedlings were obtained.

Two thousand of the best seedlings were shipped in Wardian cases from Kew to botanic gardens in Ceylon, Malaya and Java. Some

Fig. 2. *Hevea brasiliensis* seedling tree being tapped by a variation of Ridley's system. The previous cut is reopened every third day by removing a thin strip of bark. The cut is made as deep as possible without actually wounding the cambium. Under conditions of proper tapping, the exploited bark is renewed and becomes available in due time for retapping. (Photograph by the author.)

reports state that the bulk of them went to Ceylon and that only 22 seedlings out of the total shipment reached Malaya. In any case, we know that the rubber trees in southeast Asia, millions of hectares of them, are derived from a very few plants of Wickham's original stock from the banks of the Tapajoz. A few seedlings from the original lot were sent from Kew to botanic gardens in other tropical locations, and some of these original trees still survive. I have been privileged to see and study one of them, now a magnificent tree that flourishes near the fern house in the Botanical Garden of Queen's Park in Port-of-Spain, Trinidad. Botanic gardens played a big role in establishing *Hevea* as a new crop, just as they have with a number of other new agricultural enterprises.

Several of the circumstances and outright accidents relating to the Wickham seeds will be of special interest to economic botanists. Wickham did not know it then, but it is now known that *H. brasiliensis* is the only *Hevea* species indigenous to the Tapajoz area where he collected. Had he collected elsewhere, he probably would have come up with seeds of one of the other less productive *Hevea* species, because he could not at that time have known enough about the genus to select only *Hevea brasiliensis*. Had he collected one of the other *Hevea* species, the development of rubber cultivation would have been delayed everywhere, perhaps by many decades.

In two other respects, however, Wickham's choice of collection site was less fortunate: 1) Yield potential of the Tapajoz populations of *H. brasiliensis* is lower than that of the populations found farther up the Amazon. This fact, not discovered and demonstrated until the 1940's, probably delayed the development of high-yielding trees by plant breeders in southeast Asia. 2) The Tapajoz population was all highly susceptible to South American Leaf Blight (SALB), the disease that to this day has thwarted, delayed or hampered all attempts to develop rubber plantings in the Western Hemisphere. This disease, caused by the fungus *Microcyclus ulei* (P. Henn.) Arx, was not recognized in Wickham's time. Polhamus (1) states in his book *Rubber* that it was clearly a stroke of luck that *Microcyclus* was not carried along with the seeds to Kew and thence to the Orient on the seedlings. If it had been, we can be sure that rubber planting in southeast Asia could not have succeeded, and the story of rubber would have been a very different one. To this day, SALB has not invaded the rubber plantings of either southeast Asia or Africa. When and if it does, it will surely cause major economic dislocations for the millions of people associated with the production of rubber. For more information about this vastly important disease, one should refer to Holliday's excellent paper (2) on this subject.

Successful transfer of the Wickham material from South America to the Orient, leaving SALB behind, was certainly the *first* big step in domestication of *Hevea*. Arrival of some of the Wickham seedlings at the Singapore Botanic Garden in Malaya set the stage for the *second* and equally important step, namely the development of a superior tapping system by Mr. H. N. Ridley. Ridley saw that the haphazard and destructive tapping methods used on wild trees would not do for a permanent plantation crop. After patient and brilliant work, he came up with an improved tapping system which caused minimal tree damage. It economized on bark consumption, allowed a tree to be tapped 100 or more times per year and greatly increased annual yields. His tapping method, with minor modifications, remains in use today (Fig. 2).

A recent successful innovation in the Ridley system is to tap upwards on the panel rather than downwards. Half-spiral cuts opened every fourth day on the upward-cut system are reported to be giving as good yields as half-spiral cuts opened every third day on the downward-cut system.

