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GUAYULE (*PARTHENIUM ARGENTATUM* GRAY) — AN UNDER-EXPLOITED RUBBER YIELDING PLANT FOR EXPLOITATION IN WASTELANDS

Vandana Joshi, Bhag Mal and B.S. Phogat

National Bureau of Plant Genetic Resources
Pusa Campus, New Delhi 110 012

Guayule, a desert shrub native to Mexico and South-west Texas (USA) is currently being developed as a supplementary source of natural rubber in addition to *Hevea brasiliensis* rubber. Natural rubber accounts for abot 30% of world's total rubber production and is being preferred in comparison to synthetic rubber due to certain unique characteristics of elasticity, flexibility, resilience and low heat build up. Rubber in the guayule plant is located throughout the stem, branches and roots and is *ca* 5-12 %. The paper reviews the history of guayule, its botany, rubber and co-products, genetics and breeding behaviour, agroclimatic requirements, propagation and research work carried out under coordinated research programme in India.

There are may species of plants which contain rubber but only few have been exploited for commercial use. These are *Hevea brasiliensis* Muel. Aug. (the common rubber/Brazilian rubber) and the guayule shrub (*Parthenium argentatum* Gray). This is the only plant other than *Hevea brasiliensis* which has been found to contain latex in sufficient amounts and it can be used as a commercial source of natural rubber. Natural rubber is in great demand since transportation depends heavily on it as it is the basic ingredient of tyres. Natural rubber is ingredient of many other elastic products also that require high tensile strength, durability and low heat build up. So the rubber synthesised from petroleum products cannot completely replace natural rubber. Moreover, natural rubber is a renewable resource in comparison to synthetic one.

At present, *Hevea* tree provides the natural rubber used all over the world. Cultivation of this tree is restricted to a limited tropical zone, mainly in south-east Asia. Any biological change in this small zone could endanger world's supply of natural rubber from *Hevea*. Therefore, there should be an alternative substitute to rubber tree which can be grown in other kinds of agroecological zones also. 'Guayule' is such an alternate source for commercial rubber production which can be grown suitably in wastelands and marginal areas of semi-arid regions.

History of Guayule

Guayule plant is a native of Chihuahuan desert of north-central Mexico and south-western United States (Hammond and Polhamus, 1965). Some explorers have seen native Americans in Mexico playing with a bouching ball made from guayule rubber. But the commercial utilization of rubber began in 1888 and extraction plants were set up for rubber production from native wild populations (Lloyd, 1911). Commercial utilization of guayule from natural plant stands dates back to the late 1980s. Domestication and development of the first guayule cultivar 593, was initiated in 1910 (Mc. Callum, 1941). In 1942, the Emergency Rubber Project, was initiated to domesticate and develop guayule as an alternative rubber crop during World War II. Unfortunately, the programme was abruptly terminated in 1946, but the USDA-ARS breeding programme was continued until 1959 at a minimal level. Hammond and Polhamus (1965) published a comprehensive summary of the research activities and accomplishments made during 1942 to 1959 period. No cultivars were formerly released during this period. They have provided sources of germplasm used in developing 31 guayule selections, 24 of which provide the major germplasm pool for the current USDA-sponsored cultivar developmental efforts initiated in the late 1970.

Germplasm and cultivar development is a major component of the current commercialization effort. Breeding and genetic research in the USA is concentrated in four closely cooperating locations : University of Arizona, Tucson; USDA-ARS, Phoenix, AZ; University of California-Riverside and the Texas A&M University Agricultural Field Station at Fort Stockton. The primary breeding objective was to develop new cultivars.

Botany

It is a woody perennial shrub of family Asteraceae, less than 135cm. in height and produce silver grey leaves. The flowers are produced in clusters in inflorescences on peduncles which extend outward in all directions from the plant. The inflorescence forms a spherical clusture containing bisexual flowers. The composite flower has female flowers along the outer ray and male flowers in the centre as well as on both sides of each female flower. Floral tillers start producing from May and continue till August in various flushes. Seed setting starts from June - July and continues till September to October. The seed unit consisted of an achene, two attached staminate florets and a subtending bract.

