Minireview

Production of natural rubber from Para rubber tree

Yasuyuki Hayashi

Bridgestone Corporation, Kodaira, Tokyo 187-8531, Japan

E-mail: hayashi.yasuyuki@bridgestone.co.jp Tel: +81-42-342-6514 Fax: +81-43-498-2392

Received December 22, 2008; accepted January 27, 2009 (Edited by H. Suzuki)

Abstract Natural rubber is one of the most important polymers produced by plants because it is a strategic raw material used in more than 40,000 products. It has unique properties as a polymer owing to its specific structure, its high molecular weight and yet-to-be-defined contributions of minor components in the latex. Among over 2500 rubber-producing plant species, the Para rubber tree (*Hevea brasiliensis* Muell. Arg.) is presently the only commercial source of natural rubber. The objective of this review is to provide readers with information on the newest trends and market conditions of natural rubber and also explain the historical background and a global view of *Hevea* breeding and genetics, together with information about alternative resources.

Key words: Alternative rubber sources, biotechnology, breeding, end-use markets, *Hevea brasiliensis*, natural rubber, supply and demand.

Natural rubber as a composite of poly *cis*-isoprene and minor components

Natural rubber is a biopolymer consisting of isoprene units (C_5H_8)_n linked together in a 1,4 *cis*-configuration. Various latex-producing plants synthesize natural rubber in their specifically differentiated cells in a manner such that C5-monomer units, isopentenyl pyrophosphate (IPP) molecules, are sequentially condensed into allylic primers, like FPP or GPP by *cis*-prenyltransferase (Figure 1) (Takahashi 2006). Not only poly *cis*-isoprene molecules, but also other cellular components, are included in the latex. Namely, natural rubber is, in a sense, a composite of these components, while synthetic rubber is almost simply composed of poly-isoprene with not more than 90% of *cis*-bond. Because of its molecular structure (high *cis*-bond content of over 99.5%) and high molecular weight (more than 1×10^6 Da) of polymer component and yet-to-be-defined contributions of minor components in the latex, such as proteins, minerals, carbohydrates and lipids, natural rubber has superior resilience, elasticity, abrasion resistance, efficient heat dispersion and impact resistance to synthetic rubber.

Uses of natural rubber and its importance in tire production

Natural rubber is used in over 40,000 products, including

tires, medical devices, surgical gloves and various engineering and consumer products (Mooibroek 2000). Of these end-use markets for natural rubber, tire products accounts for over 50% of natural rubber consumption. Natural rubber continues to hold an important position in tire consumption, competing with synthetic rubber. Because of its superior tear strength and excellent resistance to heat, natural rubber is better-suited for

Figure 1 Biosynthesis of natural rubber.

Abbreviations: IPP, Isopentenyl pyrophosphate; RFLP, Restriction fragment length polymorphism; AFLP, Amplified fragment length polymorphism; CIRAD, the Centre de cooperation internationale en recherche agronomique pour le développement; QTL, Quantitative trait locus; SALB, South American leaf blight

This article can be found at <http://www.jspcmb.jp/>

high-performance tires used on trucks, buses, aircraft and racing cars. For example, natural rubber and synthetic rubber content in a relatively small-size truck tire are 27% and 14% respectively, while those in a passenger tire are 14% and 27% respectively (Market information in the commodities area UNCTAD <http://www.unctad.org/infocomm/anglais/rubber/sitemap.htm>)

Supply and demand of natural rubber

Global natural rubber production has grown an average of 3.0% per year for the past 50 years, while consumption has increased an average 3.2% per year. Thus, demand and supply of natural rubber have almost always been in a tight balance. Various factors, like production capacity, processing costs as well as price differences with synthetic rubber, have influenced the supply of natural rubber. Active demand and escalating rubber prices in recent years expanded natural rubber production that reached to 9.62 million tons in 2006. Natural rubber production in five leading countries, Thailand, Indonesia, Malaysia, India and China (in descending order) accounted for 89% of global production in 2005 (Figure 2A). In the meanwhile, global consumption of natural rubber reached 9.21 million tons in 2006. The five largest consumers are China, USA, Japan, India and Malaysia (Figure 2B). China leave the rest far behind in terms of increasing consumption (from 0.4 million tons in 1999 to 1.5 million tons in 2006). In 2006, the natural rubber consumption in Japan was 0.87 million tons, while the supply was 0.89 million tons (Rubber Statistical Bulletin, International Rubber Study Group <http://www.rubberstudy.com/statistics-pubs.aspx>). As mentioned above, there is always a chronic imbalance between demand and supply of natural rubber. Thus, endeavors to increase production capacity, not only by increasing the productivity of rubber plantations, but also by expanding resources for commercial rubber production, will be necessary.