GENETIC IMPROVEMENT

Until the early 1900's, there was still was disagreement as to whether *Castilla, Hevea, Manihot* or some other plant should be chosen for cultivation on a large scale. The southeast Asian experience with the Wickham progenies soon made it clear, however, that *Hevea* was the best choice. It also became clear that yields per tree and per hectare would have to be improved. British, Dutch, French, and local specialists, and later North and South American scientists as well, all had a part in developing better planting stocks and improving culture of the trees. The first unselected Wickham trees had a yield potential no higher than 225 kg per hectare per year, even with Ridley's best tapping methods. Crosses between some of these original trees gave encouragement to the early workers in the form of vigorous progenies that out-yielded their parents. It has been suggested that a number, perhaps all, of the original Tapajoz seedlings were in fact inbreds, as a result of many generations of natural selfing of individual, isolated, wild forest trees, and that subsequent

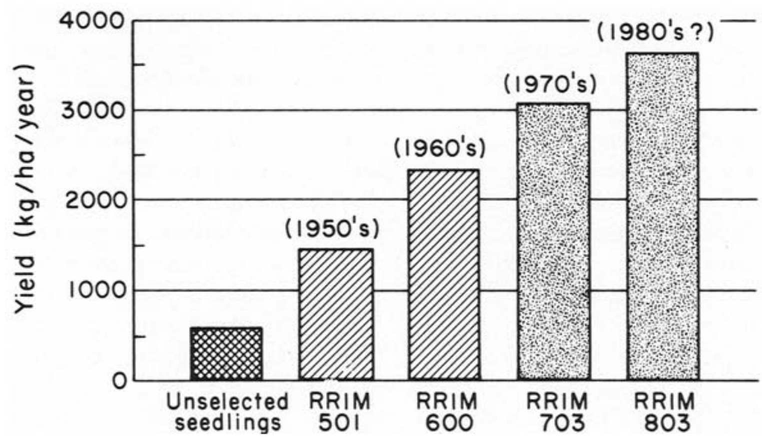

Fig. 3. Progress in breeding and selection for yield at the Rubber Research Institute of Malaya. (From Planters Bulletin, November 1975.)

crosses between seedlings from some of these natural inbreds produced progenies that exhibited heterosis. These early generation, vigorous seedlings offered promising stocks from which additional superior, higher-yielding trees and clones eventually were derived.

Bud grafting of *Hevea*, developed in Java by Dutch horticulturists, was the *third* great step in the domestication of this plant. Bud grafting made quick propagation possible and, to the extent desired, any superior seedling selection, and thus enabled growers to establish plantations of high-yielding clonal trees. Without a successful method for vegetative propagation, it would not have been possible to use genetically improved trees on a large scale. Over the years, improvements in bud grafting have been made, including its adaptation to very young seedlings and to crown budding, but the basic patch-budding method used is the same as that developed in Java.

Average plantation yields had risen above 400 kg per hectare by the 1930's and some experimental blocks of clonal rubber by that time were yielding approximately 1000 kg per hectare. More recent improvements have raised average commercial plantation yields to 1200 kg per hectare, and some plantations do better than 1600 kg. Planting materials with a potential above 3000 kg per hectare are now available (Fig. 3). In general, large plantations have better management and higher yields than the small holders' plantings. Yields of the latter tend to vary greatly, but there are examples of small holder yields equalling those of the best plantations.

In summary, we can note that genetic and agronomic improvements raised productivity of the *Hevea* tree more than tenfold above yields of the first trees produced from Wickham's original seed collection of 1876. So far as we are aware, none of man's other crops has an equal record in this respect and none has made as great an impact on civilization during the first 100 years of its domestication as *Hevea* has done.

HEVEA REBOUNDS TO TROPICAL AMERICA AND TO AFRICA

In the 1920's, high prices and threats of monopoly spurred new attempts by interests in the United States at plantations in South America and in West Africa. Plantings in Liberia, started by Firestone, prospered on the lateritic soils of that country and have contributed heavily to world rubber needs and to the Liberian economy. Production in Africa eventually spread from the large company plantations onto private, native holdings just as it did in southeast Asia. Today, approximately half the total production in both areas comes from small independent holders. Research sponsored by company plantations and by governments continues to provide improved plant materials and technology while the private growers today do most of the actual planting and production.