Guayule rubber

Rubber in the guayule plant is located in stem, root and branches in sclerenchyma cells of cortical tissues. Mehta *et al.* (1979) has identified certain anatomical features as an indication of high rubber bearing plants. Plants having longer vascular ray fissres contain more rubber. Larger number of leaf hairs have shown positive correlation with rubber content (Healey *et al.*, 1986). Guayule rubber is similar to *Hevea* rubber in chemical composition. It is a polymer with a chain of thousands of isoprene molecules (C_5H_8) linked together. Polymers can be of 25,000 or more units. Variation of 8-26 per cent in rubber content of guayule have been observed. Naqvi and Hanson (1980) have found 19 per cent rubber content in a native population of Mexico. Tipton and Gregg (1982) observed similar rubber content in native populations of Texas.

Processing of rubber

During World War II, guayule rubber was obtained by grinding the shrub in water and skimming off the floating rubber "worms". Unfortunately, the rubber from this process contains resinous impurities that make the rubber tacky, soft and likely to break with time. Afterwards in 1970s, new procedures were developed. In the new process, resin in the worms was removed by solvent extraction. Rubber produced in this way can make high- performance aircraft tyres. Further improvement in rubber quality and efficiency of production came about with the sequential extraction procedure. The sequential process used two different solvents : one to dissolve and remove the resin and the other to dissolve and separate the rubber. The latest extraction process uses only the solvent to dissolve both the rubber and the resin. Dissolved rubber in the mixture is them removed by selective coagulation and precipitation. In the late 1980s, Bridgestone/Firestone, Inc., built a pilot facility in Arizona for extracting rubber with this process. Garrot *et al.* (1981) recommended a modified procedure by using liquid nitrogen which has been used to estimate the length of time required for drying. Freshly cut plant approximately 8 cm above the root crown has to be parboiled at 80°C for 15 minutes and then air dried for 16 minutes, chopped into lengths of 2.5- 5.0 cm and frozen in liquid nitrgoen. The frozen material has to be then processed for rubber extraction.

Application of rubber and its co-products

The demand for rubber continues to grow. Natural rubber now accounts for 31.5 per cent or 4.7 million tons annually, of the total rubber market worldwide. About two-thirds of this natural rubber is used for tyres and related products. A passenger tyre is made up of 30 per cent natural rubber and aircraft tyre 100 per cent. The remaining natural rubber goes into making other rubber products such V-belts, conveyor belts, storage tank linings and hoses. A small amount is used in footwear and adhesive products.

Blending guayule rubber with polyolefins produces a polymer for making extruded or injection-molded products. Chemical modification of guayule rubber has produced new types of polymers. These polymers have properties similar to those of existing thermoplastic elastomers for making various types of molded goods. Resin like compounds derived from the rubber extraction process add to the co-product value of the guayule shrub. The co-products of guayule consists of low-molecular-weight rubber, organic and water soluble resins and Bagasse (plant residue). These low molecular weight rubbers are used in manufacture of various polymers which serve as building blocks for making more complex compounds that are useful in industry. Epoxy compounds of low molecular weight rubber has potential in making adhesives and thermoplastic polymers. Hydroxylated compounds of this low molecular weight rubber can make polymer farming raw materials used in producing polyesters. The resin can be used as a plasticizer for other high-molecular weight polymers. Wood impregnated with organic soluble resin is resistant to attack by marine borer, termites and soil fungi. The bagasse can be converted to an important chemical raw-material for manufacturing industrial solvents, resins and plastics.

Genetics and breeding behaviour

Guayule plants are either diploid (2n = 3) and sexual or polyploid (2n = 54, 72 and higher) and facultative, apomicts (Bergner, 1946; Esau, 1944). The flowers do not require pollination to set seed. The varietal characteristics can be perpetuated through the seeds, which facilitates plantation culture. The occurrence of B-chormosomes among diploids and polyploids (Bergner, 1946; Catcheside, 1950) and the presence of a sporophytic system of self-incompatibility at the diploid level (Estilai, 1984; Gerste, 1950) further complicates genetic studies. The non-availability of easily recognizable genetic markers is also a factor.