Natural rubber-producing plant sources

Hevea brasiliensis has been only one resource for commercial natural rubber production. Attempts to develop alternative sources of natural rubber have been made at various times and no fewer than eight botanical families, 300 genera and 2500 species have been found to produce natural rubber in their latex (Metcalf 1966). Only two species, in addition to the Para rubber tree, are known to produce large amounts of rubber with high molecular weight: a shrub named guayule (*Parthenium argentatum* Gray) and the Russian dandelion (*Taraxacum koksaghyz*). These plants were considered sufficiently promising as alternative rubber sources that several research programs have been conducted on these plants,

Figure 2 Production and consumption of natural rubber in 2005. (A) Production of natural rubber (B) Consumption of natural rubber.

especially during World War II. Other alternative rubber-producing plants, like lettuce (*Lactuca serriola*) and fig tree (*Ficus bengalensis*), have not yet been sufficiently studied to establish their usability (Beilen 2007). The ideal rubber-producing crop would be an annual, fast-growing plant that can grow even on non-crop land.

Hevea brasiliensis, the only source for commercial natural rubber

Hevea brasiliensis is a deciduous tree, belonging to the Euphorbiaceae. One of the 10 species of the genus, *Hevea brasiliensis* is exclusively cultivated on over 10 million hectares throughout the world for industrial production of natural rubber. Natural rubber is produced in Southeast Asia (92%), Africa (6%), and Latin America (2%) (Rubber Statistical Bulletin 2006). The *Hevea* tree produces natural rubber in laticifer, a specifically differentiated organ localized in the vascular tissue. Laticifer consists of anastomosed laticifer cells, in which natural rubber is synthesized and stored as rubber particles (Figure 3). By tapping, rubber particles can be collected, together with other cellular components in latex. Rubber content of *Hevea brasiliensis* accounts for 30–40% of the dry weight of latex, which should be about 2% of the dry weight of the tree. The yield potential should be over 2500 kg/ha/year for high-yielding clones. *Hevea* rubber contains poly *cis*-isoprene with an average molecular weight as high as 1×10^6 Da,

and it also contains minor components that are important for the expression of intrinsic physical strength. Because of these characteristics in yield and rubber quality, *Hevea brasiliensis* remains the only source for commercial natural rubber. A huge amount of research has been conducted, making use of conventional breeding technologies, leading to the creation of various clones with improved yield and improved tolerances against either biotic or abiotic stresses (Priyadarshan 2004). Furthermore, new attempts have been made to broaden genetic diversity by applying biotechnologies.

Conventional breeding of *Hevea brasiliensis*

Rubber is currently propagated vegetatively in nurseries through bud-grafting. The buds are collected from budwoods grown in the source-nursery that are developed for the high-yielding clones. These buds are grafted onto rootstock plants grown in plastic bags and then budded materials are transplanted in the soil at a density of about 500 trees per hectare. Bud-grafted materials are expected to have a high level of homogeneity and minimized intra-clonal variation in yield. Most breeding efforts are focused only on the bud-wood, aerial part of tree, while rootstock traits that also affect growth and yield have generally been left unexplored.

Yield improvement

Latex productivity has long been the main objective of breeding. The main component of productivity is growth of the trunk both in the immature and mature stages of the rubber tree. Growth of the trunk in the immature stage determines the duration of the immature phase, while that of the mature stage determines total yield per tree during its lifetime. Latex productivity is also affected by tappable tree density per ha related with planting density and resistance to stress factors like tapping panel dryness (TPD), wind damage, various diseases, and wintering. Progress in yield improvement in *Hevea* resulted in a gradual increase, from 650 kg/ha in unselected seedlings during the 1920s to 1,600 kg/ha in the best clone during the 1950s. The yield potential was further enhanced to 2,500 kg/ha in Prang Besar Rubber Estate in Malaysia (Clement-Demange 2007).

Disease resistance

The SALB prevents South America from developing rubber plantations and it represents a permanent major threat to rubber in Asia and Africa (Davies 1997). Recently, the genetic determinant of the resistance source of *H. benthamiana* (F 4542), widely used in many backcross programs, was characterized by a genetic map (Lespinasse 2000). Several promising resistant clones were recently selected by CIRAD researchers (Guen 2008).

Figure 3 Histological study of the laticifer of *Hevea brasiliensis*. Horizontal, tangential, and vertical section were made from vascular tissue of an 8-year-old *Hevea* tree and microscopic analysis was performed to clarify structure of laticifer. Oil-red-O was employed for staining laticifer. L: Laticifer, C: Cork, R: Ray parenchyma, X: Xylem.

Environmental stress resistance

Temperature, humidity, light condition, water availability and wind are the environmental stress factors influencing growth of rubber trees. For example, rubber trees in China often suffered from chilling injury. Chinese scientists have already developed Zhanshi 86, a clone borne out of a random cross between SCATC 93-114 and Wuxing I3, which has shown significant cold tolerance (Senyuan 1990).

Application of biotechnologies for improving *Hevea* clone

There is only limited genetic diversity among modern *Hevea* clones, because they originated from rather small numbers of plant sources that were collected by Henry Wickham. For exploring new genetic potential of *Hevea* and for shortening a long breeding cycle, application of biotechnologies for improving *Hevea* clones is necessary, in parallel with conventional breeding.