Attempts at planting in South and Central America did not go as well as those in Africa. The Ford Motor Company's plantations in Brazil, started in 1928, and those of Goodyear in Costa Rica and Panama, started in the 1930's, ended up as costly failures because of SALB. These companies were defeated in trying to plant the genetically improved stocks from southeast Asia because all of this material was highly susceptible to SALB. Furthermore, they quickly found not only that all the accessible Western Hemisphere material was low-yielding, but also that under monoculture conditions almost all of it was likewise highly susceptible to SALB. It was eventually clear that, inless special ecological zones unfavorable to SALB could be found in the Western Hemisphere, the only solution lay in a breeding program to combine high yield with SALB resistance. Even though these early and costly private company efforts produced little rubber, they were not in vain. They provided a base for cooperative rubber research among agencies of the governments of Brazil and other tropical American countries, the United States Department of Agriculture (USDA) and private rubber companies. This program, which started in 1940 and continued well into the 1950's, will be described in some detail because it opened important new chapters in the story of *Hevea*. It was the author's good fortune to be closely associated with this stimulating program for 12 years.

THE RUBBER CRISIS OF WORLD WAR II

It is hard for today's younger scientists to appreciate the critical situation our country faced in 1939 with regard to rubber. The war in Europe was enlarging, access to southeast Asian rubber was in peril, wild rubber production had almost ceased, stockpiles were inadequate, synthetic rubber capacity was insignificant, quality of known synthetics was inferior for most critical uses, and the necessary research had not been done to ensure successful establishment of Western Hemisphere plantings. This crisis sparked three programs that have greatly affected the story of *Hevea*: 1) the synthetic rubber program, 2) the Rubber Development Corporation, set up within the United States Department of Commerce to promote wild rubber collections, and 3) the Cooperative Rubber Research Program, which was led by the USDA.

1) The United States government's synthetic rubber program was an enormous success. It still is regarded as one of our country's major industrial achievements. Synthetic rubbers, poor in quality at first, were soon improved and special types were developed. The superior rubber molecule produced by *Hevea* is chemically *cis*-1,4-polyisoprene. It has a high degree of geometrical regularity, a molecular weight above 1 million and is not easily duplicated synthetically. However, one type of synthetic rubber was developed, synthetic polyisoprene, which is an approximation of the *Hevea* rubber molecule. The synthetics soon relieved the country from utter dependence on the dwindling stockpiles of natural rubber (NR) and on the meager supplies of wild rubber. By the end of the war, synthetic rubber (SR) was well established as an acceptable raw product. In fact, by this time, SR had several advantages over NR. The SR types could be designed for special industrial uses and supplied in standard uniform quality. Also, SR was not subject to uncertainties of long and costly ocean shipments.

The rapid capture by the synthetics in this period of a large part of the booming rubber market led some economists and others to predict the early decline of tree rubber as a world commodity. Events have disproved this prediction in that production of NR has in fact tripled since World War II. Over 3.4 million metric tons of NR are used annually, about one third of total consumption (Tables I and II). NR retains supremacy for some of the most demanding uses, such as airplane tires, which still contain 90 to 100 percent NR (Table III). Heavy-duty equipment tires for use in off-the-road conditions also require natural rubber because there is less destructive heat buildup with NR. Anyone who has seen the punishment given to tires of heavy construction equipment in rocky terrain will have to respect the toughness of this natural tree product. No man-made rubber has ever performed so well.

Botanists will be amused by the following definition, which used to be jokingly applied

TABLE I.
Basic Rubber Statistics, 1970
(*from* Malaysian Rubber Research and Development Board).

Region	Rubber consumption ('000 tons)	NR consumption ('000 tons)	NR share (%)
U.S.A.	2517	568	22.6
EEC	1859	701	37.7
Japan	779	283	36.3
Subtotal	5155	1552	30.1
Analysis total	3857	1240	
Free World Total	6755	2290	33.9
Centrally-planned countries total	(1845)*	700	(38)
World	(8600)	2990	(35)

*FAO estimate.

to some of the earlier, far from satisfactory, SR types: "Synthetic rubber is a wonderful material. It can be mixed in any proportion with natural rubber and the more natural one adds the better it is." Today it is not a question of NR *versus* SR, but one of NR *and* SR since both are needed. They are somewhat complementary and each also has certain preferential uses.