Parthenium has 17 recognized species. Rollins (1944) described natural hybrids between *P. argentatum* and *P. incanum* H.B.K., commonly known as mariola. Rollins (1946) made crosses of guayule plants (2n = 36 and 72 chromosomes) with *P. tomentosum* DC and *P. stramonium* (*P. tomentosum* var. *stramonium*) both with 2n = 36 chromosomes. These hybrids were generally intermediates between the two species with respect to leaf size, flower size, number of disc florets per head and the length of peduncles. The primary breeding objective is to develop new cultivars with a high concentration of rubber and adequate biomass to produce economically viable annual rubber yields. This can be accomplished either through interspecific hybridization between desirable diploid *Parthenium* species or by making further selections from among the existing apomictic USDA lines. The NAS report of 1977, and the articles of Thompson and Ray (1988) and Estilai and Ray (1991) have thoroughly reviewed the past and current status, development and future trends in the area of guayule germplasm collection, evaluation, enhancement, genetics and breeding. Thompson *et al.* (1988) initiated a selection programme from germplasm held by NPGS. Dierig *et al.* (1989 a, b) evaluated selections of this population and established relationship of morphological variables of rubber production and variation among and between various selected apomictic lines. A large amount of genetic variability has been shown to exist within the facultative apomictically reproducing polyploid populations. Thompson *et al.* (1988), Dierig *et al.* (1989 a, b) and Ray *et al.* (1990) have explained the model for the role of apomixis in generating genetic diversity which can be used in further selection.

Agro-climatic requirements

High temperature does not appear to affect this plant but low temperature governs its growth and survival. It withstands temperature between –18° and 40°C in its native habitat. The growth slows down below 16°C and it becomes semi dormant at temperatures below 4°C. Exposure to frost conditions (–7°C) may injure tender plants but those induced into dormancy by gradual decline in temperature remain unaffected. It has been found to be growing in a wide variety of shallow, stony, calcarious and friable soils but the most suited is well drained sandy loam soil since it is very susceptible to water logging. Water requirements have been estimated to be 450-600 mm (NAS, 1977). Excessive vegetative growth takes place in areas having higher rainfall, more than 640 m, but rubber is low.

Propagation

Guayule grows in a wide variety of shallow, stony, calcarious and friable soils. Annual rainfall in its native habitat is 230 to 400 mm but water requirements have been reported to be 450-600 mm (NAS, 1977). Excessive irrigations (1330 mm) in arid regions have been reported to cause faster growth, higher rubber yield and early harvesting (Bucks *et al.*, 1985). One of the major problems for Guayule propagation is poor germination due to seed dormancy. This is due to embryo dormancy of 2 months and longer lasting (6-12 months) action of seed coat. There are certain inhibitors also in the male florets which remain attached to seeds (Naqvi and Hanson, 1980). Treatment of new seeds for two hours with a solution of equal parts of 200 ppm GA 3 and 1.0 per cent NaOCl after soaking in distilled water for 8 hours have been reported to result in high germination percentage on fresh seeds (McCallum, 1929; Naqvi and Hanson, 1980). Chandra (1991) reported that osmo conditioning improves seed quality for germination. Seeds treated with polythylene glycol (MW 8000) and 100 µm gibberelic acid have shown more than 90 per cent germination. Seed size and depth of seeding have also been reported to affect seeding emergence. Emergence percentage is decreased constantly with increase in depth of seeding when seeding was done from surface to 18mm below surface. About 500 g seeds is enough for raising a nursery for one hectare plantation. For this purpose, a raised nursery bed of 1.25 × 1.20 m size is required. In the nursery, plants need to be hand watered and irrigated twice a day till two weeks before transplanting and weeding is required twice a week.

Direct seeding has not been successful because of the small seed size, low and variable seed germination rates, low seedling survival, and weed competition. (Fangmeier *et al.*, 1994; Hammond and Polhamus, 1965). As a result guayule fields are established by transplanting atleast 8 weeks old seedlings that had been raised in green houses. Nuresery raised seedlings are ready for transplanting about 6-8 weeks after sowing and the month of April has been identified as the best time for transplanting of Guayule in field under north Indian conditions. (Bhag Mal *et al.*, 1994). These seedlings should be transplanted at a row to row spacing of 60-75 cm and plant to plant spacing of 45 cm so as to obtain plant population of 30,000 to 55,000 plants/ha depending upon the growth habit of genotype and availability of water. Establishment of seedlings is a difficult and costly task. Severe losses are encountered during transplanting, unless the seedlings are induced into near dormant state by cold or drought. For this purpose, irrigation to the nursery is stopped two weeks prior to transplanting. Immediately after transplanting, the seedlings are furrow irrigated and light/sprinkler irrigations are given twice a week for the next two weeks and once a week for the succeeding five weeks (Bucks *et al.*, 1985). Once the plants are well established, not much irrigation is required in the semi-arid regions. However, irrigation is important from the point of view of cutting down the life for economic harvest from 5-8 years under rainfed conditions to 3-5 years under irrigated conditions (Bucks *et al.*, 1985). For north- west Indian conditions, it was observed that one flood irrigation per month during spring-summer (March-June) coupled with rains during July to September induced good growth. Withholding irrigation during winter could induce dormancy and force rubber formation to facilitate harvest towards the end of winter season. It was reported that high irrigation encouraged biomass production but rubber concentration remained low. (Hammond and Polhamus, 1965). High rubber yields could be achieved by alternating long periods of low and high water stress. Trends towards higher rubber percentages were obtained after frequent and moderate periods of stress in the growth cycle. (Retzer and Mogen, 1947). Although maximum production of rubber require large quantities of water (Miyamoto and Bucks, 1985), the efficiency of water use, that is, rubber yield per unit of irrigation water, is actually higher under high stress conditions (Miyamoto *et al.*, 1984). Thus in places where water shortage prevails, growing guayule under low irrigation could be commercially advantageous.