Somatic embryogenesis and genetic transformation

Somatic embryogenesis was studied in *Hevea* for rapid clonal propagation as an alternative budding technique. Furthermore, plant regeneration through somatic embryogenesis enables us to apply genetic transformation technology for *Hevea* breeding. Choosing appropriate explant for callus induction and selection and maintenance of embryogenic cell lines should be key factors for somatic embryogenesis. At the Rubber Research Institute of India (RRII), high-frequency somatic embryogenesis and plant regeneration were

achieved from immature anthers of Indian *Hevea* clones (Kumari Jayashree 1999). At CIRAD, the inner integument of immature seeds was chosen as explant (Carron 1982), leading to the establishment of the highest-frequency somatic embryogenesis procedure. At the same time, efforts have been made to transform *Hevea* cells. Integument-derived embryogenic calli of PB260 have been transformed by a *Agrobacterium tumefaciens*-mediated method (Montoro 2003), and more than 200 transformed plantlets have been obtained.

DNA marker and linkage map

RFLPs, AFLPs, microsatellites, and isozyme markers have been established, not only to identify clones, but also to assist breeding of clones with ideal traits. CIRAD already established a set of microsatellite markers that can identify over 300 clones. Finally, a comprehensive genetic linkage map of *H. brasiliensis* was formulated recently with the help of RFLPs, AFLPs, microsatellites, and isozyme markers (Lepinasse 2000). For marker assisted-breeding, QTLs for resistance to SALB (*M. ulei*) were already mapped using 195 F1 progeny derived from a cross between PB 260 (susceptible) and RO 38 (resistant) clones.

Future prospects

Energy problems and global warming became new motive-forces to the improvement and development of crops for the renewable production of energy and materials. To ensure a stable supply of natural rubber and to decrease our dependence on petroleum-based synthetic rubber, both development of alternative sources of natural rubber and improvement of the *Hevea* tree for higher productivity would be necessary. Recent progress in plant molecular sciences not only provide us with powerful tools, like genomics, metabolomics and proteomics, to scrutinize the mechanism of natural rubber synthesis, but also provide us new methods for improvement, like marker-assisted breeding.

References

- Beilen JB, Poirier Y (2007) Establishment of new crops for the production of natural rubber. *Trends Biotechnol* 25: 522–529
- Carron MP, Enjalric F (1982) Studies on vegetative micropropagation of *Hevea brasiliensis* by somatic embryogenesis and in vitro cutting. In: A Fujiwara (ed), *Proc 5th Int Congr. Plant Tiss Cell Cult.* Maruzen, Tokyo, pp 751–752
- Crement-Demange A, Priyadarshan PM, Thuy Hoa TT, Venkatachalam P (2007) *Hevea* Rubber Breeding and Genetics. *Plant Breed Rev* 29: 177–283
- Davies W (1997) The rubber industry's biological nightmare. *Fortune* 136: 86
- Guen VL, Guyot J, Reis Mattos CR, Seguin M, Garcia D (2008) Long lasting rubber tree resistance to *Microcyclus ulei* characterized by reduced conidial emission and absence of telomorph. *Crop protection* 27: 1498–1503
- Kumari Jayashree P, Thomas V, Saraswathyamma CK, Thulaseedharan A (2001) Optimization of parameters affecting somatic embryogenesis in *Hevea brasiliensis*. *J Nat Rubber Res* 14: 20–29
- Lepinasse D, Grivet L, Troispoux V, Rodier-Goud M, Pinard F, Seguin M (2000) Identification of QTLs involved in the resistance to South American Leaf Blight (*Microcyclus ulei*) in the rubber tree. *Theor Appl Genet* 100: 975–984
- Lepinasse D, Rodier-Goud M, Grivet L, Leconte A, Legnate H, Seguin M (2000) A saturated genetic linkage map of rubber tree (*Hevea* spp) based on RFLP, AFLP, microsatellite and isozyme markers. *Theor Appl Genet* 100: 127–138
- Metcalfe CR (1966) Distribution of latex in the plant kingdom. *Econ Bot* 21: 115–127
- Montoro P, Rattana W, Pujade-Renaud V, Michaux-Ferriere N, Monkolsook Y, Kanthapura R, Adunsadthapong S (2003) Production of *Hevea brasiliensis* transgenic embryogenic callus lines by *Agrobacterium tumefaciens*: Role of calcium. *Plant Cell Rep* 21: 1095–1102.
- Mooibroek H, Cornish K (2000) Alternative sources of natural rubber. *Appl microbiol and biotechnol* 53: 355–365
- Priyadarshan PM, Crement-Demange A (2004) Breeding *Hevea* rubber: Formal and molecular genetics. In: Hall JC, Dunlap JC, and Friedmann T (ed), *Advances in genetics*. Elsevier Academic Press, Amsterdam, pp 51–115
- Senyuan G (1990) *Hevea* breeding and selection for cold resistance and high yield in China. *Proc IRRDB Symp, Oct5-6*, Kunming, China, International Rubber Research and Development Board, Brickendonbury, pp 154–164
- Takahashi S, Koyama T (2006) Structure and function of *cis*-prenyl chain elongation enzymes. *Chem Rec* 6: 194–205