2) The Rubber Development Corporation (RDC) was set up to increase wild rubber production from all sources, almost regardless of cost, in order to augment dwindling NR stockpiles. This program was a successful cooperative effort between the United States and the tropical American countries. The valuable contributions of our tropical American neighbors in this work is well remembered by all who participated. After the war ended, RDC went out of existence, its job having been well done by providing the United States with many thousands of tons of wild rubber it could not otherwise have had. An extra dividend from the RDC work was the opportunity it gave for botanists and rubber specialists to penetrate into remote areas in the Amazon basin to study local *Hevea* populations and to obtain new germ plasm for research stations.

3) The USDA Cooperative Rubber Research Program was initiated in 1940 when an alarmed Congress decided that dependable sources of rubber had to be developed for the Western Hemisphere. USDA scientists who had experience in tropical agriculture, Dr. E. W. Brandes, Dr. R. D. Rands and Mr. L. G. Polhamus, were selected to organize and lead this work. Besides *Hevea*, the program also included guayule, Russian dandelion, golden rod and *Cryptostegia*. For *Hevea*, there was set up a superb, international tree crop improvement program, the goal being to develop commercial, high-yielding, disease-resistant planting stocks of *Hevea* for SALB-infested areas. A coordinated plan was devised to achieve this goal and despite the constraints of emergency wartime conditions, the program moved ahead. Surveys were made, central testing stations were established, clones and seeds were assembled, bilateral agreements were signed with 13 countries and plant scientists were hired and deployed to strategic areas.

By 1954, after 14 years of operation under a modest budget, and despite some major setbacks in the form of new and unexpected diseases, impressive progress had been made.

TABLE II.
Consumption and Market Share 1900-1970
(*from* Malaysian Rubber Research and Development Board).

Year	Total World rubber consumption ('000 tons)	NR consumption ('000 tons)	NR share of the market (%)
1900	53	53	100
1910	102	102	100
1920	302	302	100
1930	722	722	100
1940	1127	1127	100
1950	2339	1750	75
1960	4400*	2095	48
1970	8600*	2992	35

*FAO estimates, including SR consumed in centrally planned countries.

Several hundred clones with good levels of resistance to the two major leaf diseases had been developed, some of them with near-commercial yields. Areas in the Amazon basin with superior and useful germ plasm had been delineated. Methods for controlling SALB in nurseries had been developed. New techniques for speeding up the multiplication of scarce and new selections were developed, such as the practice of using very young seedlings of pencil diameter for rootstocks and use of the youngest green clonal growths as sources of scion buds. Advances were also made in the production and use of the 3-component tree, a tree consisting of a seedling rootstock, a high-yielding trunk clone and a disease-resistant canopy clone united into a single plant through bud grafting. These 3-part trees, the product of what we could call horticultural engineering, provided interim planting stocks, pending success with the longer-term genetic engineering approach. A full description of this program and its achievements is given by Rands and Polhamus (3). Discovery and development of resistance to SALB under this program can be considered a *fourth* great step in *Hevea* domestication.

Despite the program's many achievements, it became necessary by 1954 for the USDA to withdraw from it. The rubber crisis had ended and alternate uses for rubber research funds became more attractive. Formal closure of USDA's program, however, did not stop the flow of benefits to world natural rubber production that had come from it. Private companies and other agencies continued to make use of the experience, results and germ plasm that had been accumulated.

It was well understood in some quarters that commercial planting stocks with resistance to SALB would have to be used eventually in Asia and Africa. Even though SALB had not yet invaded these areas, it had been shown by the USDA and cooperators that these vast *Hevea* plantings consisted entirely of trees highly susceptible to SALB. Resistant clones could provide some insurance and protection in this precarious situation. Arrangements were made, therefore, for some of the best of the newly selected plant materials to be introduced into southeast Asia and later into Africa. This was the first significant infusion of improved *Hevea* germ plasm since the arrival of the original Wickham seedlings in 1877. *Hevea* production will be favorably affected for the next 100 years through the

TABLE III.
NR Share of Each End Use, Percent, 1970
(*from* Malaysian Rubber Research and Development Board).