As rubber in the plant is contained in stem, root and branches, the whole plant is normally dug out for rubber extraction. Bucks *et al.* (1985) have suggested that only above grown portion (5 cm above ground) should be clipped for harvesting, to allow regeneration from the roots left in the ground. This method is called pollarding or coppicing. Most roots have been reported to regenerate and grow into new shrubs so fast that a one year old pollarded guayule bush becomes as large as a two year old seedling. In principle, this method rapidly produces two crops while avoiding the expensive replanting normally required. Under rainfed conditions of arid/semi-arid regions, 5-8 years are required to bring to economic harvest. This duration can be reduced to 3-5 years by enhancing growth rate with the help of supplemental irrigation,

Time (season) of harvest depends upon rainfall distribution and prevailing temperatures as it has a peculiar need for induction of semi-dormant state to be able to accumulate rubber. The highest amount of resin and rubber have been reported to occur at the end of the dormancy period (NAS, 1977). Under the north-west Indian conditions, this is in late February and March.

Research work under coordinated research programme

Agronomic and genetic research has been initiated to increase rubber poduction. Twenty three germplasm lines assembled from different countries were evaluated at the NBPGR Research Farm at Isapur for various agro-morphological traits and the promising types with high biomass production potential were identified which were tested at different locations under the coordinated programme. Based on multi-locational testing, HG 8, the most promising one was released in 1991 for general cultivation in arid and semi-arid regions of the country. This variety contains 6-7 per cent rubber and produced 10 q/ha raw rubber under Hisar conditions.

Chemical analysis revealed that rubber content varied from 3.4-7.00 per cent while the resin content varied from 4.69-6.25 per cent. Studies conducted at monthly intervals at Delhi indicated that the best time for raising the nursery under north-west Indian conditions was February. (Bhag Mal *et al.*, 1994).

Agronomic studies conducted showed 60 cm to be the optimum spacing between rows and 45 cm between plants. Fertilizers application of 40 kg N and 30 kg P for first year and 20 kg N in second year is congenial for good growth of Guayule. Irrigation during March-June induced good growth.

At HAU, Hisar, ten genotypes were studied for twelve quantitative characters. Analysis of variance showed significant variability and potential for improvement through breeding. (Chhabra *et al.*, 1990). Rubber yield exhibited significant positive correlations with plant circumference, basal branches per plant, and fresh and dry shrub yield per plant. Therefore, direct selection for number of basal branches per plant and plant diameter can be made to get plants having higher rubber production.

CONCLUSION

Low rubber yield of the available germplasm and the high cost of growing and processing the shrub, as well as the need for high capital investment for the construction fo processing plants are considered major hurdles in guayule commercialization. (NAS, 1977; Estilai, 1987; Thompson, 1989). Farmers don't grow the crop because the rubber processing facility is not available and industry do not build the facility because of the lack of a reliable source of the shrub. Therefore, some special incentives and subsidies from government agencies should be given to the farmers and industrialists to encourage guayule cultivation and commercialization respectively. And this is the right time for it, because producers are willing to experiment with something new which produces a raw material of significant industrial importance, and also the stand crops are no longer profitable with subsidy.

Guayule has great potential to become an important source of natural rubber. Increasing the yield, decreasing the production costs and finding new products of guayule will improve and hasten its chance for commercialization. Since abundant area in India, are lying uncultivated in arid and semi-arid marginal lands in parts of Rajasthan, Gujarat, Haryana, Punjab, Maharashtra and Tamil Nadu states, guayule holds a great promise of increasing production of natural rubber (Paroda, 1979) The promising varieties available should be multiplied at 2 or 3 centres. The best identified varieties should be tested under mini-kit trial on large scale in collaboration with the forest and agriculture departments in different states.

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