Product	U.S.A.	EEC	Japan*
Types: car	12.5	22	28
truck/bus	55	75	50
tractor, etc.	30	60	n.a.
bicycle/m'cycle	10	30	63
aircraft	90	90	100
retreading	12	33	54
inner tubes	5	5	10
Latex products	22	33	n.a.
Belting)		30	52
Hose)	25	25	43
Footweat	25	35	44

*The Japanese figures are calculated directly from official statistics, quoted here without rounding off.

impact of this selected new Western Hemisphere germ plasm.

Technology that had been developed under the cooperative Western Hemisphere program was transferred also by USDA personnel who joined other agencies. We cite as one outstanding example the work of Mr. W. E. Manis, University of Michigan Botanist, who joined the USDA program in 1943 as a scientist with *Hevea* experience gained in Liberia and Brazil. Under USDA his work had included research and development with *Hevea* in Colombia, Nicaragua, Panama, and particularly Costa Rica where for 10 years he was in charge of the famous Los Diamantes Rubber Experiment Farm. Following his long USDA service, Manis' expertise became available to rubber projects in Nigeria, Sri Lanka, and Thailand, in which places he emphasized the importance of SALB and the proper uses of the new Western Hemisphere clones for disease control. Other examples could be cited if space allowed.

In the absence of a single coordinated program, progress has been slower than it otherwise could have been. Nevertheless as a result of the continuation of some phases of the research program, there are available today limited planting stocks which are suitable for use in some parts of the SALB-infested Western Hemisphere tropics. Ongoing research will produce still better ones. Ultimately stocks with a safe horizontal-type of SALB resistance may be developed.

RUBBER COMPANY RESEARCH AND DEVELOPMENT

The Goodyear Company conducted testing and development work in Guatemala and also opened a plantation near Belem, Brazil. They have continued to the present date working toward blight-resistant, commercial planting stocks using mainly special *Heavea Benthamiana* Muell. Arg. selections as sources of genes for resistance. However, they still find it necessary to use aerial spraying on their Brazilian plantation during the annual leaf-change period in order to control SALB and get good annual refoliation.

The Firestone Company, under the guidance of their Research Director, Dr. K. G. McIndoe, went on to develop an admirable program which has continued to the present time. They have concentrated on germ plasm from the Madre de Dios area of Peru where USDA scientists had found wild *Hevea* tree populations with high quality rubber, higher than average yield, and a notable level of re-

Fig. 4. Center row, seedlings from *Hevea pauciflora* × *H. brasiliensis*. On each side, seedlings of *brasiliensis* × *brasiliensis* parents. All of equal age growing on poor soils at Belterra on the Tapajoz River near Santarem, Brazil. (Photograph by the author.)

sistance to SALB. Using duo-clone breeding gardens and isolated seed fields on their plantations in Guatemala and Liberia, Dr. McIndoe conducted 15 years of rubber-tree breeding for Firestone, with high-yielding but susceptible clones from southeast Asia and resistant selections from the Madre de Dios area. Promising seedlings were tested for resistance, cloned and divided between Guatemala and Liberia, using an intermediate station in Florida for shipments in each direction. Over 2,500 clones have been transferred to date. The best are now in yield tests and some commercially suitable, blight-resistant ones have been identified. Firestone is also incorporating germ plasm of *H. pauciflora* (Spruce ex Benth.) Muell. Arg. into this breeding program as a means of broadening the genetic base for resistance to SALB. Some of the hybrids between *H. brasiliensis* and *H. pauciflora* have shown remarkable vigor and growth rates in tests on some of the poor soils of the Amazon basin (Fig. 4).

Since 1954 Firestone has developed in

Bahia, Brazil, in an SALB-infested area, a highly successful 6000 hectare plantation using *Hevea* selections that have some degree of resistance to SALB. Their production is approximately 1200 kg per hectare. They plan to augment the Guatemala-Liberia breeding project described above by doing a large amount of the future research and selection work on their Brazil plantation. By continuing this well conceived, interhemispheric rubber breeding project, Firestone will help to insure the future availability of safe planting stocks for use of small farmers in the developing countries of tropical America and Africa. Benefits will accrue also to the Asian small farmer in the form of insurance against SALB.

In 1954, the B. F. Goodrich Company, the only one of the big four U.S. rubber companies (Goodyear, Firestone, Goodrich and U.S. Rubber Co.) that had never engaged in natural rubber production, started a new plantation in Liberia. This change in course on the part of Goodrich was an interesting indication that SR was not a complete answer to industry's rubber needs. They developed an 8,000 hectare plantation in a part of Liberia well removed from the older Firestone plantings. This new Goodrich project benefited by having as its technical director Mr. William MacKinnon, who had had a long career in rubber in southeast Asia and also had served in the New World tropics under the Rubber Development Corporation and the USDA cooperative rubber program. He brought to the project knowledge and technology from all these sources.

Several other rubber companies have made recent and significant investments in rubber plantation development. Among these are Uniroyal, Michelin and Pirelli. Uniroyal, formerly called the U.S. Rubber Company, had started plantings in Sumatra as long ago as 1910 and later in Malaysia. In 1965, they began new developments in west Africa. Michelin is putting in new plantations in the Ivory Coast Republic. Pirelli has a plantation development near Belem in the state of Para, Brazil. While these developments have not included a strong research element on SALB similar to that made by Firestone, they have served to transfer advanced rubber technology into new areas.

The Brazilian government continued after 1954 with some parts of the original rubber program, and they have cooperated with U.S. and European companies in establishing tests and plantations in the Amazon and in Bahia. The Rubber Research Institute of Malaya (RRIM) is cooperating with the Brazilian government in continuing exchanges of rubber germ plasm, using a station in Trinidad for resistance screening. The RRIM is concentrating on sources of SALB resistance from *H. brasiliensis* populations other than the Madre de Dios material and also using *H. Benthamiana* and *H. pauciflora* as sources of resistance and vigor.

FUTURE OF HEVEA

Predictions that NR is on the way out are not heard any more. World markets take every ton of natural rubber produced. Price trends indicate that they would take more if it were available. It is estimated that consumption in the early 1980's may be 16 million metric tons with natural rubber supplying 37 percent of this, or 6 million metric tons. The world's present rubber plantings cannot supply 6 million metric tons. However, by replanting old areas with superior clones, plus extensive use of yield stimulants, plus some new plantings, a 6 million metric ton annual crop may be possible by the mid-1980's. Much of the land now devoted to rubber is not highly regarded for food-crop production, so no great diversion of land from rubber to food crops is likely to take place in the future, but there will be trends in this direction as human populations continue to rise. This can be countered in part by intercropping young rubber with food crops, a practice which, when properly controlled, can actually favor growth of the young rubber.

Production of the synthetic rubbers appears to have reached a point at which costs increase almost directly with increase in wage rates in the industrialized countries. This, coupled with the rising costs of the petroleum-based raw materials needed for manufacture of synthetics, can be expected to put NR in a better cost-competitive position than at any time in the last 25 years. Furthermore, there are some cost-reducing adaptations still to be widely employed in NR production, such as improved collection and processing of crude lump rubber and latex from small holders, and the more extensive use by small planters of higher-yielding new clones.

The strong trend toward use of radial tires is favoring greater use of NR. For best performance radials require a higher percentage of NR than has commonly been used in passenger vehicle tires since World War II.

Under conditions developing in the world today, it appears that *Hevea* as a crop for some of the developing countries holds more promise than it has held at any time in the past. As a tree crop, *Hevea* causes a minimum of damage to the environment and little, if any, soil degradation, in contrast with annual cropping and the slash and burn system, both of which have well known destructive effects on soils and environment in most parts of the humid tropics. The crop is well suited to the small or independent land holder. It is labor intensive and could help counter the disastrous migration from rural areas into city slums caused by a lack of employment opportunities in rural tropical areas. Rubber tapping is best done in the early daylight hours. This leaves time for production of food crops and other farming activities. Rubber is easily stored and is a readily salable export product for which the market is increasing. At the same time it is a prime material on which to base industrialization in the developing countries. A rubber plantation can produce rubber for 16 to 30 years before it has to be replanted. By that time, it will have a biomass consisting of 250 to 375 large trees per hectare which can be used for fuel, chipboard, pulp, or rough lumber. Proper use of this residue may cover costs of replanting a plantation with improved clones.

Expansion of *Hevea* culture in the Ivory Coast Republic of Africa is receiving expert guidance through cooperative efforts between French and Ivory Coast scientists and plantation experts. The best and most impressive young *Hevea* plantations I have ever seen were in the Ivory Coast a few years ago. Continuation of these high standards of development plus the scientific cooperation and backstopping from the excellent French rubber research groups will soon make *Hevea* an important crop in the Ivory Coast.

The Amazon basin, home of *Hevea*, is often mentioned as a logical place for extensive plantings. However, the disease problems are formidable, and it is known that extensive soil areas where *Hevea* grows wild are not suitable for plantation rubber. Another problem in some areas will be the early morning rains, which will interfere with tapping. Although *Hevea* occurs naturally throughout much of the Amazon basin, only a few wild trees may be found per hectare among a great mixture of other tree species. SALB does little damage to these scattered *Hevea* trees, but it becomes devastating when *Hevea* monoculture is attempted. Barring the unexpected discovery of a practical chemical control for SALB, *Hevea* culture in the Amazon basin cannot succeed unless it is based on planting materials with multiple-gene type of resistance, or a horizontal-type resistance to major strains of *Microcyclus ulei.* True immunity to SALB may not be found, but plantings with a canopy of clones that carry resistance factors of diverse origins can be expected to produce well in spite of SALB. Local testing of all new material will be required before it can be safely used in any area. Brazil has recently established at Manaos, in the heart of the Amazon basin, a center for research on rubber. Such a center may show the way to use selected parts of the basin for profitable rubber production and may help to restore this product to an important position in the Amazonian economy.

Many special plant-derived products are synthesized or even improved upon by the chemist soon after being discovered and thereafter are produced in a factory rather than by agriculture. *Hevea* rubber, as we have pointed out, has held its own against the best efforts of the chemists. It has remained economically competitive mainly because some of the NR producing countries maintained strong support for research and technology. RRIM, the world's largest single crop research institute, has been the leader in this successful fight to maintain *Hevea* rubber's strong position. The RRIM has made striking advances in breeding for yields (Table I). They now consider 5000 kg per hectare as a possible goal. Yield increases per tree, per hectare and per man hour, which have resulted from genetic improvement over the past 100 years, can be considered the *fifth* and most economically important step in the history of *Hevea* culture.

Another notable contribution of the RRIM has been in development of standardized, special-purpose types of NR to meet specific industry needs. The RRIM also has been a leader in research on the use of chemical yield stimulants on tapping panels. These stimulants can induce yield increases of 25 percent on an annual basis. Additional research on this subject will bring more valuable results. Yield stimulants could be considered as the *sixth* great step in *Hevea* domestication. However, all clones do not respond equally well to use of yield stimulants. Improper use of stimulants can result in a reduction in yields at some future date and in poor tree growth.

RESEARCH NEEDS

High-grade intensive research must continue, and its application must be expedited if 16 million metric tons of *Hevea* rubber are to be available by the mid-1980's. There persists a wide gap between potential yields, as determined in experimental blocks, and the actual yields obtained in the plantation or field, even with good management. Clones and planting stocks are needed that are less environment-specific so the average small farmer can benefit from higher yields. A research area that holds promise for increasing yields but which has not received serious attention is the development of special rootstocks for clonal rubber. Research on this subject might lead to a *seventh* great step in rubber domestication and improvement.

Even though more new germ plasm has become available to *Hevea* breeders in recent years than in the whole previous history of the crop, there is a need for germ plasm with more diverse sources of resistance to SALB. There is also a great need to locate, assess and somehow preserve additional material. A number of *Hevea* species in the Amazon have been studied inadequately or not at all for their potential in breeding for vigor, disease resistance and yield, or for their possible use as rootstocks, or for developing special hybrids which could be used to advantage as rootstocks. There are several genera closely related to *Hevea* which may have value in genetic improvement programs but which have not been assessed. A long-term study of Amazonian flora is being initiated by the National Research Council (C. N. Pq) of Brazil, and participation of U.S. scientists has been invited. This study should provide opportunities to locate and collect or preserve additional supplies of germ plasm within the Euphorbiaceae.

An additional warning note has to be sounded about SALB. If this disease somehow reaches southeast Asia or Africa, it surely will reduce the world's supplies of *Hevea* rubber. Fortunately, the governments and rubber interests, particularly in Malaya, are fully alert to this possible disaster and are prepared to attempt eradication if the disease should appear. Meanwhile, there is no time to spare in developing and using a good backlog of clones, cultivars and planting stocks with broadly based resistance to strains of the causal organism, *Microcyclus ulei.*

SUMMARY

We have pointed out that the story of *Hevea* as a crop covers barely a century, and we have mentioned six great steps in *Hevea* domestication.

1) *Hevea* transfer by Wickham from South America to the Orient, leaving SALB behind.

2) Development of a superior tapping method by Ridley.

3) Vegetative propagation by bud grafting.

4) Discovery and development of *Hevea*

5) Yield increases resulting from genetic improvements.

6) Use of chemical yield stimulants on the tapping panel.

The stage appears to be set for an eventful second century in which the crop will play an increasingly important role in the developing countries.

For those who wish to delve more deeply into the botanical, agronomic and technical story of natural rubber we recommend the book *Rubber* by Polhamus (1). For the romantic and exciting but also tragic early history or rubber, the reader should turn to the book by Vicki Baum entitled *Weeping Wood* (4). An interesting account of this tree in Liberia, which covers its improvement through an international exchange and breeding program, is to be found in a booklet, *The Rubber Tree in Liberia*, by K. G. McIndoe (5).

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3. **Rands, R. D. and L. G. Polhamus.** 1955. U.S. Dept. Agric. Circular No. 976 (June).

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BOOK REVIEWS

(Continued from page 237)

Export Potential Selected Medicinal Plants. 278 pp. illus. Basic Chemicals, Pharmaceuticals and Cosmetic Export Council, 7 Cooperage Road, Bombay, India, undated. Rs. 15 ($5.00), postpaid.

This paperbound volume is aimed at providing that information needed for promoting production for potential export of some important Indian crude vegetable drugs and their derivatives. The book also aims to give information on future possibilities for export of crude drugs as well as on import substitution of certain items. It admirably achieves these objectives.

The publisher deserves compliments for compiling and presenting information not ordinarily or easily available to the public. The Council has marshalled the important trade data on several crude drugs. Part of the data is based on information obtained from *Markets for Selected Medicinal Plants and their Derivatives* published by International Trade Centre UNCTAD/GATT (1974); the rest is obtained from Indian Trade Missions abroad, embassies of foreign countries in India, and other official sources.

The booklet covers *Catharanthus roseus* and its alkaloids, *Cinchona* bark and its alkaloids, *Dioscorea* and diosgenin, ipecacuanha and its alkaloids, *Psyllium* husk and seeds, nux vomica and its alkaloids, papain, *Rauvolfia serpentina* and its alkaloids, and senna. The drugs are covered under various headings: cultivation or origin, constituents and specifications, uses, exports from India, competing countries, export prices, and further export possibilities. Information is clearly and objectively provided to reflect related problems of trade. The introduction briefly gives the general role of botanicals in modern medicine before discussing India's natural resources and her role in world trade of medicinal plants and their derivatives.

The following plants are reported to have been given priorities, by the National Council of Science and Technology, for large scale cultivation: *Pyrethrum, Dioscorea* spp., *Solanum* spp., *Atropa belladonna* and *A. acuminata, Duboisia* spp., ergot, *Glycyrrhiza*, ipecac, and opium.

The book contains 52 "annexures" (appendixes) of 160 pages in the form of tables that give figures in terms of quantity and value of export/imports in recent years of various botanicals in crude form, extractives, or refined derivatives. Annexure IX gives addresses of foreign importers. These annexures are important information for the export/import trade of medicinal plants and their products with reference to India (and competing countries in certain cases). This handbook can be recommended to all those interested in the export/import trade of medicinal plants with India.

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